Tennessee Mitigation Assessment Tool
Tennessee Debit Tool

User's Manual

Drakes Creek tributary, Drakes Creek Park, Hendersonville, Tennessee

TN Department of Environment & Conservation

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Disclaimer

The Tennessee Mitigation Assessment Tool and Debit Tool for streams, including the spreadsheet and measurement method manuals are intended for the evaluation of impact sites and compensatory mitigation projects and their departure from reference conditions in terms of functional loss or lift, respectively. The measurement methods are scored based on their current condition as compared to a reference standard. In part or as a whole, the function-based parameters, measurement methods, and their index scores are not intended as engineering design criteria and do not serve as the basis of engineering design. The Tennessee Department of Environment and Conservation assumes no liability for engineering designs based on these tools. Designers should evaluate evidence from hydrologic and hydraulic monitoring, modeling, nearby stream morphology, existing stream conditions, sediment transport requirements, and site constraints in order to determine appropriate restoration design variables and specifications.

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Acronyms

ARAP – Aquatic Resource Alteration Permit
BEHI/NBS – Bank Erosion Hazard Index / Near Bank Stress
BHR – Bank Height Ratio
BKF /BF = Bankfull
BMP – Best Management Practice
CA – Converted Area from Restoration
CEM – Channel Evolution Model
CFR – Code of Federal Register
CFS – Cubic Feet per Second
CWA – Clean Water Act
DEM – Digital Elevation Model
DFSA – Developed Floodplain Surface Area
ECS – Existing Condition Score
EMAP – Environmental Monitoring and Assessment Program
EPT – Ephemeroptera, Plecoptera, and Trichoptera
ER – Ecoregion
ETR – Entrenchment Ratio
FF – Functional Feet
FAR – Functioning-At-Risk
FEMA – Federal Emergency Management Agency
FPW = Flood Prone Width
FSIP – Floodplain Storage Infiltration Potential
HSG – Hydrologic Soil Group
IBI – Index of Biotic Integrity
IDF – Intensity-Duration-Frequency
IRT – Interagency Review Team
LDA – Lateral Drainage Area
LWD – Large Woody Debris
MRLC – Multi-Resolution Land Characteristics Consortium
MS4 – Municipal Separate Storm Sewer System
NF – Not Functioning
NFHL – National Flood Hazard Layer
NLCD – National Land Cover Database
NPDES – National Pollutant Discharge Elimination System
NRCS – Natural Resource Conservation Service
OHWM – Ordinary High Water Mark
PCS – Proposed Condition Score
PFDS – Precipitation Frequency Data Server
PSD – Particle Size Distribution
PWO – Process Wastewater Outfall
Q – Channel Discharge (in ft^3/s or m^3/s)
QSSSOP – Quality System Standard Operating Procedure
RGA – Rapid Geomorphic Assessment

RBP – Rapid Bioassessment Protocols
RRSI – Reach Runoff Stormwater Infiltration Field Value
RSA – Runoff Source Area
SIF – Stormwater Infiltration Factor
SOP – Standard Operating Procedure
SQSH – Semi-Quantitative Single Habitat
TDEC – Tennessee Department of Environment and Conservation
TDOT – Tennessee Department of Transportation
TFSA – Total Floodplain Surface Area
TMAT – Tennessee Mitigation Assessment Tool
TMDL – Total Maximum Daily Load
TMI – Tennessee Macroinvertebrate Index
TN SQT – Tennessee Stream Quantification Tool
TWQCA – Tennessee Water Quality Control Act of 1977
TWRA – Tennessee Wildlife Resources Agency
USACE – U.S. Army Corps of Engineers
USEPA – U.S. Environmental Protection Agency
USFS – U.S. Forest Service
USFWS – U.S. Fish and Wildlife Service
USGS – U.S. Geological Survey
UT – Unnamed Tributary
WOTS – Waters of the State
WOTUS – Waters of the United States

Glossary of Terms

Active Channel Width – Active channel is observed by the lower limit of perennial vegetation, and/or evidence of scour lines on the bank and/or from continued flood flows exposed root hairs. The width is the cross-sectional length across the channel at the observation.

Alluvial Valley – Valley formed by the deposition of sediment from fluvial processes. A confined alluvial valley is confined between adjacent hillslopes and meander bends often intercept the hillslope. An unconfined alluvial valley is a wide, low gradient valley.

Assessment Reach – A sub-section of the project reach to compute metrics where the measurement methods require a shorter stream length than the entire project reach. The assessment reach is selected to best quantify the character of the metric being measured, and criteria for determining upstream and downstream boundaries typically are but not limited to tributary junctions, hydraulic grade controls, and stable riffles.

Bankfull Discharge – The streamflow effectively maintaining channel cross-sectional shape under geomorphic equilibrium for floodwaters and sediment transport filling a stream channel before overtopping onto a floodplain; it has been equated to dominant discharge and often associated with a flood recurrence interval of approximately 1.5 to 2 years.

Bankfull Indicators – Channel features created by a reoccurring dominant discharge in which fluvial geomorphic processes are in equilibrium for flow capacity and sediment dynamics.

Bankfull Slope Line – The longitudinal slope through multiple bankfull indicator elevations.

Best Management Practice (BMP) – A method that is recognized as an efficient, effective, and practical means of preventing or reducing pollutants in the waters of the state. A BMP may be a physical facility or a management practice achieved through action.

Catchment – Portion of the stream watershed that drains to the uppermost end of the reach. The catchment is the total drainage area above the project reach.

Channel Incision – A rapid geomorphic adjustment of a channel where physical or hydrologic disturbances cause vertical downcutting of the bed, followed by lateral erosion on the banks with possible geotechnical mass failure of the soil banks.

Colloidal Sediment – A soil or sediment, typically clay and fine silt, with dimensions ranging from 1 nm to 1 µm, that are small enough to move via Brownian motion rather than gravitational settling and have a chemical charge contributing to its cohesive properties.

Colluvial Valley – Valley formed by the deposition of sediment from hillslope erosion processes. Colluvial valleys are typically confined by terraces or hillslopes.

Condition – The relative ability of an aquatic resource to support and maintain a community of organisms having a species composition, diversity, and functional organization comparable to reference aquatic resources in the region (33CFR 332.2).

Condition Score – A scaled score between 0.0 to 1.0 that expresses whether the associated metric, parameter, functional category, or overall restoration reach is not functioning, functioning-at-risk, and functioning compared to a reference condition. ECS = Existing Condition Score. PCS = Proposed Condition Score. The condition score for a metric is that determined by the reference standard the metric's index Score.

Credit – A unit of measure representing the accrual or attainment of aquatic functions as a compensatory stream mitigation site. The measure of aquatic functions is based on the resources restored, established, enhanced, or preserved by the authorized activity (33 CFR 333.2). Credit = Proposed FF – Existing FF [positive].

Debit – A unit of measure representing a loss of aquatic functions at an impact/project site. The measure of aquatic functions is based on the resources impacted by the authorized activity (33 CFR 333.2). Debit = Proposed FF – Existing FF [negative].

Dominant Discharge – A channel forming discharge most responsible for maintaining geometric shape of the channel under equilibrium conditions at which the most sediment is transported over a long period in alluvial rivers and streams.

Field Value – A field measurement or calculation input into the TMAT for a specific measurement method. Units vary based on the metric or measurement method used.

Floodplain – An area of low-lying ground adjacent to a river, formed mainly of river sediments and subject to flooding.

Floodplain Inundation – The statistical frequency in which floodwaters overtop the channel onto the floodplain.

Full Restoration Potential – The project has the potential to restore functions within all categories, including biology, back to a reference condition. This is consistent with the 'full-restoration' concept, where actions restore habitat-forming processes and return the site to its natural or reference standard range of conditions and equilibrium dynamics.

Functions – The physical, chemical, and biological processes that maintain an aquatic ecosystem (as defined in 33 CFR 333.2).

Functional Attribute – Similar to the functional statement adding specific characteristics for a function-based parameter.

Functional Condition – The relative ability of an aquatic resource to support and maintain biotic integrity comparable to reference aquatic resources in the ecoregion; the lotic condition reflecting the ecological processes supporting community composition, diversity, species abundance, and tropic structure.

Function-Based Parameter – A metric or group of metrics that describes the functional statement of each functional category.

Functional Capacity – The degree to which an area of aquatic resource performs a specific function. (*see* 33 CFR 332.2).

Functional Category – Components of an assessment framework to measure functional capacity generally consisting of Hydrology, Hydraulics, Geomorphology, Physiochemical (Water Quality) and Biology. Other assessments have included categories such as: system watershed dynamics, hydrologic balance, sediment processes and character, physical habitat maintenance processes, biological support, and chemical processes and pathways. Each category is defined by a functional statement.

Functional Feet (FF) – The product of a condition score and stream length; Existing FF = Existing Condition Score (ECS) x existing stream length; Proposed FF = Proposed Condition Score (PCS) x proposed stream length. The final Functional Feet value should be rounded up to the nearest tenth.

Functional Lift – The increase in functional condition as measures by the index value.

Functional Loss – The decrease in functional condition as measures by the index value.

Functional Statement – Broad descriptions of the functions and processes per category.

Headwater Stream – Streams located at the beginning of a stream network in a watershed, also known as the small source streams that are typically ephemeral.

Hydraulic Grade Control – A “hard point" on the streambed that resists the vertical erosional forces so that streambed elevation is maintained. Controls can be natural such a bedrock channel bottoms, or artificial such as culverts, bridge crossings, low-head dams, and restoration structures (i.e., cross vanes, j-hooks, weirs).

Index Value – The same as the condition score. A dimensionless value between 0.1 and 1.0 expressing the relative functional condition of a metric’s field value, as compared with a reference standard. Values for the suite of metrics are combined to generate the existing and proposed condition scores.

Lateral Drainage Area (LDA) – The portion of the watershed that drains laterally to the stream’s project reach.

Measurement Method – Specific tools, equations, assessment methods, etc. that are used to quantify a function-based metric.

Metric – A measured assessment characteristic, either by desktop data collection or field measurement within functional categories/parameters for hydrology, hydraulics, geomorphology, water quality, and biology.

Partial Restoration Potential – The potential for a restoration project to improve some functions compared with pre-project or baseline conditions. One or more functional categories may be restored to conditions typical of or approaching reference condition, but some catchment stressors or reach-scale constraints are preventing the site from reaching full potential.

Performance Standards – Observable or measurable physical (including hydrological), chemical, and/or biological attributes that are used to determine if a compensatory mitigation project meets its objectives (33 CFR 332.2).

Project Reach – A stream reach within the project area with common characteristics, i.e., a stream segment with similar valley morphology, stream type, channel stability, riparian vegetation, and bed material composition. Multiple project reaches may exist within an overall project area where there are variations in stream and riparian characteristics and/or differences in reach designs.

Reference Aquatic Resources – A set of aquatic resources that represent the full range of variability exhibited by a regional class of aquatic resources as a result of natural processes and anthropogenic disturbances (33 CFR 332.1).

Reference Condition – A stream condition that is considered functioning for the parameter being assessed. It does not simply represent the best condition that can be achieved at a given site; rather, a functioning condition score represents an unaltered or minimally impacted system.

Reference Curves – A relationship between observable or measurable metric field values and dimensionless index values. These curves best represent the degree of departure from a reference standard for a given field value and used to determine the index value for a given metric at a project site.

Reference Standard – A reference standard to evaluate the functional capacity of a measured metric to an index score, where the index score is classified using a 0.00 to 1.00 scale as functioning, functioning-at-risk, or not functioning.

Riparian Corridor – A strip of land adjacent to a river, stream, or other body of water as the ecotone between the terrestrial and aquatic ecosystems. Riparian corridors typically consist of a strip of dense undisturbed perennial, native vegetation, either original or reestablished that provides canopy, bank stabilization, pollution filtering, and wildlife habitat.

Riparian Vegetation – Plant communities contiguous to and affected by shallow water tables and fluvial disturbance

Runoff Source Area – The runoff source area (RSA) where excess polluted runoff is generated from human activities on the land surface.

Stormwater Control Measure (SCM) – A structure, land feature, or practices that treats pollutants in stormwater runoff.

Stormwater Infiltration Factor (SIF) –A ratio describing what portion of a stormwater BMP or SCM's design volume that will be infiltrated by the BMP/SCM.

Stream Assessment Framework – A suite of metrics and their measurement methods organized by functional categories that quantifies the functional condition of a stream, such as those organized in the TMAT.

Stream Restoration – The manipulation of the physical, chemical, or biological characteristics of a stream reach with the goal of returning degraded aquatic resources to fully or partially natural functions resulting in functional lift (*See* 33 CFR 332).

Stream/Wetland Complex – A stream channel or channels with adjacent riverine wetlands located within the floodplain or riparian geomorphic setting, where overbank flow from the channel(s) is the primary wetland water source.

Thalweg – It is the lowest stream bed elevation as a line or curve of flowing water from one point to the other along the channel's longitudinal profile, where per point it is identified as the deepest point in the channel cross-section.

Watershed – The total drainage area or catchment upstream of a stream reach location commonly defined at the confluence with another stream. It consists of a drainage network of channels.

1. Background and Purpose

1.1 Regulatory Introduction

Alterations to Tennessee's aquatic resources associated with commercial, residential, and agricultural land development, construction of transportation and utility systems, and other activities have the potential to degrade water quality and result in loss of resource values. In a regulatory context, aquatic resource values are the properties that maintain its legally designated uses. In Tennessee, one such designated use for streams is the support of fish and aquatic life, and resource values that maintain this support include provision of habitat. The Tennessee Department of Environment and Conservation (TDEC) and the U.S. Army Corps of Engineers (USACE) currently require compensatory mitigation for certain stream alterations authorized by State or Federal permits that would otherwise result in loss of resource value

1.1.1 Impacts to Waters of the State

The TDEC Division of Water Resources (DWR) requires compensatory mitigation to offset unavoidable adverse impacts associated with an activity authorized by an Aquatic Resource Alteration Permit (ARAP) that would otherwise result in an appreciable permanent loss of aquatic resource value. ARAP rules (TDEC Rule 0400-40-07-.04(7)) modified in 2019 establish mandatory requirements for mitigation sufficient to compensate for the loss of resource values from existing conditions resulting from permitted alterations to Waters of the State (WOTS). In July 2000, the Tennessee Water Quality Control Board adopted the rules clearly specifying that alteration of WOTS must not result in a net loss of water resource value, establishing the mitigation permit requirements.

The DWR has the responsibility and legal authority to ensure that impacts to WOTS, that are not wet weather conveyances, do not result in a net loss of water resource values. No individual ARAP shall be issued unless the applicant has first demonstrated through an alternatives analysis that there is no practicable alternative to the proposed activity that would result in less adverse impact on resource values, so long as the alternative does not have other significant adverse environmental consequences. ARAP rules and mitigation requirements are formally detailed in the *Tennessee Stream Mitigation Guidelines* (TDEC DWR-NR-G-01), and document obtained from TDEC's website:

> https://www.tn.gov/environment/permit-permits/water-permits1/aquatic-resource-alteration-permit--arap-.html

Where the state jurisdictional status of a watercourse is in question, a *Hydrologic Determination* should first be performed unless the applicant chooses to treat a watercourse as a jurisdictional stream (Rule Chapter 0400-40-17.01). The identification of wet weather conveyances and jurisdictional streams is performed using a consistent and standardized methodology as outlined in the CWA and the TDEC DWR's Guidance. Compensatory mitigation is not required by the TDEC DWR for features formally determined to be a wet weather conveyance. However, aquatic resources determined to be federally jurisdictional may require compensatory mitigation in accordance with federal regulations, particularly in headwater streams. For more information, go to TNHDT.org, or TDEC's water quality training webpage:

https://www.tn.gov/environment/program-areas/wr-water-resources/water-quality/water-quality-training.html

1.1.2 Impacts to Waters of the United States

The USACE may require compensatory mitigation for unavoidable impacts to Waters of the United States (WOTUS) resulting from impacts regulated by Section 404 of the Clean Water Act (CWA) to ensure that the activity complies with the Section 404(b)(1) Guidelines of the Clean Water Act. Compensatory mitigation may also be required by USACE to ensure that an activity requiring authorization under CWA Section 404 and/or Sections 9 or 10 of the Rivers and Harbors Act of 1899 is not contrary to the public interest.

USACE compensatory mitigation requirements will be implemented in accordance with 33 CFR Part 332, 40 CFR 230.70-77, 40 CFR 1508.20, 40 CFR 1502.14, as well as the Regulatory Guidance Letter (RGL) 05-01, 08-03, and 19-01. In overall terms, the objective of federal compensatory mitigation is to offset environmental losses resulting from unavoidable impacts to WOTUS authorized by USACE permits. In particular, it should be noted that the evaluation of impacts to resource functions may vary per WOTUS and WOTS, particularly in headwater channels. In addition, requirements for compensatory mitigation may differ between USACE nationwide permits (NWPs) and TDEC General ARAPs. Mitigation may in fact be required under an NWP in order to ensure an activity will result in no more than minimal individual and cumulative adverse environmental effects, which is the standard for an activity to be authorized under the NWPs.

1.2 Stream Impacts from Disturbance Activities

Common impacts to streams from disturbance activities that cumulatively or individually may result in an appreciable permanent loss of resource values to a stream include, but are not limited to:

- the placement of fill into stream;
- installation of pipes and/or culverts;
- road constriction and other infrastructure development adjacent to streams;
- loss of stream length through channelization or structural encapsulation;
- streambank armoring;
- impoundments of streams;
- water withdrawals that result in a degradation or loss of physical habitat;
- significant loss of streambank vegetation and riparian canopy;
- channel modifications including: deepening, straightening, widening, relocation, disconnection with floodplains, and removal of in-channel vegetation or bedload;
- any activities that result in an unstable geomorphic and/or hydraulic condition resulting in a water surface rise during flood events; and
- other changes that may alter the physical characteristics of the stream, including but not limited to changes to the physical habitat, water quality, and/or aquatic fauna such that the amount of degradation resulting in loss of resource value.

1.3 Development of the Stream Mitigation Assessment Tool

Prior to 2008, the mitigation program regulated by the USACE and the U.S. Environmental Protection Agency (USEPA) used a ratio-based mitigation system to compensate for aquatic resource losses through restoration of wetlands and streams. Permit decisions for stream restoration based on the ratio-based method were made by USACE district Interagency Review Teams (IRTs). In 2008, the USACE and USEPA promulgated the final federal compensatory mitigation rule *Compensatory Mitigation for the Losses of Aquatic Resources*, referred to as the "2008 Mitigation Rule", promoting functional assessments to quantify the amount of compensatory mitigation needed to replace authorized loss of resource functions in WOTUS. Changes in resource value in aquatic systems can be quantified by measuring or modelling changes in functions based on the physical, biological, and chemical processes occurring in aquatic ecosystems. For streams, the federal 2008 Mitigation Rule requires mitigation of stream function loss commensurate with permitted impacts.

Mitigation permit applicants must comply with all regulatory requirements applicable to the federal 2008 Mitigation Rule and the Tennessee state ARAP. To meet these state and federal requirements, an assessment methodology was developed by regulators and the mitigation industry to quantify existing stream functional condition, as well as changes in functional conditions following authorized, proposed stream impacts (debits) or restoration (credits). Harman et al. (2012) developed a function-based framework for stream assessments and structured pyramid framework hierarchically organizing the functions of hydrology, hydraulics, geomorphology, physiochemistry, and biology. This function-based framework applied the prior published work by Fischenich (2006) in which functional objectives for stream restoration were summarized into five functional categories as: system (process) dynamics, hydrological balance, sediment processes and character, biological support, and chemical processes and pathways (Section 3.2.1). To complement the functional framework, Harman et al. (2012) devised an assessment tool called the Stream Quantification Tool, or SQT (TDEC 2018). This tool was adapted for use in Tennessee in 2019, leading to the first implementation of the TN SQT by TDEC and USACE Nashville District Office.

After the TN SQT implementation in 2019, based on experience and feedback received from agency staff and practitioners it was recognized that a revision was needed to address issues with quantification of functional condition scores for several measurement metrics. In August 2020, a statewide, multidisciplinary review working group was convened consisting of TDEC, USACE, and practitioners. This document Acknowledgements recognizes the effort by the individuals in the working group. The goal of the revision was to: 1) reduce the time and effort to conduct an assessment; 2) balance the number of metrics per functional category; 3) address issues with metrics that were reductant, inappropriate for certain stream reach condition particularly where stationary bankfull indicators were absent, and better represent functions associated with the riparian corridor and floodplains; 4) incorporate stormwater management practices embracing watershed-scale restoration than a channel-focused approach; and 5) provide greater flexibility to restoration design approaches better aligning with site conditions. This technical review of the 2019 TN SQT generally followed the protocols described in the USACE document by David et al. (2021). The outcome of the review and generation of this

User's Manual fulfilled the goals. Following public notice and review, the revised version now identified as the Tennessee Mitigation Assessment Tool (TMAT) was implemented in 2025.

Overall, the TMAT and the Tennessee Debit Tool (TN Debit Tool) were created to provide regulators and permittees with a consistent, transparent, and defensible methodology to perform stream functional assessments and mitigation calculations. Thus, a key goal of the TMAT is to produce objective, verifiable, and repeatable results by consolidating well-defined procedures for quantitative measures of structural or compositional attributes of a stream and its underlying morphological and ecological processes.

TDEC's and USACE's requirements to address stream functional losses and the mandatory compensatory offsets is based on assessing changes in stream function using a quantifiable method such as the TN Debit Tool and TT. However, permit applicants may apply alternative methods only if they demonstrate that these methods are scientifically defensible and comply with all applicable legal requirements.

1.4 Uses of the Tennessee Mitigation Assessment Tool

The primary use of the TN Debit Tool and TMAT is to calculate functional loss and ecological lift associated with stream impacts and restoration projects. In addition, the TMAT can assist in mitigation site selection, determining project specific function-based goals and objectives, understanding the potential for functional lift at a site, determining success criteria, and developing a monitoring plan. Some of the potential uses of the TMAT are listed below.

1. Restoration Potential – The tool can assist in determining the level of restoration a project can achieve through evaluation of site constraints, watershed stressors, and selection of reach-based parameters for functional lift.
2. Watershed Stressors – A watershed assessment can be performed to determine factors that limit the potential stream functional lift that can be achieved by a restoration project, including for the purpose of compensatory mitigation.
3. Site Selection – The tool can help determine if a site can benefit from a restoration project and if the site has significant limitations that would inhibit a project from being successful. Site selection is critical to determine whether a proposed stream restoration project can achieve enough functional lift to meet project goals and objectives. Reach assessment methods coupled with a watershed assessment can be used to evaluate and select a site at the development phase of a project.
4. Function-Based Goals and Objectives – The TMAT can be used to describe project goals that match the restoration potential of a site. Quantifiable objectives and performance criteria can be developed that link restoration activities to measurable changes in stream functional categories and function-based parameters assessed by the tool.
5. Functional Loss – Functional loss can be determined with the TN Debit Tool, a separate workbook from the TMAT. The Debit Tool workbook uses the same logic as the TMAT but predicts proposed condition scores based on existing conditions and modeled functional loss based on the effect of typical impact activities.

6. Functional Lift – The TMAT can quantify functional lift from a proposed or active stream restoration project. Lift is estimated during the proposal, design or mitigation plan phase and is calculated for each post-construction monitoring event.
7. Compensatory Mitigation – The TMAT can be applied to on- or off-site compensatory mitigation projects. These include mitigation banks, in-lieu fee mitigation, and permittee responsible mitigation. The tool can help determine if the proposed mitigation activities will provide sufficient functional lift to offset unavoidable adverse impacts to streams. It can also be used to develop monitoring plans to gauge a project's success against established reference standards and applied to annual monitoring to assess project success over time.
8. Stormwater Best Management Practices (BMPs) Used with Stream Restoration – The TMAT was developed with careful consideration to how stream restoration projects using stormwater control measures (SCM) as BMPs to treat adjacent runoff can achieve functional lift.

Use Numbers 1 through 4 are pre-project planning activities which are described in greater detail in Section 5 of this User's Manual. *Use Numbers 5 and 6* identify the quantification of aquatic resources loss from an impact, and functional lift from restoration which are described in Sections 2 and 4 in this User's Manual. *Use Number 7* recognizes the use of the TMAT for stream mitigation. *Use Number 8* is unique within the TMAT recognizing watershed scale improvements through stormwater BMPs (SCM) enhancing functional lift by providing physical habitat and ecological benefits to stream reaches.

This User's Manual is not intended to describe all the federal and state mitigation requirements in Tennessee. A general summary of possible relevant federal and state regulations is listed in Appendix 9.1. Requirements for the review and approval of third-party mitigation, In Lieu Fee (ILF) mitigation, and Permittee-Responsible Mitigation (PRM) projects can be obtained from Nashville and Memphis Districts of USACE and TDEC websites.

1.5 Purpose and Organization of TMAT User's Manual

The purpose of this User's Manual is an aid to support practitioners with completing the TMAT to fulfill the regulatory requirements for functional stream assessments. In addition, the Manual's purpose is for practitioners to generate metric field values with accuracy and precision, as best possible depending on a site condition's complexity. Practitioner variability of data collection can be reduced through experience and professional training to generate defensible field values for the TMAT metrics.

This User's Manual is organized into the following sections:

Section 1: Background and Purpose. A general description of the regulatory context for assessing functional conditions and use of the stream quantification tool.

Section 2: TMAT Functional Categories, Parameters, and Metrics. A description of TMAT specific functional categories, parameters, and metrics, descriptions of basic stream assessment terms, a summary of their functional attributes, and overview of TMAT data collection and analysis.

Section 3: Physical and Ecological Principles Supporting TMAT Use. A summary of the fundamental scientific background associated with the measurement parameters included in the TMAT.

Section 4: Stream Mitigation Functional Loss and Lift. Method descriptions of determining debits from functional loss and credits from functional lift.

Section 5: Project Site Assessment, Data Collection and Field Preparations. An outline of procedures for project data collection, including reach segmentation, and identification and verification of bankfull indicators.

Section 6: TMAT Metrics: Data Collection Procedures. Detailed methodology for desktop-based data collection procedures and computations, and field-based metric data collation and metric index score computations.

Section 7: Field Datasheet/Worksheet Completion Procedures. A field data sheet is provided for use in which data can be entered into the worksheet computing condition scores for category, parameter and metrics.

Section 8: References. A list of references cited in this User's Manual.

Section 9: Appendices. Appendices on federal and state statues, performance standards.

2. TMAT Functional Categories, Parameters, and Metrics

Section 2 of this User's Manual introduces the TMAT functional categories and parameters, and the metrics within each. It also summarizes the functional statements for the different categories and metrics defining the functional attributes quantified by the TMAT measurement methods. The scientific basis for the functional parameters and metrics, and their reference standards are summarized in Section 3. Applying the TMAT, Section 4 provides a procedural overview of stream mitigation debiting and crediting with flow charts aiding practitioners with helpful guidance to the relevant manual sections to complete these procedures.

2.1 TMAT Function-Based Framework and Categories

2.1.1 Description of Functional-Based Frameworks for Streams

In general, stream quantification tools are organized by stream functional categories and parameters representing broad groupings of physical, chemical, and biological conditions of a stream reach (Harman et al. 2012). A *functional statement* describes the overarching functional attributes for each category/parameter supporting the metrics used to quantify functional capacity (Figure 2.1). Each metric is measured by either desktop and/or field measurements to compute a *field value*. They are calculated using well-established *measurement methods* (specific tools, equations, assessment methods), many of which are commonly used by stream restoration practitioners. *Reference standards* are functional condition values derived from field measurements generated using existing assessment datasets. In many cases, they are ecoregion-specific. *Reference standards* are used to determine measured functional condition relative to expected reference condition for each metric. The reference condition for a metric represents a condition found in an unaltered or minimally impacted system and does not necessarily represent the best condition that can be achieved such as a TDEC ecoregion reference site. Based on comparison to the reference standards, each metric's measured *field value* is converted to an index score ranging from 0.0 to 1.0, where 1.0 is equivalent to the highest achievable reference condition. This comparison is the performance relationships by the assessed metric to a condition index score.

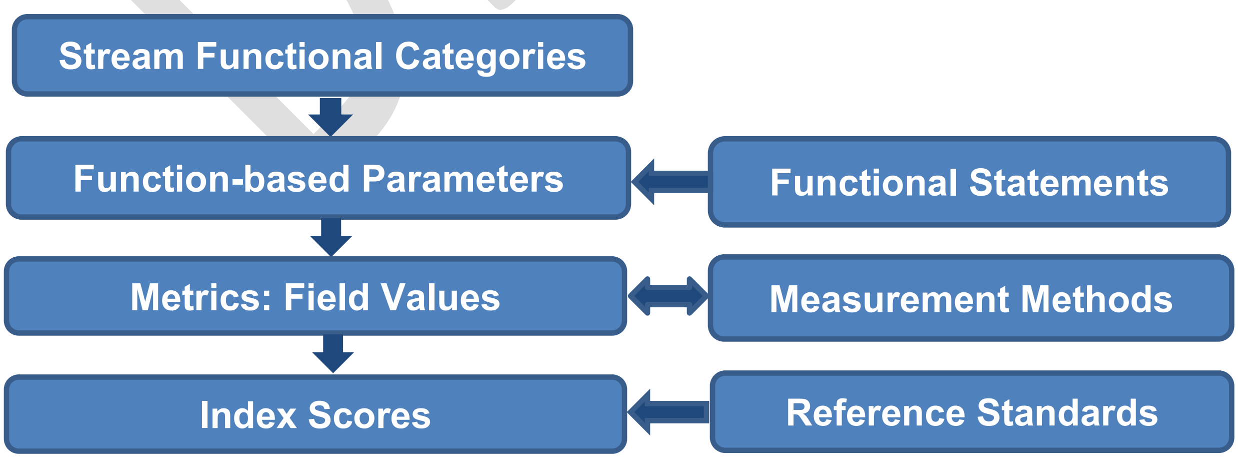


Figure 2.1. General procedural structure of stream quantification tools (TDEC 2018).

Function-based frameworks assembly functional categories/parameters organizing and defining the metrics that are to be used to collectively assess the overall functional condition. Harman et al. (2012) describes a pyramid, hierarchically structured framework which includes in order: Hydrology, Hydraulics, Geomorphology, Physiochemical, and Biology. The TMAT is organized non-hierarchically by function-based parameters within five categories, which categories are Hydrology, Hydraulics, Geomorphology I and II, and Water Quality/Biology (Figure 2.2). Parameters relate functional attributes, for example the TMAT Geomorphology categories include Large Woody Debris, Riparian Corridor, Channel Stability, and Physical Habitat. As described above, specific metrics are measured and index scores computed, which group of metrics per category is averaged, or rolled up to compute a category index score (Figure 2.1). Within the TMAT, the five categories are balanced with a similar number of metrics so not to overweight one category during the roll-up procedure quantifying the total index score for a project reach. This reach index score is the Existing Condition Score (ECS) prior to any impact or restoration. It is termed a Proposed Condition Score (PCS) for anticipated functional condition loss from an impact or functional condition lift from a proposed restoration project.

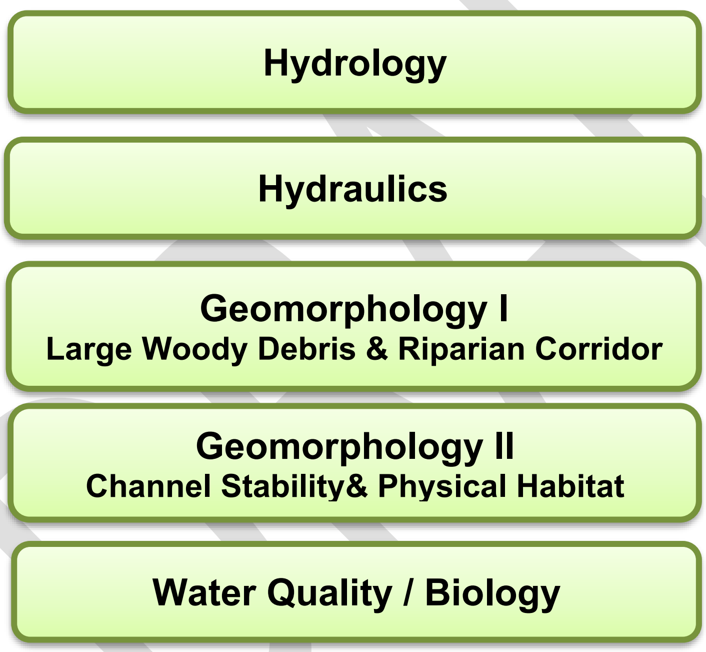


Figure 2.2. Functional categories of the TMAT.

2.1.2 Stream Functional Conditions

The reach index score or ECS corresponds to one of three functional condition score categories: 1) functioning, 2) functioning-at-risk, or 3) not functioning. Definitions for each functional condition score category are as follows:

- Functioning – A functioning score means the measured metric is indicative of a function-based parameter that fully supports aquatic ecosystem structure and function. The range of values (0.70-1.00) accounts for natural variability in high-quality reference stream datasets and the potential for these datasets to include minimally and least disturbed sites.

- Functioning-At-Risk – A functioning-at-risk score (0.30 - 0.69) means that the measured metric is indicative of a function-based parameter that may partially support aquatic ecosystem structure and function, but not at a reference condition. In some cases, this may indicate the function-based parameter is adjusting in response to changes in the reach or the catchment and may be trending towards lower or higher function.
- Not Functioning – A not functioning score [0.0 – 0.29] means that the measured metric is indicative of a function-based parameter that does not support aquatic ecosystem structure and function. An index score less than 0.30 represents an impaired or severely altered condition relative to reference condition.

2.2 TMAT Function-based Parameters and Metrics

2.2.1 Summary List of Metrics for the TMAT

Metrics within function-based parameters for the five functional categories shown in Figure 2.2 are presented in Table 2.1. Table 2.1 also includes a selection guide as to whether a parameter metric is *required* or whether it is *optional*. It also defines the weight per metric score toward the total condition score (ECS or PCS). Two calculation pathways to compute functional conditions ECS or PCS are provided in the TMAT, which are bankfull and non-bankfull methodologies. One method pathway for several metrics requires a bankfull determination, whereas a second pathway does not. However, both pathways and suite of metrics measure the same functional attributes. A flow chart summarizing the parameters and metrics per functional category is shown in Figure 2.3.

The Hydrology category includes three parameters and three metrics related to watershed and reach-scale runoff attributes (Table 2.1), none of which require a bankfull determination. The Hydraulics category includes one parameter of floodplain connectivity with a choice of two metrics that require bankfull determination or two metrics that do not. Users should select the bankfull-based metrics unless well-defined bankfull indicators are unavailable or watershed conditions are not stable due to continued shifts in hydraulic regime and sediment transport. Whether to use the bankfull or non-bankfull pathway is described in Sections 5.3.3 and 5.3.4. Geomorphological parameters are divided into two functional categories (I and II). The Geomorphology I category consists of two parameters associated with site vegetation characteristics including Large Woody Debris and Riparian Corridor. The Geomorphology II category consists of two parameters associated with bed and bank morphological characteristics of Channel Stability and Physical Habitat parameters. The Large Woody Debris parameter consists only of one metric. The Riparian Corridor parameter consists of four metrics. The Channel Stability parameter consists of four metrics. The Physical Habitat parameter consists of three or four metrics depending on whether bankfull indicators are present. The Pool-Depth Ratio metric is only used if bankfull indicators are present. The measurement method for the Pool to Pool Spacing metric using bankfull width is modified using the active channel width if bankfull indicators are not adequate. Lastly, the Water Quality/Biology category consists of parameters for each, and only one required metric for Biology. Metrics within the Water Quality parameter are optional.

Table 2.1. Summary of TMAT function-based parameters per functional category, metrics per parameter, a metric selection guide, and the score weight per metric, per parameter, and per category.

Functional Category	Functional Parameter	Metric	Selection Guide	Metric Index Score	Parameter Score	Category Score
Hydrology	Catchment Hydrology	Watershed LUR	Always	0.067	0.067	0.2
	Reach Runoff	Stormwater Infiltration	Always	0.067	0.067	
	Floodplain Storage	Infiltration Potential	Always	0.067	0.067	
Hydraulics	Floodplain Connectivity	Bank-Height Ratio	Bankfull available	0.1	0.2	0.2
		Entrenchment Ratio	Bankfull available	0.1		
		Aggradation Ratio	BF available (optional)	(0.067)		
		Floodplain Inundation Frequency	Bankfull not available	0.1	0.2	
		Channel Incision	Bankfull not available	0.1		
Geomorphology I	Large Woody Debris	Large Woody Debris	Always	0.1	0.1	0.2
	Riparian Corridor	Riparian Corridor Width	Always	0.025	0.1	
		Riparian Canopy Cover	Always	0.025		
		% Invasive Species	Always	0.025		
		Average DBH	Always	0.025		
Geomorphology II	Channel Stability	% Streambank Erosion	Always	0.033	0.1	0.2
		% Streambank Armoring	Always	0.033		
		Rapid Geomorphic Assessment	Always	0.033		
	Physical Habitat	Wolman Pebble Count	Always	0.025 (BF), 0.033 (NBF)	0.1	
		% Riffle	Always	0.025 (BF), 0.033 (NBF)		
		Pool-Pool Spacing Ratio	Always (NBF alterative)	0.025 (BF), 0.033 (NBF)		
		Pool Depth Ratio	Bankfull available	0.025		
Biology / Water Quality	Biology	Tennessee Macroinvertebrate Index	Always, unless TMI sub-metrics option chosen	0.2 or 0.1	0.2 or 0.1 if WQ option used	0.2
		% Clingers	TMI sub-metrics option	0.2 Or 0.1		
		% EPT - Chuematopsyche				
		% Oligochaetes & Chironomids				
	Water Quality	% Nutrient Tolerant TMI submetric	Water quality option	If applied, 0.1	0.1	
		Mean Nitrate/Nitrite				
		Mean Total Phosphorus				
		Geomean *Escherichia coli (E. coli)*				

<u>Acronyms</u>: LUR = Land Use Runoff; DBH = Diameter at Breast Height; BF = Bankfull; NBF = Non-Bankfull; TMI = Tennessee macroinvertebrate Index; MI = Macroinvertebrates; EPT = Ephemeroptera, Plecoptera, & Trichoptera; WQ = Water Quality

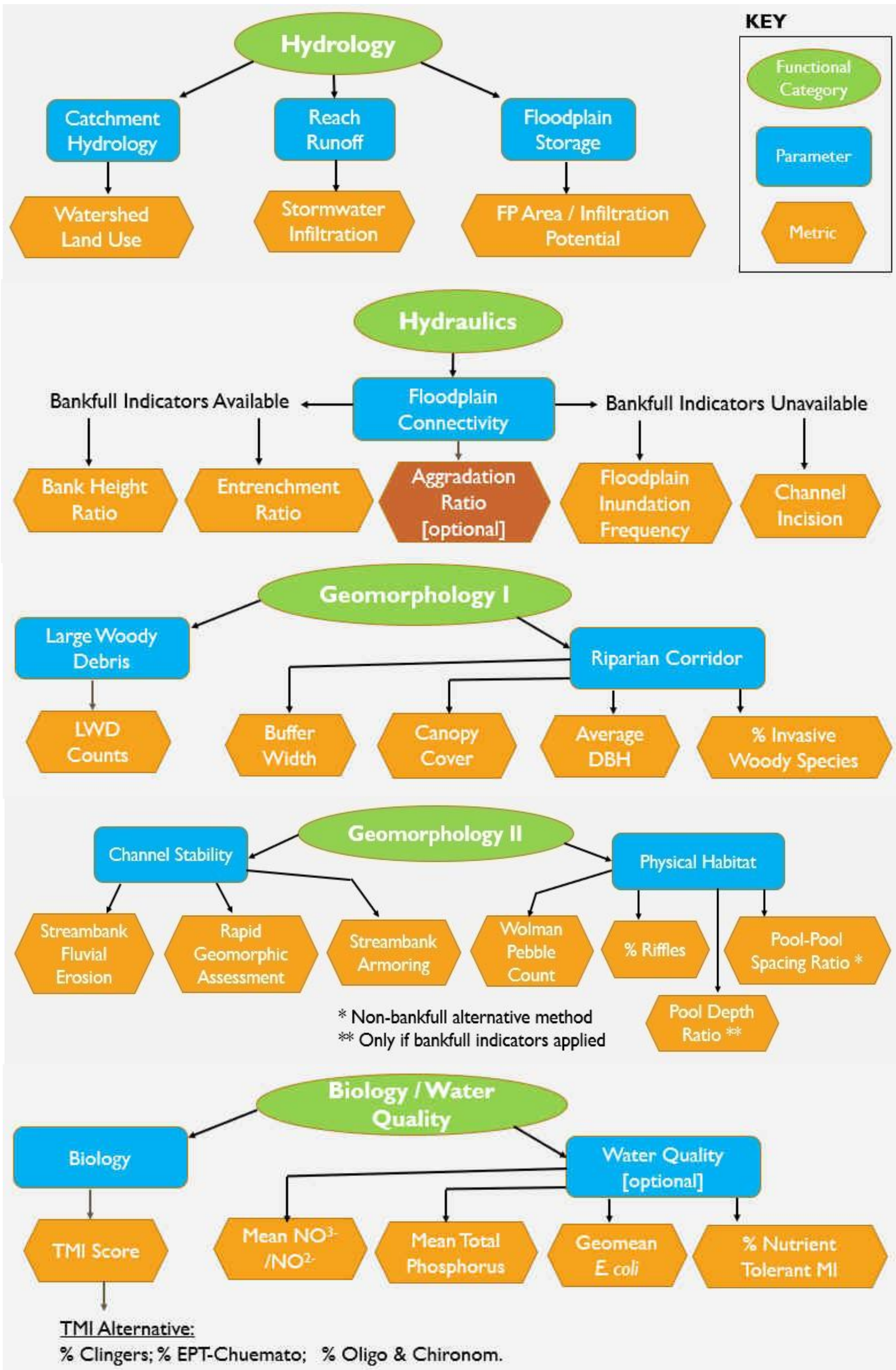


Figure 2.3. TMAT functional categories, and their component parameters and metrics.

2.2.2 Relations Between TMAT Functional Categories, Parameters, and Attributes

Defining the relationships between functional parameters and category functional attributes supports the scientific basis for the TMAT metrics. Functional statements and attributes for each functional parameter and metrics are summarized in Table 2.2. The scientific basis for the functional parameter and metrics, referencing published physical and ecological principles are summarized in Section 3 of this User's Manual. The TMAT is a selection of metrics that relate to the functional attributes, which inform the *Reference Standards* and therefore the determination of the scaled *Index Scores* (condition scores). However, alternative metrics may be used if they accurately quantify the functional attributes described here within and approved for use by TDEC and the USACE.

In Table 2.2, provided here for convenience are the acronyms used: BF = bankfull, NBF = non-bankfull, LWD = large woody debris, DBH = diameter at breast height; TMI = Tennessee Macroinvertebrate Index; NO_3^-+NO_2^- = nitrate + nitrite; and TP = total phosphorus. Also, to note: TMI sub-metrics include: % Clingers, % EPT – Cheumatopsyche; and % Oligochaetes and Chironomids. EPT = Ephemeroptera, Plecoptera, and Trichoptera.

2.3 Overview: TMAT Data Collection and Analysis

A primary goal of this User's Manual is to provide practitioners the instructions to correctly implement the measurement methods for each metric in the TMAT and accurately quantify the metric's field value used to calculate the index scores. Measurement methods include desktop data collection and analysis and field-site data measurement and analysis. Proper collection of data in an objective, consistent manner is key to understanding a site's existing condition and its potential functional loss from a permitted impact and its potential for functional lift from stream mitigation projects.

Whether parameter metrics are determined by desktop-based or field-based measurement methods is summarized in Table 2.3. Section 6 of this User's Manual provides instructions for both desktop-based measurements and field-based measurements. Individuals or interdisciplinary teams collecting and analyzing desktop and field measurement data should ideally have expertise and experience in the discipline areas of hydrology, stream hydraulics, fluvial geomorphology, and biology/ecology. Data entry into field sheets and the TMAT worksheet are described in Section 7.

Few of these measurement methods are unique to the TMAT and are often detailed in other instruction manuals, or published literature and government documents. Where appropriate, this Manual will reference other data collection documents making clear any differences in data collection or analysis methods with the TMAT. TDEC has compiled existing instructional resources and made several of them available on its compensatory mitigation website at:

https://www.tn.gov/environment/permit-permits/water-permits1/aquatic-resource-alteration-permit--arap-/permit-water-arap-compensatory-mitigation.html.

Table 2.2. Summary of TMAT functional statements per parameters and metrics.

Functional Category	Functional Parameters and Metrics	Functional Statements and Associated Attributes
Hydrology	▪ Catchment Hydrology ▪ Reach Runoff – Stormwater Infiltration ▪ Floodplain Storage – Infiltration Potential	▪ Watershed scale runoff affected by upstream land cover/land use. ▪ Water quality improvements and enhanced infiltration of surface runoff. ▪ Floodplain area available for flood water infiltration, and peak flow attenuation.
Hydraulics	Floodplain Connectivity ▪ Bank Height Ratio ▪ Entrenchment Ratio ▪ Floodplain Inundation ▪ Channel Incision ▪ Aggradation Ratio	▪ BF: A measure of floodplain inundation and channel incision. ▪ NBF: A measure of floodplain inundation and channel incision. ▪ Excessive sediment deposition, habitat quality.
Geomorphology I	Large Woody Debris Riparian Corridor ▪ Riparian Width ▪ Canopy Cover ▪ Average DBH ▪ % Invasive Sp.	▪ LWD provides structure in channel supporting enhanced stream habitat quality. ▪ Riparian vegetation provides for channel bank stability and shade regulating for water temperature; provides for habitat quality. ▪ Invasive species limit vegetation diversity.
Geomorphology II	Channel Stability ▪ % Streambank Erosion ▪ Rapid Geomorphic Assessment ▪ % Streambank Armoring Physical Habitat ▪ Wolman Pebble Count ▪ % Riffle ▪ Pool Spacing Ratio ▪ Pool Depth Ratio	▪ Degree of bank erosion and rapid channel vertical and lateral geomorphic adjustments. ▪ A measure of streambank habitat quality. ▪ Sediment supply/transport and bed sediment for habitat quality maintenance. ▪ Mesohabitat quality for pool habitat units. ▪ Bedform diversity.
Biology / Water Quality	Biology ▪ TMI ▪ TMI Sub-metrics Water Quality ▪ % Nutrient Tolerant MI ▪ NO_3^-+NO_2^-, TP ▪ *E. coli*	▪ A measure of biotic integrity and degree of water quality impairment. ▪ A TMI indicator for excessive nutrients. ▪ Direct nutrient chemical measure of Nitrate + Nitrite and Total Phosphorus. ▪ A measure of fecal pollution.

Table 2.3. Desktop/field data sources per TMAT functional category and function-based parameters/metrics.

Functional Category	TMAT Parameters / Metrics	Data Source
Hydrology	Catchment Hydrology, Reach Runoff/Stormwater Infiltration, Floodplain Storage	Desktop
Hydraulics	Floodplain Connectivity ▪ Bank-Height Ratio, Entrenchment Ratio ▪ Floodplain Inundation, Channel Incision	▪ Field ▪ Desktop & Field
Geomorphology I and II	LWD, Riparian Corridor, Channel Stability, and Physical Habitat.	Field
Biology / Water Quality	Tennessee Macroinvertebrate Index (TMI), and TMI sub-metrics; NO_2^-/NO_3^-; TP; *E. coli*	▪ Field ▪ Desktop

3. Physical and Ecological Principles Supporting TMAT Use

3.1 Stream Assessments for Restoration

3.1.1 Overview of Stream Assessments

Many stream assessment methods have been developed with the overarching goal of managing natural resources and were modified over years by multiple federal and state agencies for specific purposes (Somerville 2010). Purposes vary but include: source areas of water pollution for watershed restoration planning; management of fisheries and other aquatic resources; implementation of citizen surveys; developing threatened or endangered species recovery plans; protecting infrastructure from channel instabilities; and monitoring compliance for state or federal regulatory permits. Somerville (2010) summarizes 32 different assessment protocols and 70 unique assessment parameters differing by region, and federal, state, and local government agency. Federal agencies include: the USEPA, US Forest Service, US Fish and Wildlife Service (USF&W), US Geological Survey (USGS), USACE District Offices, and USDA Natural Resource Conservation Service (NRCS). Numerous assessment protocols, but not limited to, are non-regulatory and comprise of rapid visual techniques for forestry, fish and wildlife resource conservation (Pfankuch 1975; Platts et al. 1983; Harrelson et al. 1994; Bain et al. 1999; Roper et al. 2002; Oakley et al. 2003; NRCS 2007, 2009; USFS 2009; Starr et al. 2015). Other stream assessment protocols have a regulatory mission consisting of an objective framework, associated metrics, and measurement methods used by the USEPA and USACE.

The CWA implemented by the USEPA is "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters" (33 U.S.C §1251(a)). Under Section 303(d) of the CWA, states, territories and authorized tribal "states" are required to identify and list impaired waters that do not meet established water quality standards. This regulatory effort required the development of water quality standards and biomonitoring programs. USEPA formulated guidance on the development of state biomonitoring programs for surface waters based on the concept of ecological health (USEPA 1990). To quantify stream ecological health and determine whether a waterbody is impaired, Karr et al. (1986) produced methods to compute indices of biological integrity (IBI). The IBI conceptual framework developed by Karr et al. (1986) forms the basic functional categories used to relate environmental stressors to their response in biological condition, collectively quantifying ecological health of a stream (Figure 3.1).

Further guidance on the IBI methodology by the USEPA included the Rapid Bioassessment Protocols (RBP), which was developed for use in wadable streams by Barbour and others (1999). The RBP includes IBI methodologies for fish, benthic macroinvertebrates, and periphyton. It also includes an index methodology for physical habitat assessments. The state of Tennessee modified the basic RPB framework as the Tennessee Macroinvertebrate Index (TMI) and implemented the TMI to meet their requirements in §303(d) of the CWA (TDEC 2017). The TMI is applied in the TMAT (Table 2.1). TDEC (2017) also includes the methodology for the state's habitat assessment and index computations.

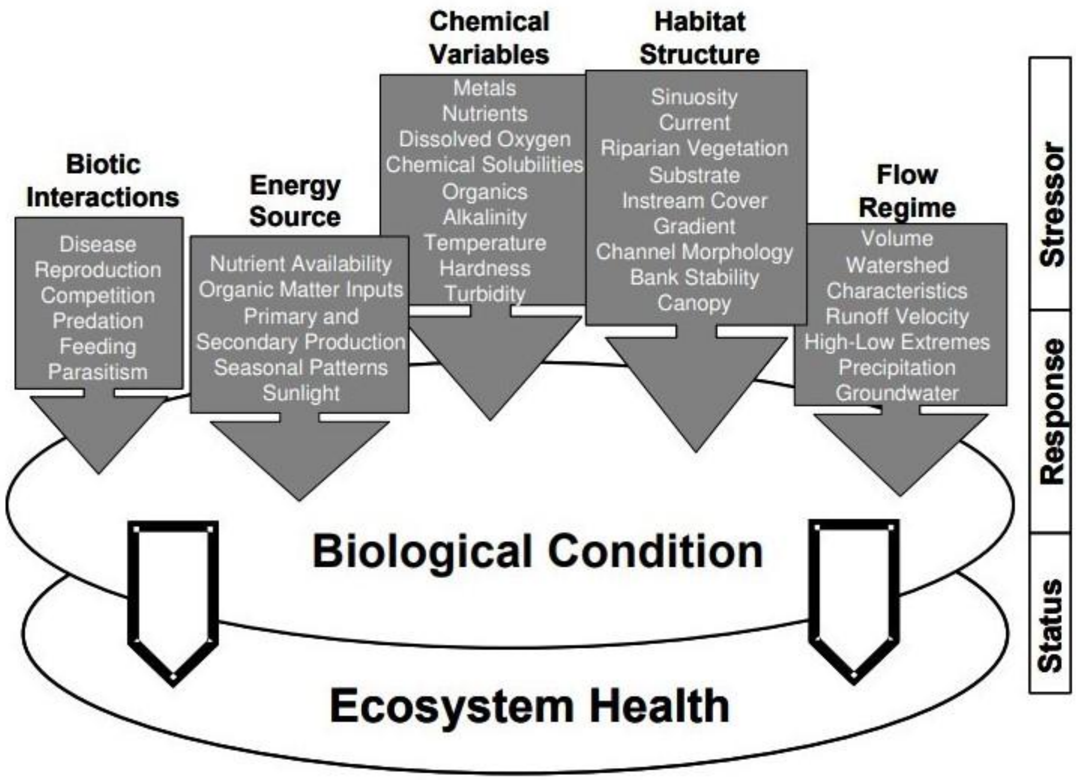


Figure 3.1. Five classes of environmental variables that affect water quality, biotic integrity and ecosystem health (modified from Karr et al. 1986).

Stream assessment protocols were further advanced by the USEPA supporting the Environmental Monitoring and Assessment Program (EMAP), which was developed by Kauffmann and others (1999). The document by Kaufmann et al. (1999) is a helpful resource for basic stream survey techniques, and some metrics in the EMAP protocols are similar to those used in the TMAT. The fundamental goals of the CWA are best addressed by explicitly integrating physical stream habitat criteria into water quality standards (Asmus et al. 2009; Bauer and Ralph 2011).

CWA Section 404 regulates impacts to WOTUS and in Tennessee the ARAP program regulates impacts to WOTS (Section 1.1). The federal 2008 Mitigation Rule requires compensatory mitigation projects to be evaluated by objective and verifiable measurements of stream condition based on *best available science* and conducted in a practicable manner. Somerville and Pruitt (2004) described an assessment classification system to reduce variability, and be objective and quantitative with a fluvial geomorphic emphasis for the CWA Section 404 Regulatory Program. Stepchinski et al. (2025) reviewed many agency stream assessment frameworks and protocols and summarized the ecological impacts and benefits as related for use by compensatory mitigation programs. An on-line database of assessment protocols can be obtained at http:/emrrp.el.erdc.dren.mil/. Stepchinski et al. (2025) also evaluated the technical level of detail each protocol provides to generate output for performance standards. Overall, stream assessments need to be conducted in an objective manner to document appropriate ecological performance standards for compensatory mitigation programs. Chapter 3 of this User's Manual documents the scientific support for the metrics applied in the TMAT.

3.1.2 Components of Stream Assessment Methods for Compensatory Mitigation

To Restore and maintain ecological functions of physical, chemical, and biological conditions of streams as regulated by the CWA Section 404 (33 CFR §33, CFR §332.5; 40 CFR §230.95) and the state of Tennessee ARAP (TDEC DWR Rule 0400-40-07), objective and verifiable ecological performance standards must be developed and implemented. Measurements of ecological performance standards assess the *functional capacity* of a stream, defined in 33 CFR §332.2 as the "degree to which an area of aquatic resources performs a specific function." Stream condition is defined as the relative ability of a lotic ecosystem to support and maintain a community of organisms comprised of species diversity, abundance, and trophic organization compared to a high-quality reference aquatic resource in a region (Nadeau et al. 2018; Davies 2000; David et al. 2021). Snap-shot assessments of stream condition are measures of *functional capacity* of existing aquatic resources prior to an impact or restoration project, and a sequence of condition measurements after restoration. This measurement framework allows for debiting of functional "loss" and crediting of functional "lift", where measurement units are computed in terms of linear functional feet (Harman et al. 2012). To characterize *functional capacity*, the aquatic resource condition is put into context with other streams within a defined region, typically a state and ecoregion, and compared to a target or *reference condition* (Section 2.1.1).

The target or *reference condition* is defined in the 2008 Mitigation Rule as "a set of aquatic resources that represent the full range of variability exhibited by a regional class of aquatic resources as a result of natural processes and anthropogenic disturbances." Stream assessments of aquatic ecosystems depend on the ability to compare current conditions against some expectation of how they could be in the absence of significant human disturbance (Stoddard et al. 2006). The concept of a *reference condition* is often used to describe the standard or benchmark against which current condition is compared. David et al. (2021) defines the *reference condition* of a stream as having high-quality aquatic resources within a defined region. A stream assessment framework and its metrics based on or related to regional reference conditions is developed and applied for mitigation where condition scores are compared between project and reference sites. This comparison is the basis of mitigation debiting and crediting.

David et al. (2021) state "an effective stream assessment method underlies development of other function-based regulatory tools that allow regulators and their partners to: (1) develop mitigation crediting and debiting protocols, (2) determine mitigation project performance, (3) compare streams to a target condition, and (4) determine the current status of a stream and in what direction the stream is trending." As noted above, stream assessments include metrics that characterize chemical, physical, and biological conditions of a stream. Such metrics should be process-based so that trends in condition can be evaluated. Thus, the importance of metrics as indictors of ecological health conditions should be responsive to regionally specific impacts and/or restorations. Responsive measures may include changes in flow regimes (hydrology and hydraulics), channel geomorphology and associated physical habitat maintenance processes, riparian vegetation, and water quality. Bledsoe et al. (2022) relates metrics of intertest, specific measurement methods, process interactions, spatial scales, and crediting suitability to four restoration practice categories: 1) bed and bank stabilization, 2) riparian buffers, 3) in-stream enhancements, and 4) floodplain reconnection.

Components of stream assessment methodologies are most commonly comprised of geomorphic, physical habitat, and biological parameters (Stepchinski et al. 2025). Measures of physical habitat are nearly ubiquitous with all stream assessment protocols (Somerville 2010). To assess whether aquatic biota is impaired as it relates to functional capacity, a broader suite of measures is needed to assess functional stream condition including principles of hydrology and hydraulics and the ecological and geomorphic role of riparian vegetation. A broader suite of measures should also relate to biotic integrity as a surrogate indicator of water quality, and a functional relationship to these principles. Noting the published work by Fischenich (2006), Harman et al. (2012); and Bledsoe et al. (2022), a comprehensive suite of functional conditions may consist of functional categories such as hydrology, hydraulics, floodplain dynamics, channel geomorphology, riparian corridor vegetation, in-stream habitat, water quality, and aquatic biota. Within these functional categories, spatial scale and operating processes and responses from impacts need to be understood for effective implementation of the TMAT (Section 3.2.2). Section 3.3 describes the assessment framework for the TMAT as introduced in Section 2.2.

3.2 Functional Objectives for Stream Restoration

3.2.1 Summary of Functional Objectives

In 2006, the Ecosystem Management and Restoration Research Program of the USACE Engineer Research and Development Center (ERDC) noted that specific functions for stream and riparian corridors had yet to be defined in a manner that was generally agreed upon and suitable as a basis for which management and policy decisions could be made (Fischenich 2006). In an effort to fill this need for USACE programs, an international committee of scientists, engineers, and practitioners defined 15 key stream and riparian zone functions aggregated into five categories: 1) system dynamics, 2) hydrologic balance, 3) sediment processes and character, 4) biological support, and 5) chemical processes and pathways (Table 3.1). Underlying the functional categories are watershed system dominant controls on both geomorphological and ecological processes of geology and hydrology. Hydrology is driven by the temporal scale variations in climate and characterized by annual and seasonal periods as well as daily storm events (Davie and Wyndham-Quinn 2019). Geology and hydrology govern soil and vegetation characteristics across the landscape and the four controls together form the basis for ecoregion designations (Omernik 1987). The four controls thus govern valley and stream channel morphology, and the geomorphic processes that create forms (Knighton 1998).

Table 3.1. Functional categories for assessing stream condition supporting restoration objectives (Fischenich 2006).

System Dynamics	Hydrologic Balance	Sediment Processes and Character	Biological Support	Chemical Processes and Pathways
Stream Evolution Processes	Surface Water Storage Processes	Sediment Continuity	Biological Communities and Processes	Water and Soil Quality
Energy Management	Surface / Subsurface Water Exchange	Substrate and Structural Processes	Necessary Habitats for all Life Cycles	Chemical Processes and Nutrient Cycles
Riparian Succession	Hydrodynamic Character	Quality and Quantity of Sediments	Trophic Structures and Processes	Landscape Pathways

Within the five functional categories described in Fischenich (2006), 15 functions are listed and shown in Table 3.1. As components of any stream assessment tool (Section 3.1.2), functions are identified and described, indicators were established with associated functions, and measurement methods developed. Fischenich (2006) summarizes these assessment components for each function (Table 3.2). Table 3.2 is an abridged version; refer to Fishenich (2006) to see full details. Harman et al. (2012) developed an assessment framework in part derived from those categories in Table 3.1 with five categories organized hierarchically in a pyramid diagram. The five categories are: Hydrology, Hydraulics, Geomorphology, Physiochemical, and Biology, and originally used in the TN SQT. The functional categories were revised for the TMAT, which are: Hydrology, Hydraulics, Geomorphology (LWD, Riparian Corridor, Channel Stability, and Physical Habitat), and Biology/Water Quality (Table 2.1). These TMAT functional categories are further described in Section 3.3.

3.2.2 Understanding Functional Condition Scales: Watershed versus Reach

Understanding the principals and processes associated with the spatial scales that governs each metric's functional attributes will assist practitioners to more accurately measure metric field values in the TMAT. Two governing scales for assessing stream condition are the watershed and the reach (Figure 3.2). At the watershed scale, stressors from land cover and channel disturbances, and other human activities are many (Section 1.3). Watershed stressors are landscape level impacts such as hydromodification which can cause reach-scale instabilities to channel morphology and physical habitat. They can also include water quality impacts from non-point source pollutants. These impacts govern the restoration potential for biotic integrity recovery (Table 5.1). As noted above in Section 3.1.1, most stream assessment protocols are developed for the reach scale. Also, the reach is the typical scale in which restoration projects are implemented. Sections 5.3 and 5.4 of this User's Manual provides the guidance on collecting information on watershed characteristics and stressors, in addition to the procedures to classify the reach-scale Rosgen stream type. Those sections are primarily used as the guidance for the practitioner to assess a site's potential for restoration, whereas this section (Section 3.2.2) describes the key concepts for the scientific support of the TMAT.

Table 3.2. Summary of functions, descriptions, indicators, and measurements for functional categories supporting restoration objectives (Fischenich 2006).

Function	Description	Indicators	Measurements
Category: System Dynamics			
Maintain Stream Evolution Processes	Promotes normally occurring ecological changes to maintain biodiversity	Stream stability, geomorphic channel equilibrium	Geomorphic stability assessments, channel evolution model, hydrologic condition
Energy Management Processes	Spatial and temporal variability in channel processes	Stream stability, channel geomorphic equilibrium	Stream power and energy grade line; floodplain condition
Provide for Riparian Succession	Promote changes in vegetation structure for system stability; large woody debris (LWD) recruitment	Vegetation diversity and age classes	Riparian corridor width, vegetation diversity, LWD recruitment
Category: Hydrologic Balance			
Surface Water Storage Processes	Floodplain storage of floodwaters; habitat refugia	Channel flood flows connected to floodplain; watershed land uses	Floodplain storage area and floodplain inundation frequency
Surface – Subsurface Connections and Processes	Moderate high-flow erosional processes, provide habitat, maintain baseflow	Floodplain process characteristics; groundwater elevation fluctuations	Groundwater measurements; floodplain soil properties (wetlands)
Hydrodynamic Balance	Maintain natural flow regime	Active floodplain w/ and w/o wetlands	Flow duration analysis
Category: Sediment Processes and Character			
Sediment Continuity	Appropriate erosion, transport, and deposition processes; substrate sorting	Bed sediment character, changes in bed sediment erosion and/or deposition	Bedload and suspended load monitoring/ modeling; sediment yield measures
Substrate and Structural Processes	Stream channels and riparian zones substrates support diverse habitats	Bed sediment structural diversity/ complexity; habitat quality	Habitat surveys; biota surveys (bioassessments)
Quality and Quantity of Sediments	Sediment yields determining good habitat and biota	Mesohabitat structure maintained by sediment supply	Bed sediment particle sizes, embeddedness, biotic surveys

Table 3.2 *continued ……………*			
Function	**Description**	**Indicators**	**Measurements**
Biological Support			
Biological Communities and Processes	Provide for diverse biological communities	Changes in population trends, unbalanced trophic structure	Biotic surveys for population and growth, and community diversity
Aquatic and Riparian Habitats	Provide and sustains quality habitat to support diverse biological community	Presence/absence of habitat features and key indicator species	Physical habitat surveys; biotic integrity surveys
Trophic Structure and Processes	Supports food chain dynamics and complex food webs	Presence/absence of producers, prey, and predators	Biotic integrity surveys; organic matter measures; biomass profile
Chemical Processes and Pathways			
Maintain Water and Soil Quality	Water quality necessary to support biotic communities; riparian soils to maintain healthy vegetation	Aquatic and riparian vegetation biological community are diverse, and healthy	Water and soil chemistry; organic matter measures; riparian soil profiles
Chemical Processes and Nutrient Cycles	Provide nutrients and transformations for ecosystem processes	Presence/absence of indicator species and their health	Water/soil chemistry and analysis; plant growth
Maintain Landscape Pathways	Maintain longitudinal and lateral connectivity	Presence/absence of biota movements along corridors	Biological migration surveys

Drainage networks within watersheds are hierarchically organized as shown by stream order in Figure 5.2 (Strahler 1957). They can be structured into spatiotemporal scales starting at this broadest level. From the drainage network scale (stream segments), sequentially smaller scales are the segment, reach, bar unit (pool-riffle unit), and microhabitat units including bed substrate (Figure 3.3). Originally organized as geomorphic units by Schumm (1977), Frissell et al. (1986), they formulated the ecological significance of the hierarchical spatial scales as habitat units, recognizing the geomorphic processes at different scales relate to habitat maintenance. Each spatial scale within the watershed for the different habitat units have accompanying temporal scales with respect to the geomorphic processes adjusting from a disturbance and/or maintaining natural geomorphic forms (Figure 3.4). Poff (1997) provides a perspective that at each scale, the quality of that scales' habitat structure acts as a filter where collectively the pool of aquatic species can complete their life histories, governing the potential for maintaining biodiversity.

Figure 3.2. Example watershed disturbance resulting in a causal chain of alterations to stream corridor structure and function (*from* NRCS 2007).

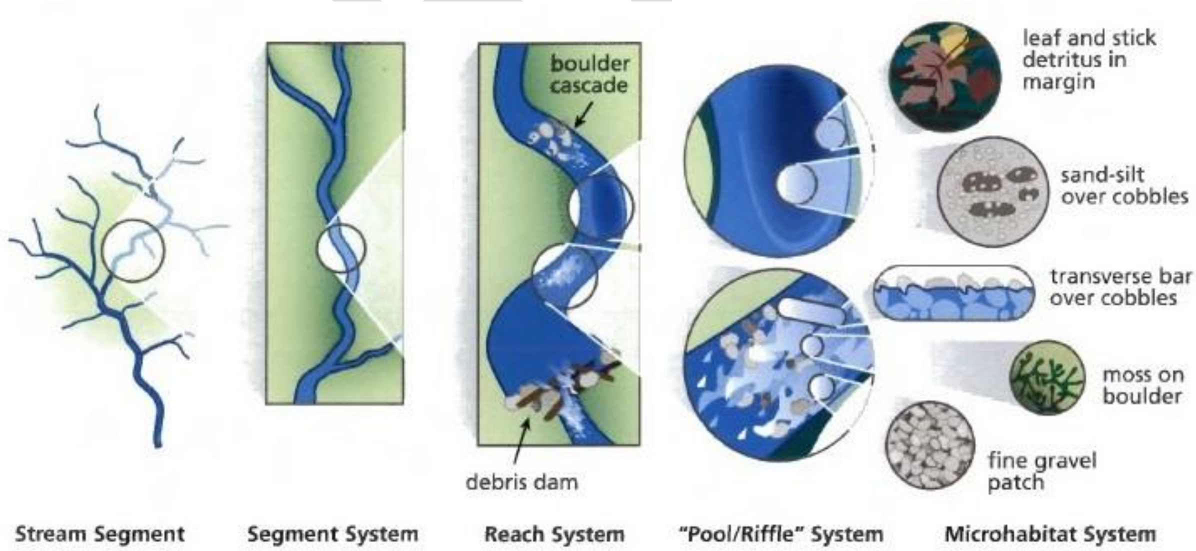


Figure 3.3. Hierarchical organization of a stream system and its habitat subsystems as described by Frissell et al. (1986) for five spatial scales within a watershed (*from* FISRWG 1998).

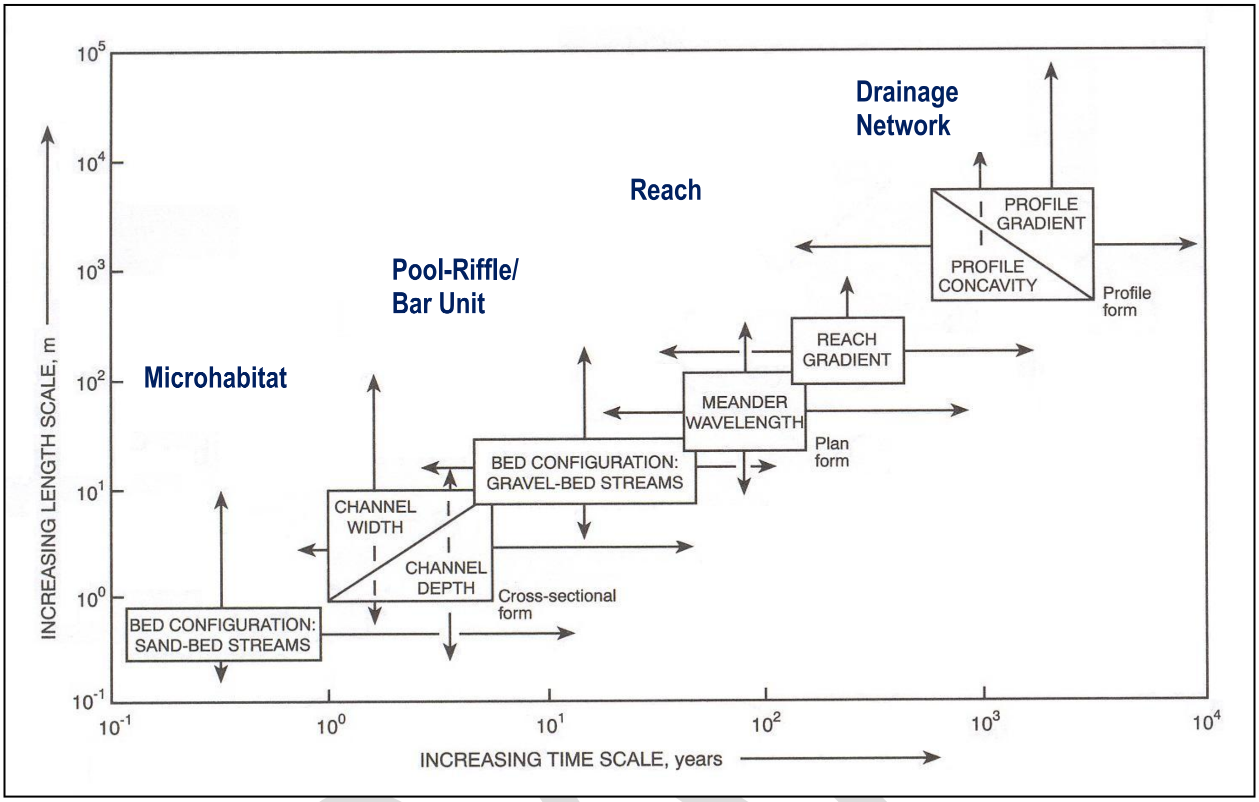


Figure 3.4. Spatial and associated temporal scales for geomorphic adjustment and form maintenance scales modified from Knighton (1998).

Advancing this organization, Gregory et al. (1991) incorporated the ecological relevance of the riparian corridor into these spatiotemporal scales of the habitat units. The riparian corridor with forested vegetation provides multiple geomorphic and ecological functions (Naiman et al. 1993; Ward et al. 199; Fischenich 2001; Wynn and Mostaghimi 2006; NRCS 2007). The functions include: supporting streambank stability, moderating stream water temperatures by shading the channel; buffering pollutants in overland flow from enter waterways, supplying LWD to the channel enhancing habitat complexity, and providing terrestrial habitat for wildlife. A continuous riparian corridor has high habitat connectivity, whereas interruptions or removal of vegetation has low connectivity (Figure 3.5). Habitat connectivity is a measure of how spatially continuous a corridor or matrix is, and how well different habitats within are connected in order for free movement of plants and animals, and the transport of materials and energy. In river systems, it is commonly referred to as how well the channel is connected to the floodplain. Developed land uses can cause habitat fragmentation, or low levels of habitat connectivity may impact aquatic organism survival and/or migration necessary for a species to reproduce. Habitat connectivity is a key element for restoring and maintain a stream's functional capacity, and the TMAT includes several metrics for measuring the resource values of riparian corridors.

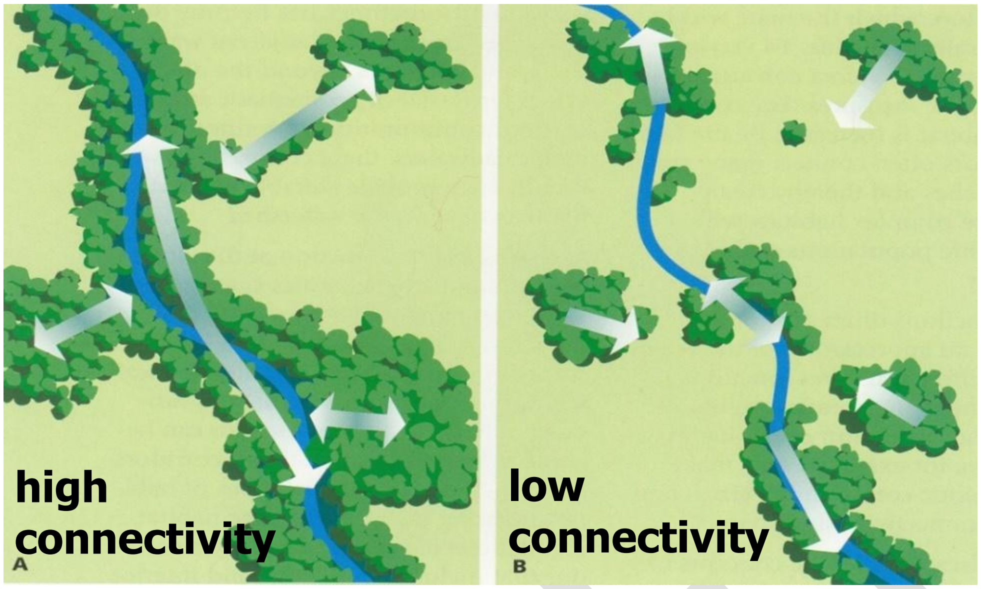


Figure 3.5. Riparian corridor examples of high and low habitat connectivity (*from* FISRWG 1998).

The spatiotemporal habitat scale in Frissell et al. (1986) was further modified by Frothingham et al. (2002) with a focus on the "pool-riffle" system, identifying that that unit is not just a pool and riffle but geomorphologically and hydraulically it consists of a pool, riffle, and bar termed a bar unit. The bar unit is maintained by helical flow patterns that result in flow acceleration and deceleration zones, sediment transport through the unit, and bar deposition processes (Dietrich 1983; Whiting and Dietrich 1991; Sear 1996; Milan 2013; Rhoads 2020). The geomorphic processes and associated helical flow hydraulics are the basis of reach-scale planform development and maintenance for meandering and braided channels (Rhoads and Welford 1991). Elements of the bar unit are fundamental habitat structures for maintaining biodiversity and biological integrity (Clifford et al. 2006; Schwartz and Herricks 2008; Schwartz 1991, 2016). Geomorphology metrics within the TMAT relate to the spatial scales illustrated in Figure 3.3, though focus particularly on the reach, bar unit, and microhabitat scales. The bar unit and microhabitat scales are referred to as bedform features. The key concept is to recognize that the hydraulics and geomorphic processes govern the maintenance of physical habitat structure essential for successful stream restoration (Smith and Prestegaard 2005).

Taking into account functional categories by Fischenich (2006), a framework that is centered on physical habitat with reaches is illustrated in Figure 3.6. This framework recognizes the hierarchical organization of spatiotemporal habitat scales described by Frissell et al. (1986) and includes the key significance of the riparian corridor and floodplain dynamics as described by Gregory et al. (1991) for maintaining physical habitat and biological integrity. In addition, Poff (1987) recognizes that habitat heterogeneity at the watershed and reach scales ultimately govern the aquatic biota community structure. Stream physical habitat provides the template for ecological processes to function, which ultimately determines the community structure and biological integrity. At the reach scale, relationships between habitat hydraulics and ecology have been termed the study of ecohydraulics because it recognizes the key role of geomorphic processes in maintaining physical habitat.

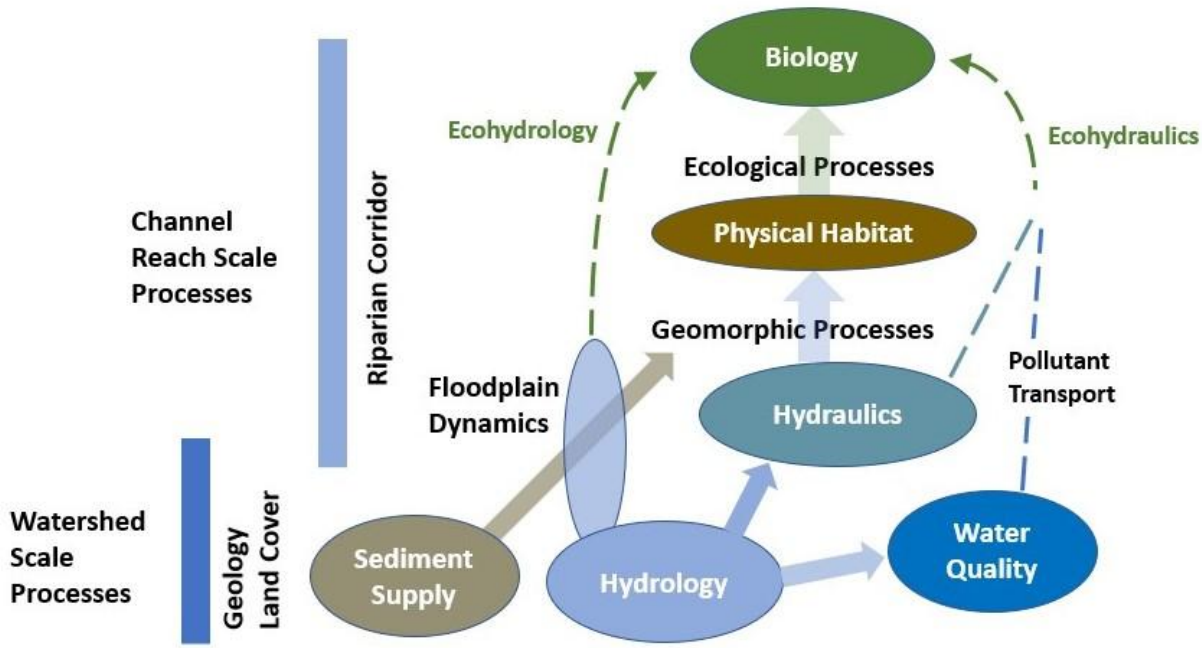


Figure 3.6. Functional framework for stream restoration recognizing watershed- and reach-scale processes.

3.2.3 Geomorphic Dynamic Equilibrium Concepts and Bankfull Discharge

The dominant geomorphic controls on channel form and adjustment processes are flow and sediment load, primarily bed load (Knighton 1998). In natural, stable alluvial stream channels, planform, slope, cross-sectional area, and bedforms continually adjust from the complex interactions with episodic events of flow and sediment transport. The concept of dynamic equilibrium implies that a stable channel reach matches sediment supply from the upstream to the transport capacity, where the form adjusts over time within a range that constitutes an equilibrium state (Shields et al. 2003; NRCS 2007). It follows the concept of a graded stream, defined by Leopold and Bull (1979) as ”one in which, over the period of years, slope, velocity, depth, width, roughness, pattern and channel morphology delicately and mutually adjust to provide the power and efficiency necessary to transport the sediment load supplied from the drainage basin without aggradation or degradation.” The dynamic equilibrium concept has been embraced in the natural channel design (NCD) methodology for stream restoration (Rosgen 1996; Hey 2006).

Applying the concept of dynamic equilibrium and regime theory, dominant discharge is defined as the channel-forming discharge whereby maintained constant over a prolonged period of years sustains the same geometric channel dimensions (Simons and Albertson 1960; Soar and Thorne 2006). A stable channel in geomorphic equilibrium is one where the tenancy of channel form change is at a minimum. Because of the dynamic nature of the flow regime and sediment transport, the dominant discharge is based on an annual flood frequency statistic. However, where highly variable or non-stationary flow regimes occur, the idea that a single discharge can explain a stable channel form may not be defensible (Stevens et al. 1975; Williams 1978; Knighton 1998). Bankfull discharge is equated as dominant discharge, the equivalency of which has been well documented (Wolman and Leopold 1957; Hey 1975; Carling 1988; Hey and Thorne 1986). Morphological significance of bankfull represents the long-term bed load and flow that transports the greatest amount of sediment over time. While larger flow events transport greater quantities per event and smaller flow events transport less and occur more frequently, it is the bankfull flow that is sufficiently effective and sufficiently frequent to perform the greatest amount of geomorphic work in maintaining channel cross-sectional shape. Thus, bankfull flow is also referred to as the "effective discharge" (Emmett and Wolman 2001).

The concepts of dynamic equilibrium and bankfull discharge have been applied to the development of downstream hydraulic geometry relationships (Leopold and Maddock 1953; Hey and Thorne 1986). Classically, hydraulic geometry relationships consist of power functions with discharge as the dependent variable, and width, depth, and velocity as cross-sectional independent variables (Knighton 1998). Cross-sectional hydraulic geometry is not only a factor of bankfull discharge but also varies with degrees of channel boundary roughness from vegetation and bed substrate, and channel slope (Hey and Thorne 1986). Hydraulic geometry has also been applied to create regional curves where bankfull discharge is substituted for drainage area (Dunne and Leopold 1978; Rosgen 1996; Johnson and Fecko 2008).

The classic definition of bankfull discharge is the point at which the flood flow just begins to overtop the channel entering the active floodplain (Leopold et al. 1964; Leopold 1994). The bankfull stage or elevation represents the break point between channel formation and floodplain processes (Wolman and Leopold 1957). In other words, it is "the discharge conveyed at the elevation of the active floodplain." Bankfull discharge is based on recurrence intervals formulated by an annual maximum series of peak flow events, and through numerous studies, it has been shown to be about equal to a recurrence interval of 1.5 to 2.0 years (Wolman and Miller 1960; Leopold et al. 1964; Hicken 1968; NRCS 2007). Though many studies report a broader range of recurrence intervals depending on stream morphology, measures of bankfull indicators are variable (Williams 1978; Simon et al. 2007; Lindroth et al. 2020; Keast and Ellison 2022). With bankfull discharge characterized as the 1.5- to 2.0-year return period, the challenge is not in estimating the discharge frequency statistic but with the elevation measurement of bankfull indicators (Johnson and Heil 1996). Rhoads (2020) describes complicating factors in determining a bankfull channel, including how benches are formed and the effect on the minimum width-to-depth ratio criteria, and channel instability with active sediment aggradation and degradation processes. Several bankfull indicators have been documented and summarized for reference in Table 3.3 (NRCS 2007; Soar and Thorne 2011).

Table 3.3. Variable criteria for identifying the elevation of bankfull indicators (modified from Soar and Thorne 2011).

Bankfull Indicator	Reference
Geomorphic/Sediment Criteria	
Elevation of active floodplain	Wolman & Leopold (1957); Nixon (1959); Leopold & Skibitzke (1967)
Highest elevation of channel bars	Wolman & Leopold (1957); Hicken (1968)
Elevation of most prominent bench	Kilpatrick & Barnes (1964)
Elevation of the "middle bench" with several overflow surfaces	Woodyer (1968)
Elevation of low bench	Schumm 1960; Bray (1972)
Elevation of upper limit of sand-sized particles in boundary sediment	Nunally (1967); Leopold & Skibitzke (1967)
Geometric Criteria	
Minimum width-to-depth (W/D) ratio	Wolman (1955); Pickup and Warner (1976)
Minimum width-to-depth ratio plus a discontinuity (vegetative and or physical) in the channel boundary	Wolman (1955)
Change in ratio of cross-sectional area to top width	Williams (1978)
Vegetation Criteria	
Lower limit of perennial vegetation	Schumm (1960)
Change in vegetation type (herbs, grass, shrubs)	Woodyer (1968); Leopold (1994)

Williams (1978) notes that substantial variation can occur in bankfull indicator elevations. Thus, it is recommended that multiple indicator measurements be taken along a longitudinal profile, and a best-fit slope line estimated through the indicator elevations (Rosgen 2014). In the TMAT, a minimum of three measurements of bankfull indicator elevations are stated. Rosgen (1994) suggests the use of a combination of different indicators including: 1) elevation associated with the highest depositional features; 2) break in bank slope; 3) change in bank material; 4) small benches and other inundation features; 5) staining on rocks; and 6) exposed root hairs.

Another indicator that has been correlated with bankfull is the ordinary high-water mark (OHWM), though it is a regulatory boundary used to delineate the jurisdictional limits of rivers and stream of the US (David and Hamill 2024). It is most similar to the vegetative criteria used for bankfull elevation (Table 3.3). It is mentioned here because it has been used in compensatory mitigation programs in lieu of bankfull indicators (USACE 2023). David et al. (2022) provides technical guidance for delineating the OHWM.

3.2.4 Geomorphic Adjustment: Channel Evolution Model

The channel evolution model (CEM) conceptually describes a sequence of changes in stream channel morphology after disturbances altering the dynamic equilibrium condition (Schumm et al. 1984; Simon 1989, 1992, 1995; Watson et al. 2002). Disturbances can differ but generally include a misbalance of sediment supply and transport capacity, changes in planform and channel slope, changes in sediment supply size characteristics, and modifications to hydrology in terms of stream power (Lane 1955; Schumm 1977; Phillips 1992). These disturbances lead to excessive fluvial erosion along the bank and bank collapse as non-equilibrium, rapid geomorphic adjustments. The CEM recognizes sequential stages or classes resulting in increased or decreased cross-sectional width-to-depth ratio and presence or absence of alluvial bed sediment (FISRWG 1998). It consists of six classes (stages): 1) premodified in dynamic equilibrium; 2) constructed from disturbances as noted above; 3) degradation from vertical downcutting; 4) threshold degradation from both vertical and horizontal erosion; 5) aggradation and widening; and 6) quasi equilibrium state with aggraded bed material (Figure 3.7). In Figure 3.7, note the direction of bank or bed erosion as vertical and/or horizontal, upward bed elevation movement from sediment aggradation, slumped bank material, and whether the bed has aggraded sediment. Figure 3.8 provides greater detail on bank profiles through the six classes.

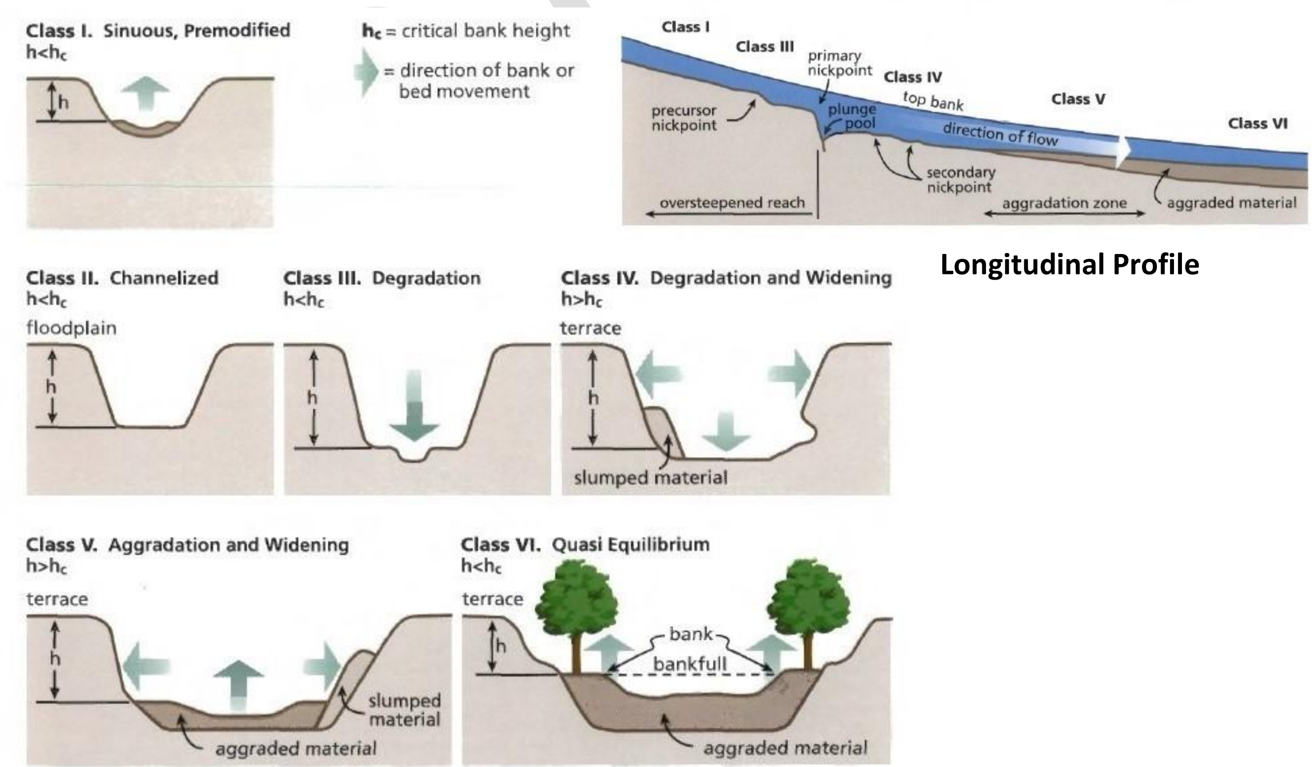


Figure 3.7. Channel evolution model by Simon (1995) defining six geomorphic condition classes

as shown by cross-sectional longitudinal profile adjustment (*from* FISRWG 1998).

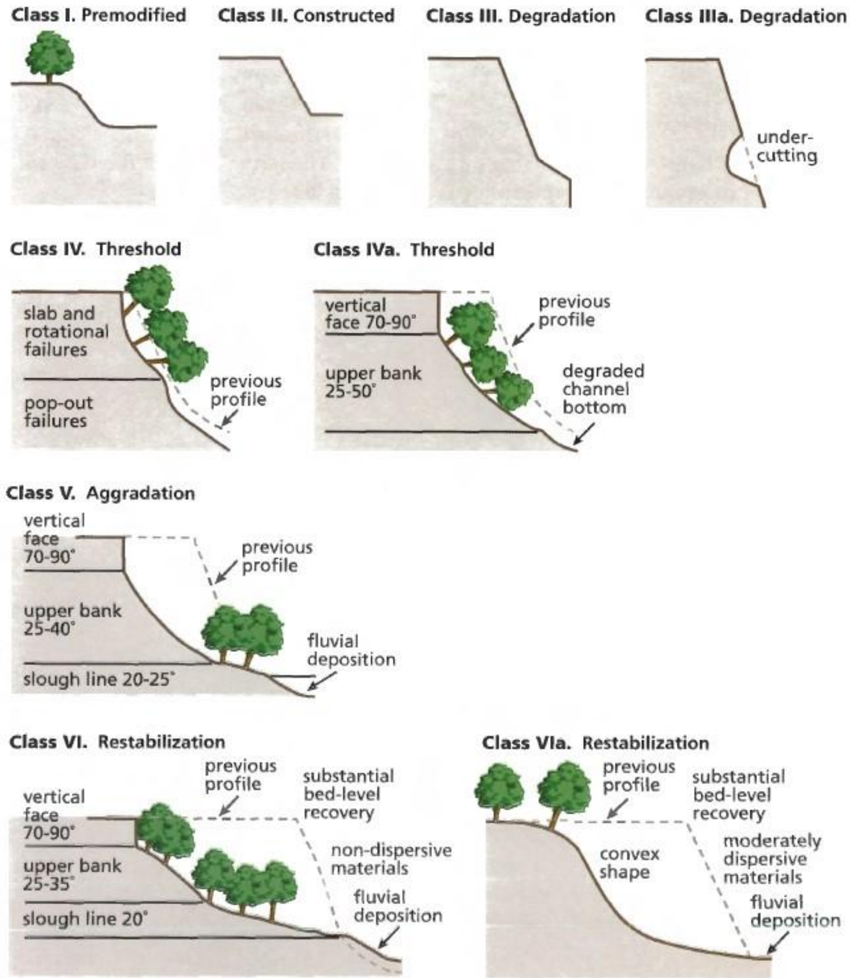


Figure 3.8. Bank profiles for the six geomorphic condition classes in the channel evolution model (*from* FISRWG 1998).

The CEM was developed for stream channels with cohesive soil banks, however the same physical processes of evolution can occur in streams with non-cohesive soil banks, though the sequence may not be the same. This is recognized by the different sequences in Rosgen stream types as identified by Rosgen (2005). The CEM initial stage starts as a C or E stream types, changes to a G, then a F, and returns to a C or E channel. Excessive sediment supply can lead to a D stream type and then depending on hydrology regime change to another stream type (Simon et al. 2007). Whether the sequence is altered by the type of disturbance or a reoccurring disturbance, the geomorphic processes associated with the different CEM classes have relevance for assessing channel stability (Downs 1995). Cluer and Thorne (2014) expanded the CEM into eight classes including a Stage 0 or anastomosing channel morphology, and considered feedback loops for various stages based on discontinuous disturbances occurring over time (Figure 3.9).

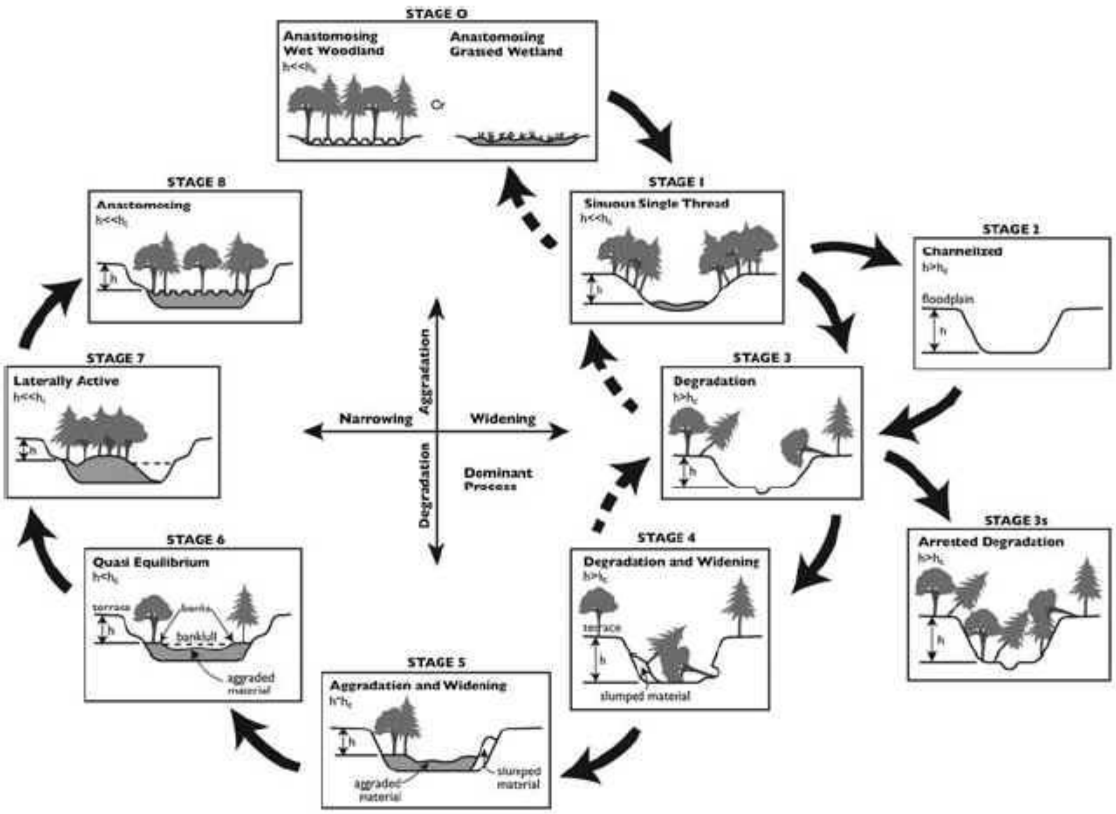


Figure 3.9. Stream evolution model by Cluer and Thorne (2014) describing eight systematic stages of channel adjustment after channel disturbance.

3.3 Tennessee Mitigation Assessment Tool Framework

Section 2 of this User's Manual defines the TMAT functional categories, parameters, and metrics. It also provides a basic description of the function-based frameworks used for compensatory mitigation. Section 3.1 expands on the regulatory methodology for developing a function-based framework and assessing stream condition. The TMAT framework consists of five functional categories; they are: Hydrology, Hydraulics, Geomorphology I and II, and Biology/ Water Quality (Figure 2.2). Geomorphology consists of two sub-categories: I) LWD and Riparian Corridor, and II) Channel Stability and Physical Habitat. A chief difference between the TN SQT and the TMAT is that the number of the required measurement metrics are more balanced among each category (Table 2.1).

Functional statements associated with each TMAT categories and parameters are summarized in Table 2.2. As the scientific basis for the TMAT framework the functional statements for each category/parameter are related to the corresponding functions and indicators compiled by Fischenich (2006) as summarized in Table 3.2. This relationship between TMAT and of comparative functions is summarized in Table 3.4. The scientific basis for each specific metric follows in Section 3.4 through 3.7.

Table 3.4. TMAT functional categories/parameters compared with selected functional category indicators in Fischenich (2006).

Fischenich (2006) Function-based Framework		TMAT Function-based Framework	
Category	**Indicators**	**Category**	**Parameters/Metrics**
System Dynamics ▪ Maintain Stream Evolution Processes ▪ Energy Management Processes	Stream stability; geomorphic channel equilibrium	**Geomorphology II**	▪ Channel Stability
System Dynamics ▪ Provide for Riparian Succession	Promote changes in vegetation structure for system stability; LWD inputs	**Geomorphology I**	▪ LWD ▪ Riparian Corridor
Hydrology ▪ Surface Water Storage Processes ▪ Surface – Subsurface Connections and Processes ▪ Hydrodynamic Balance	Floodplain storage of floodwaters; watershed land uses; active floodplain wetlands; groundwater fluctuations -------------------------------------- Channel flood flows connected to floodplain; floodplain inundation frequency	**Hydrology** --------------------------- **Hydraulics** Floodplain Connectivity	▪ Catchment Hydrology ▪ Reach Runoff/ Stormwater Infiltration ▪ Floodplain Storage ------------------------------- ▪ Floodplain Inundation Frequency ▪ Channel Incision ▪ Entrenchment Ratio ▪ Bank Height Ratio
Sediment Processes and Character ▪ Sediment Continuity ▪ Substrate and Structural Processes ▪ Quality and Quantity of Sediments	Bed sediment structural diversity/complexity; bed sediment sorting per erosion and deposition; bed sediment particle size distribution; habitat quality; mesohabitat structure	**Geomorphology II**	▪ Channel Stability ▪ Physical Habitat
Biological Support ▪ Biological Communities and Processes ▪ Trophic Structure ▪ Aquatic and Riparian Habitats	Provide and sustain habitat quality for diverse biological communities; support food chain dynamics and complexity measured by biotic integrity	**Geomorphology I** **Geomorphology II** **Biology/ Water Quality**	▪ Riparian Corridor ▪ Physical Habitat ▪ TMI or alternative sub-metrics
Chemical Processes and Pathways ▪ Maintain Water and Soil Quality	Water quality necessary to support biological communities; riparian soils to maintain healthy vegetation; maintain longitudinal and	**Geomorphology I** **Biology/ Water Quality**	▪ Riparian Corridor ▪ TMI or alternative sub-metrics

▪ Chemical Processes	lateral connectivity		▪ Water Quality

3.4 Hydrology Functional Category

3.4.1 Catchment Hydrology: Watershed Land Use Runoff

Watershed runoff contributes stormflow volumes, duration, and peaks to receiving streams, which forms a hydrograph of stream discharge over time (Davie and Wyndham-Quinn 2019). Runoff is a function of land cover characteristics among other watershed factors such as soil types and slope, and the precipitation event characteristics. Land cover change and vegetation removal alters evapotranspiration, infiltration, and interception volumes, and runoff processes (Bedient et al. 2021). Urban-developed land uses can cause hydromodification from increased impervious surfaces, which can cause greater stormflow runoff volumes and peaks and reduced infiltration (Hollis 1975; Booth and Jackson 1997). Other land use conversions from a natural landscape can cause changes in sediment supply (Haan et al. 1994). These conversions not only affect the stream hydrograph but also stream power, sediment supply, and sediment transport. Increases or decreases in net sediment transport potential imply changes in the character of channel-forming discharges, consequently affecting both the geometry and stability of existing stream channels, and physical habitat. Such alterations can degrade stream ecosystems (Poff et al. 2010; Violin et al. 2011).

The Watershed Land Use Runoff (LUR) metric in the Catchment Hydrology parameter is a measure of land use composition upstream of an assessment or restoration project reach. It is an area-weighted land use coefficient to quantify the impact of various land uses on reach runoff upstream of a site reach (Section 6.2.1). Land use coefficients are based on runoff curve numbers (CN) developed by the NRCS (1986, 2021). CNs quantify the runoff potential due to land use and infiltration capacity based on the hydrological soil group (HSG) type. CNs vary for land use characteristics, e.g., urban parking lots, grass lands, agricultural cultivated row crops, forest, etc. (Table 6.1). CNs range from 0 meaning no runoff potential to 100 meaning full runoff potential. Each contributing area is assigned a CN, and total weighted CN is computed. The total weighted CN is the field value and corresponds with an index score. Threshold values for the metric are as follow: 1) CN < or = to 40, index score = 1.0; 2) CN = 70, index score = 0.7; and 3) CN > or = to 80, index score = 0.0). Figure 3.10 illustrates the reference standard.

3.4.2 Reach Runoff – Stormwater Infiltration

As a fundamental process of the hydrological cycle balance, infiltration of precipitation is a key hydrological process that attenuates runoff, adds to soil moisture which contributes to evapotranspiration and groundwater recharge (Bedient et al. 2021). Water balance plays a crucial role in maintaining the health and sustainability of ecosystems by influencing water availability for terrestrial vegetation and wildlife, and aquatic biota (Beechie et al. 2012; Zalewski 2014). As referenced above for the Watershed LUR metric, land disturbance causes a shift in the hydrological balance generally increasing runoff and decreasing infiltration, which affects stream flow patterns both with baseflow and stormwater levels (Paul and Meyer 2001; Diem et al. 2021). Water quality – can be affected by different land uses and land cover

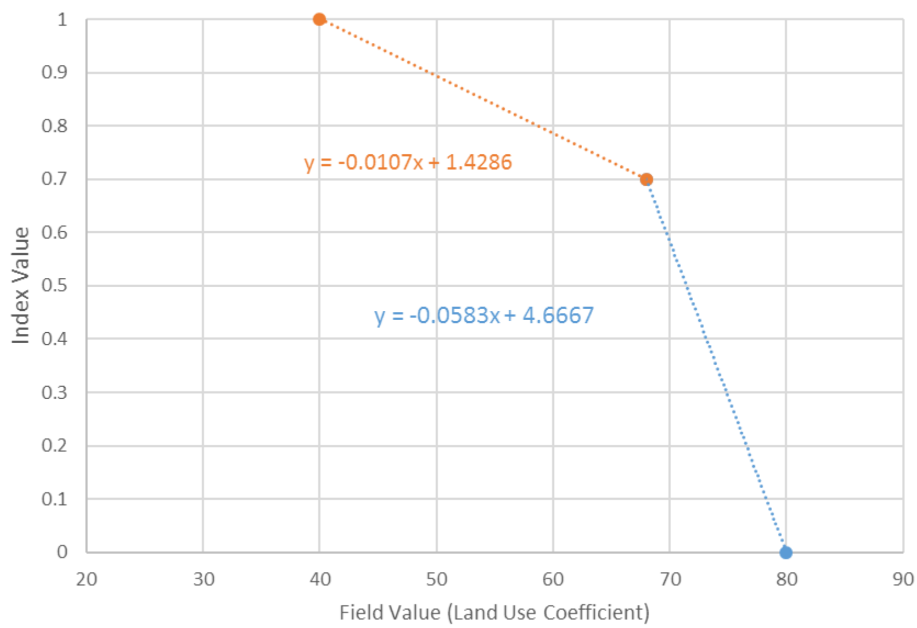


Figure 3.10. Reference standard for the Watershed Land Use Runoff (LUR) metric.

changes such as urbanization, agriculture, forest logging, and mining (Brown and Froemke 2012). Urban development is a major contributor of water pollution and hydrological balance alternation, which has led to the promulgation of stormwater control regulations under the §402 authority of the CWA (USEPA 1983, 1992). Noting the impacts on natural hydrologic systems from different land uses, watershed restoration practices include amendments to enhance infiltration (USEPA 2008). Best management practices (BMP) for on-site developments to alleviate impacts require stormwater control measures (SCM) to be constructed.

The Reach Runoff Stormwater Infiltration (RRSI) metric is a measure of infiltration within the lateral drainage area (LDA) of a project site. It accounts for infiltration from natural land surfaces and additional infiltration of the runoff from runoff source areas (RSA). Additional runoff infiltration is a result of BMP installation on the floodplain and/or SCM construction. The formulation to quantify the additional infiltration of runoff from the RSA is proportional to the total runoff, and/or the volume of water infiltrated from SCM (Section 6.2.2). The field value computed from the RRSI equations is equal to the index score. Thus, the RRSI reference standard is a 1:1 relationship between the field value and the index score where a zero indicates a project's LDA with no infiltration and a one indicates full infiltration within an LDA from natural surface and BMP/SCM.

3.4.3 Floodplain Storage – Infiltration Potential

A floodplain is a relatively flat surface occupying the valley bottom and it is normally underlain by unconsolidated deposited sediment whose surface is subject to periodic flooding (Nunnally 1967; Ritter 1986; Leopold 1994). Floodplains are formed by alluvial sediment deposits

(Howard 1992). Nanson and Croke (1992) classify floodplain types by fluvial processes primarily based on stream power and sediment deposition patterns. Floodplains provide multiple functions within a watershed integrating hydrologic, geomorphic, and ecologic processes for attenuating peak flood flows, regulating stream hydraulics and sediment transport for channel stability, enhancing habitat and promoting terrestrial and aquatic biodiversity, improving water quality, sequestering organic carbon, and recharging groundwater sources (Helton et al. 2014; Morrison et al. 2024). Russo et al. (2012) reports the importance of floodplain wetlands for enhancing soil infiltration and controlling floodwaters for reliance of riparian ecosystems. Development on floodplains can degrade the fundamental hydrologic, geomorphic, and ecologic processes disturbing connectivity between the floodplain and the channel (Brinson et al. 1995; Stone et al. 2017; Wohl 2004).

The Floodplain Storage – Infiltration Potential (FSIP) metric is a measure of the potential surface area of a floodplain for infiltration of floodwaters. The FSIP metric quantifies the areas with no development and compromised areas by some infrastructure preventing floodwater infiltration. The FSIP field value is computed from a simple equation based on a ratio floodplain uncompromised and compromised areas (Section 6.2.3). The FSIP reference standard is a 1:1 relationship between the field value and the index score, where a zero indicates the entire floodplain next to the project reach is developed with no potential for infiltration, and a one indicates the entire floodplain can provide for infiltration when inundated by floodwaters.

Note: this metric is the potential for infiltration whereas the Floodplain Inundation Frequency metric in the Hydraulics category quantifies how often the floodplain is inundated as departing from a "natural" frequency due to channel incision or entrenchment. The two metrics differ where the FSIP field value represents the relative percentage of the floodplain area available for infiltration, not accounting for the range of flood flows that can inundate it.

The FSIP field value computed from the equation is equal to the index score; it is a 1:1 relationship where a zero indicates a project's LDA with no infiltration and a one indicates full infiltration within an LDA from natural surface and BMP/SCM.

3.5 Hydraulic Functional Category: Floodplain Connectivity

Floodplain connectivity is the hydraulic and geomorphic connection between a river and the floodplains alongside it where that surface becomes inundated by floodwaters (Leopold 1994). Floodplains are described above in Section 3.4.3 for the Floodplain Storage – Infiltration Potential metric. They differ from a terrace which is an abandoned floodplain, no longer inundated by frequent flood events (Ritter 1986). Terraces may result from a hydrologically disturbed watershed causing channel incision (Section 3.2.4). Floodplain connectivity is associated with several important functions including: enhanced water infiltration by greater periodic inundation from floodwaters; improved water quality by reduction of fine sediment and nutrients; and improved healthy riparian ecosystems (Amoros and Bornette 2002; Wohl 2004). Section 3.2.3 provides the scientific background on geomorphic dynamic equilibrium and bankfull discharge which is relevant for metrics in this functional category.

The functional statement for the Hydraulics Functional Category assesses floodplain connectivity as a measure of floodplain inundation and channel incision that may limit its inundation (Table 2.2). In this category two metrics require bankfull dimensions; they are the Entrenchment Ratio and the Bank Height Ratio (Table 2.1). The bankfull metrics are based on flood prone area which includes floodplains but also bankfull benches in smaller headwater streams (Rosgen 1996). When bankfull indicators are absent and do not meet the dynamic equilibrium criteria, two metrics are to be used; they are the Floodplain Inundation Frequency and Channel Incision. This category also includes an optional metric, the Aggradation Ratio which requires bankfull dimensions, and its functional statement is a measure of excessive bedload sediment transport causing degradation of bed diversity and aquatic habitat quality.

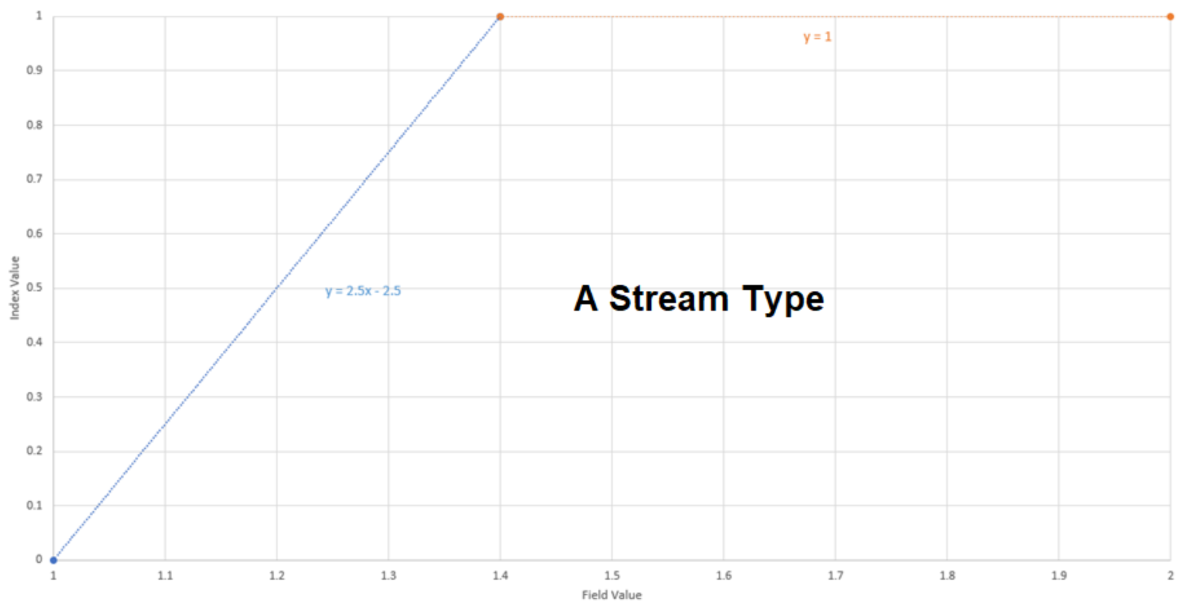
3.5.1 Entrenchment Ratio

The Entrenchment Ratio (ER) metric is a ratio of the flood-prone area width divided by the bankfull riffle width, where the flood prone area width is the width of the floodplain at a depth that is twice the bankfull maximum riffle depth (Rosgen 1996, 2006). ER is a primary metric in determining the Rosgen stream type: entrenched stream types (A, G and F streams) have ER values less than 1.4 ±0.2; slightly entrenched stream types (E and C stream types) have ER values greater than 2.2 ±0.2; and streams with ER values in between 1.4 ±0.2 and 2.2 ±0.2 are considered moderately entrenched (B stream types). The ratio of the depth of the 50-year flood to the bankfull depth ranged from 1.3 to 2.7 for all stream types except the DA channels. Less confined streams like E channels have lower ratios (the larger the horizontal area floodwaters can occupy, the lower the difference in stage between a small flood and a large one). A “typical” ratio of 2.0 was selected to calculate the elevation of the flood prone width for all stream types, as a generalized comparison of confinement. For reference, Section 5.4.2 describes the Rosgen stream type classification system and determination methodology. The reference standards for A, B/Bc, C, and E stream types are shown in Figure 3.11.

Stream types for F and G stream types are not included because these are highly incised channels, where based on Rosgen (1996) floodwaters with a 50-year return frequency remain in the channel. These stream types are not in dynamic equilibrium and the channels are in geomorphic adjustment typically within Class 3 or 4 of the CEM (Figure 3.7). DA stream types, an atypical stream type in Tennessee and not a design morphology, are also not included. If these stream types are identified at a project site, non-bankfull metrics should be used.

3.5.2 Bank Height Ratio

The Bank Height Ratio (BHR) metric is a measure of channel incision and it is equal to the low bank height divided by the maximum bankfull depth within a project reach (Rosgen 1996). The low-bank height is the flow stage in which floodwaters overtop the lowest bank onto a floodplain. Bankfull depth is measured by bankfull indicators. Through several indicators are referenced, the ones most applied are the geomorphic indictors of highest elevation of channel bars and prominent benches (Table 3.3). In a stable high functioning stream with ideal floodplain connectivity, the low bank height should be equal to the bankfull depth. Greater


A Stream Type
y = 1
y = 2.5x - 2.5
Index Value
Field Value

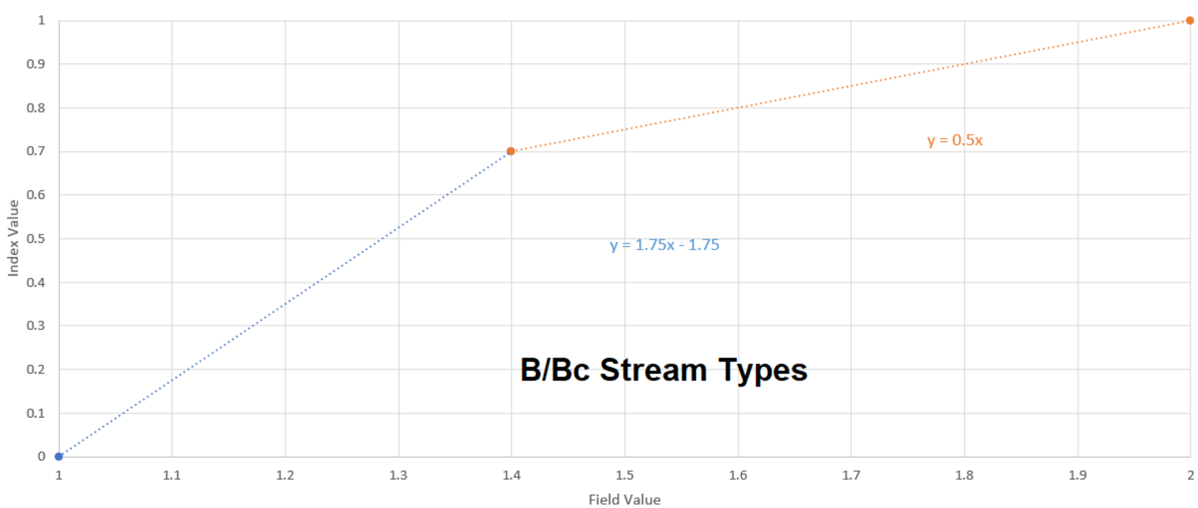

B/Bc Stream Types
y = 0.5x
y = 1.75x - 1.75
Index Value
Field Value

Figure 3.11 …….

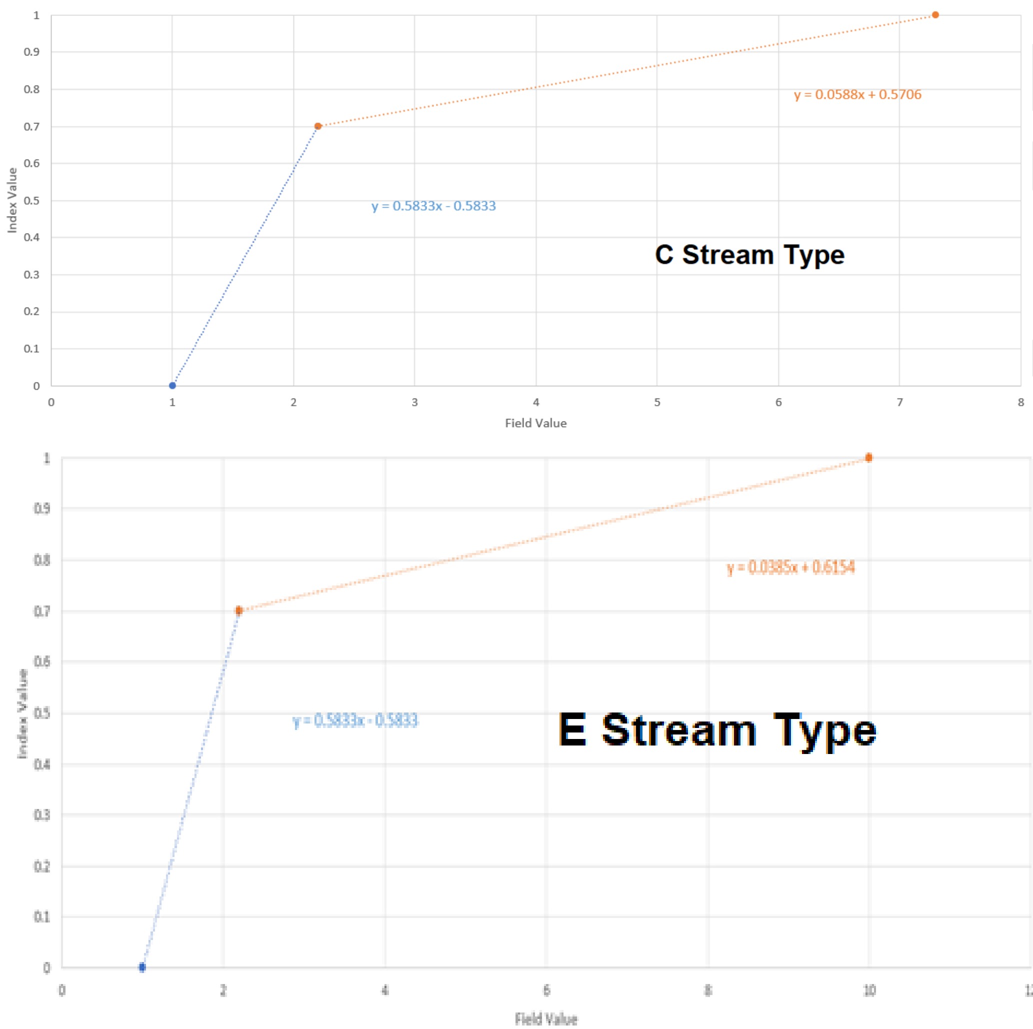


Figure 3.11. Reference standards for the Entrenchment Ratio (ETR) metric based on Rosgen stream type.

BHR values are characteristic of an unstable condition, deeper and often wider channels, and higher return intervals for flows leaving the channel (Rosgen 1996, 2006). Channels that are incised have more flows confined to the channel increasing erosive power, which represents Classes 3 and 4 of the CEM (Simon and Darby 1999; Cluer and Thorne 2014). Increased BHR is an indicator of streambed vertical downcutting and may represent a location of a moving headcut (Figure 3.7). The reference standard is shown in Figure 3.12. When a field value of one equals the index score of one this is the condition where bankfull depth equals low bank height and should occur approximately every two years (Wolman and Miller 1960; Leopold et al. 1964). This functional condition is generally considered to occur when a stream is in dynamic equilibrium (FISRWG 1998; NRCS 2007). The reference standard is shown in Figure 3.12 based on degrees of incision from Rosgen (2006). Some evidence suggests this metric is related to biological integrity (Sullivan and Watzin 2009; Donatich et al. 2020).

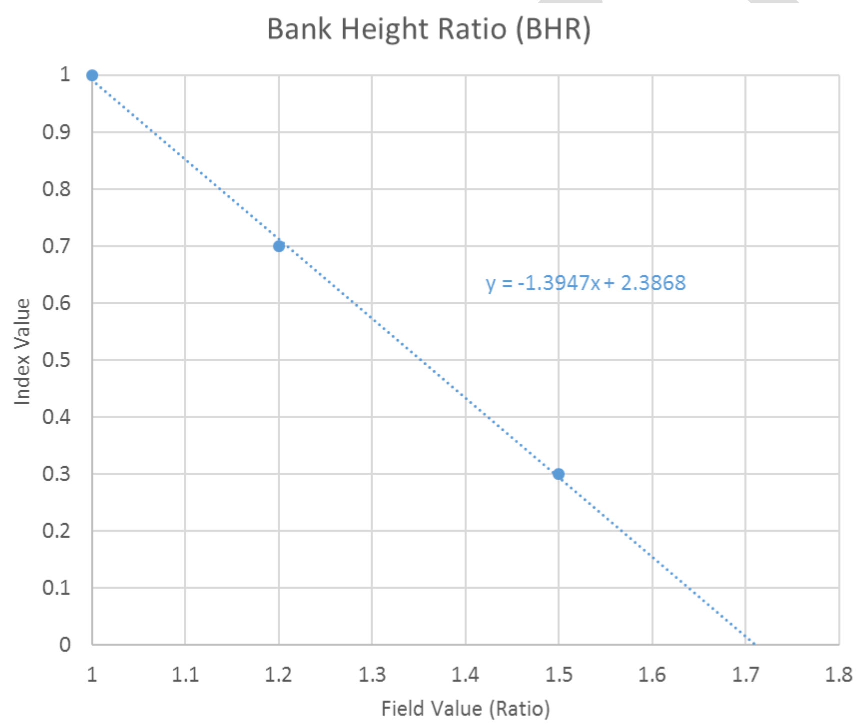


Figure 3.12. Reference standard for the Bank Height Ratio (BHR) metric.

3.5.3 Floodplain Inundation Frequency

The Floodplain Inundation Frequency metric is a measure of the flood flow rate (discharge, Q) which overtops onto the floodplain. Channels that are in dynamic equilibrium are those where cross-sectional areas and slope do not excessively adjust by either bed and bank erosion or bed sediment deposition, thus they maintain their morphology over prolonged periods (Knighton 1998; Soar and Throne 2001; Rhoads 2020). Section 3.2.3 provides the scientific background for the concept of dynamic equilibrium. Shear stresses during a dominant or bankfull discharge dynamically govern channel erosion and sediment transport, which is largely a function of water depth, channel slope and boundary roughness (Garcia and Parker 1991; Wilcock 1996; Shields et al. 2003). Therefore, based on a reach's morphology, the bankfull discharge will overtop onto a floodplain resulting is minimum increases in shear stress with any greater flow rates. The bankfull discharge quantified in probabilistic terms for a stable channel has been reported between the 1.5- to 2-year return frequency (Wolman and Miller 1960; Leopold 1994; NRCS 2007; Rhoads 2020). As the channel incises, vertical downcutting and channel widening, the flow depth increases requiring a greater return frequency discharge to overtop onto the floodplain. The scientific basis for this metric is founded on these principles, where a 2-yr frequency is a field value that equates to an index score of one, and a 100-year frequency is equal to zero, with incrementally decreasing index scores for the 5-yr, 10-yr, 25-year and 50-yrs return frequencies (Figure 3.1.3). A score of 0.7 is equated with the upper end of the 'functioning at risk' category, and a score of 0.3 is equated with the lowest end of 'functioning at risk'.

The return frequencies for a project reach site are obtained from USGS StreamStats (Ries et al. 2004). The discharge in which the channel is full accounting for cross-sectional area and wetted perimeter, slope, and channel roughness applies the Manning equation (Chow 1959, Sturm 2021). The Manning equation assumes steady flow and is acceptable for this application. Manning n roughness values are standard texts (Chow 1959, NRCS 2007).

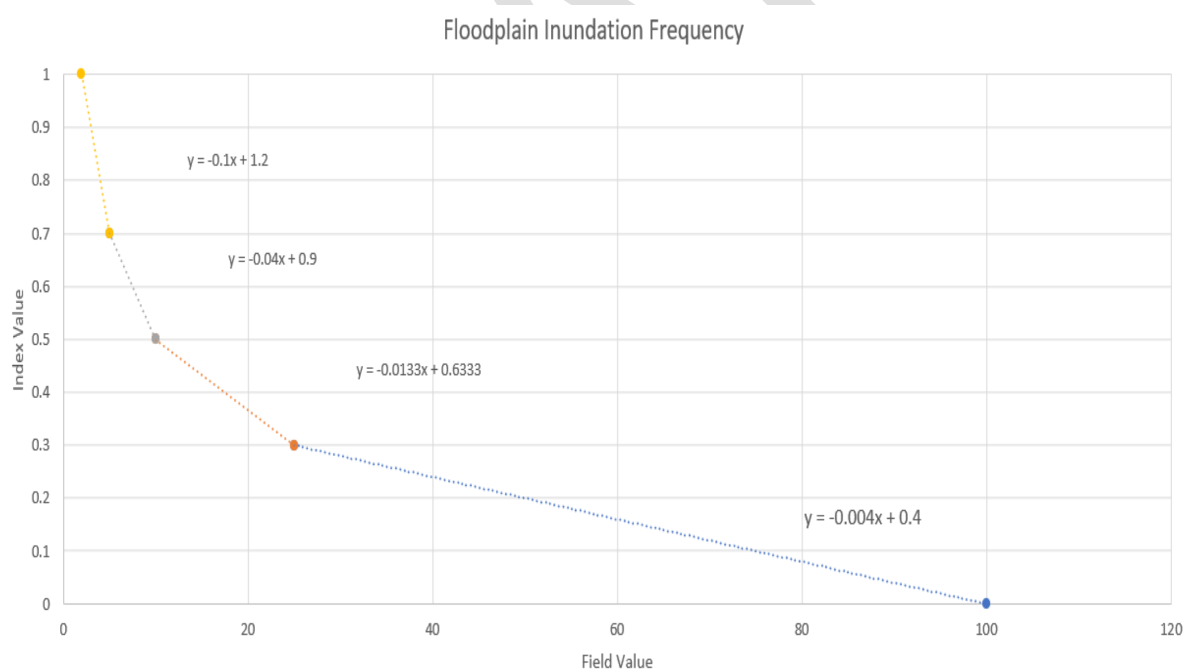


Figure 3.13. Reference standard for the Floodplain Inundation Frequency metric.

3.5.4 Channel Incision

Channel incision is the geomorphic process where a stream rapidly adjusts its morphology due to a physical disturbance such as channelization or hydromodification (Bledsoe 1999; Simon and Darby 1999; Simon et al. 2000). Channel incision is an erosional process of channel vertical downcutting and lateral widening which disconnects the channel from the floodplain (Watson et al. 2002). During the incision process the channel is unstable which is described by the channel evolution model (Section 3.2.4). Simon and Rinaldi (2006) found that while non-incised channels dissipate some of the erosive energy of high flows across the floodplain, incised channels within the same region contain flood flows of greater magnitude and return interval. Thus, the Hydraulic Category metrics are a measure of floodplain connectivity.

The Channel Incision metric is a ratio of the hydraulic shear stress (forces or stream power) to that of permissive shear stress (boundary resistance). Hydraulic shear stress (τ) is computed by multiplying the specific weight of water (γ) times hydraulic radius (R_h) and channel slope (Rhoads 2020; Sturm 2021). Permissible shear stress (τ_p) is a physical property of the boundary materials, and for this metric it is the bed material reflecting the potential resistance to vertical downcutting (Garcia 2008). Its value is obtained by published permissible shear stresses which numerous materials and τ_p values have been summarized in Fischenich (2001). The Channel Incision metric expressed as a ratio: τ / τ_p. When equal to one it is the threshold between erosion and no erosion. When the ratio is below one, the channel is stable. The range of 1 to 1.3 is considered conditionally unstable because there remains some resistance to erosion (Langendoen 2000; Fischenich 2001). In general, a ratio of 5 would constitute a highly erodible channel bed (Simon et al. 2011; Mahalder et al. 2018). Based on the above references, the threshold field values for this metric are 1, 1.3, and 5 which correspond to index scores of 0.7, 0.3, and 0.0 (Figure 3.14).

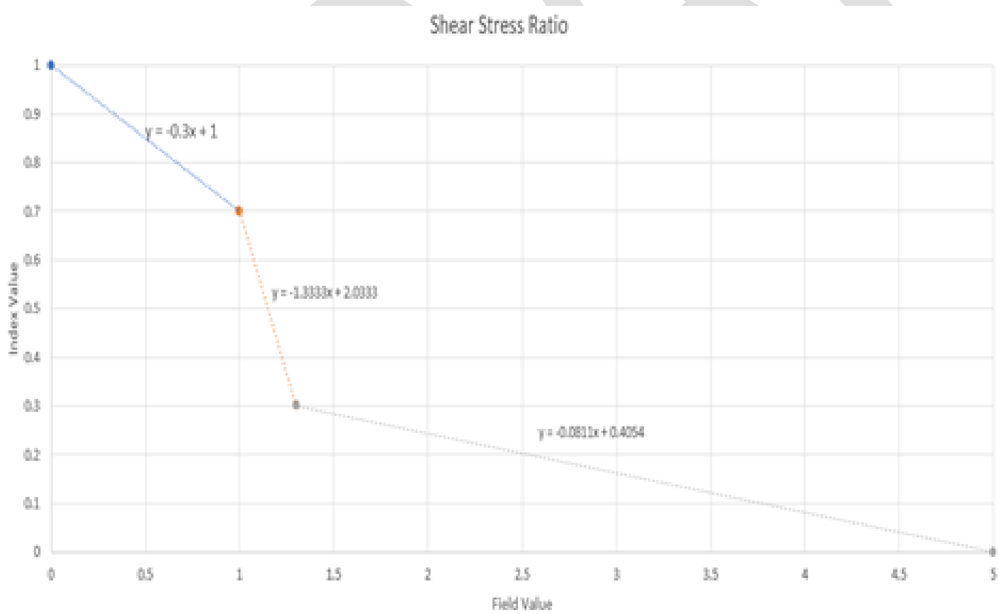


Figure 3.14. Reference standard for the Channel Incision metric based on shear stress ratios.

3.5.5 Aggradation Ratio

The Aggradation Ratio metric is a measure of the riffle width to depth ratio (WDR) compared to a reference WDR to assess the degree of aggradation in the project reach (Rosgen 2014). It was developed to assess departure from a reference condition caused by streambank erosion, excessive deposition, or direct physical impacts that lead to an over-wide channel. The WDR is the bankfull riffle width divided by the mean depth. Mean depth is the riffle bankfull cross-sectional area divided by the riffle bankfull width. Excessive deposition will be exhibited in riffles and bar structures. Deposition of sediments within a channel is a natural fluvial process, but excessive aggradation can be an indicator of sediment imbalance, where sediment supply exceeds the stream's transport capacity (Knighton 1998). Accumulation of sediments in pools would result in a lower pool-depth ratio, which is captured in the bedform diversity parameter. Similarly, accumulations of sediment in a riffle yields a higher WDR than would be expected from a WDR in a stable riffle. The reference standard for the Aggradation Ratio is shown in Figure 3.15 (TDEC 2018).

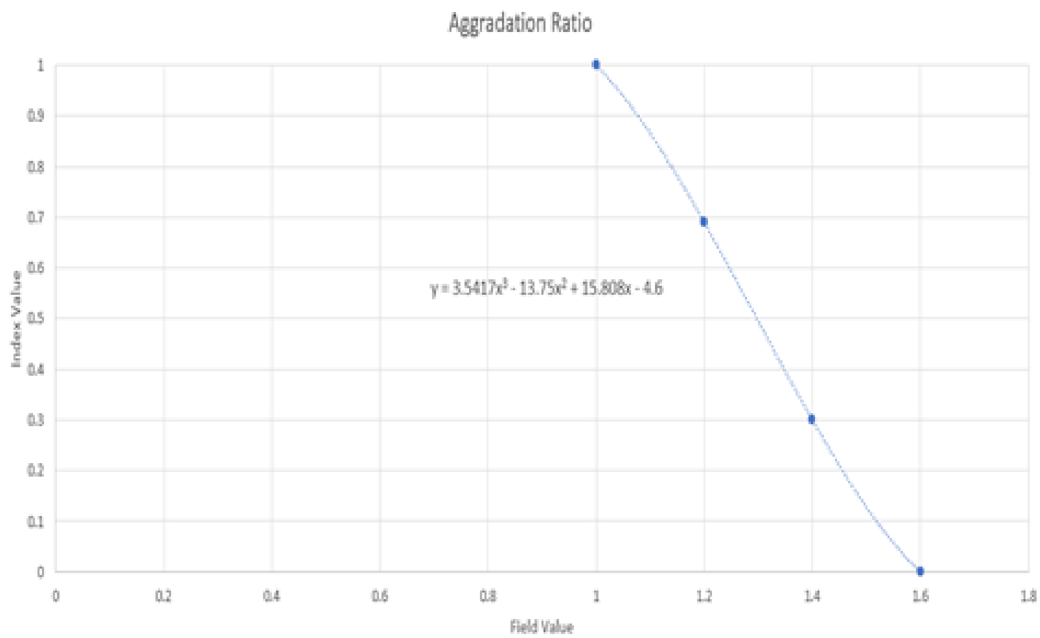


Figure 3.15. Reference standard for the Aggradation Ratio metric.

3.6 Geomorphology I Functional Category: LWD and Riparian Corridor

3.6.1 Large Woody Debris (LWD)

LWD in streams consists of logs and large branches recruited from the riparian corridor. LWD in the stream channel serves multiple functions (Keller and Swanson 1979; Gurnell et al. 2002; Shields et al. 2004; Covdova et al. 2006; Abbe and Brooks 2006). It provides flow resistance protecting bed and stream banks from excessive erosion, regulates sediment transport, supports pool formation for habitat, and generally adds to habitat complexity. LWD is recruited into the channel from forested riparian vegetation illustrating the interconnectedness between riparian corridor and channel (Gregory et al. 1991). The function of the LWD is dependent on its position in the channel and floodplain, where Robinson and Beschta (1990) classified positions into four functional zones as they relate to channel morphology. Harmon et al. (2017) summarizes these zones into an LWD index.

The LWD metric is based on the number of pieces as the field value rather than the LWD index. The pieces counted are over 1 m in length and at least 10 cm in diameter at the largest end. The index scores for the reference standard are based on field surveys by Jennings Environmental (2017) and broken out by Ecoregion (Figure 3.16).

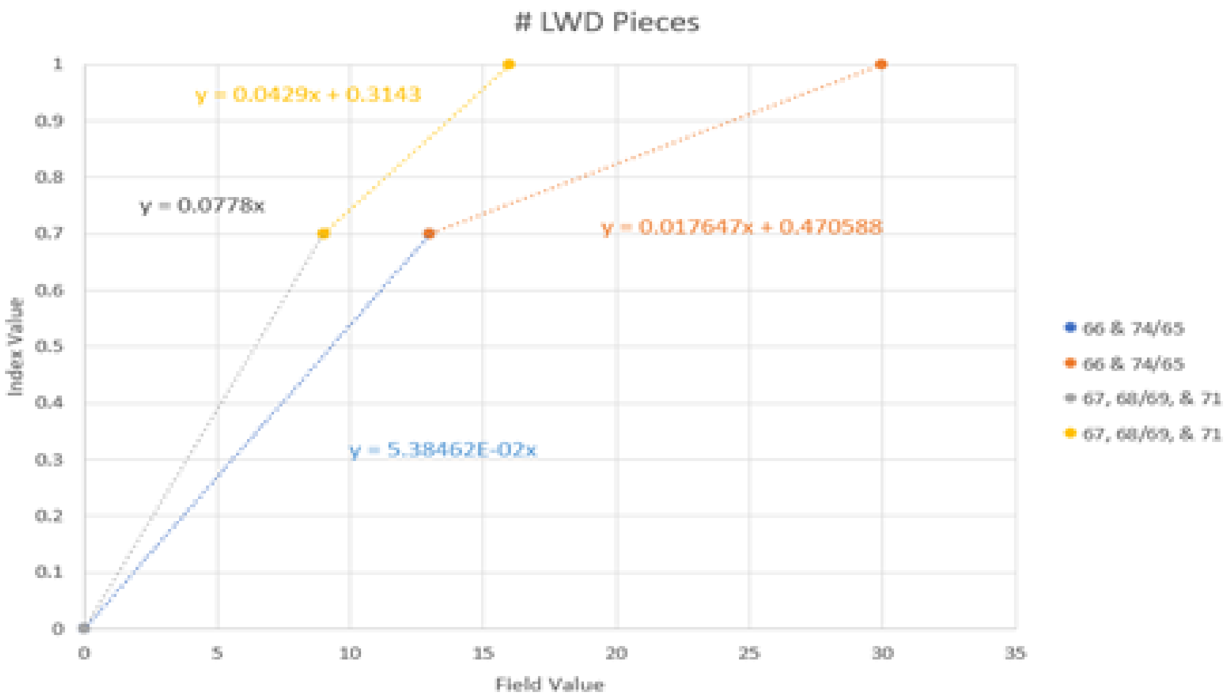


Figure 3.16. Reference standard for the Large Woody Debris (LWD) metric based on the number of in-channel pieces.

3.6.2 Riparian Corridor metrics

A riparian corridor is a strip of land that includes the stream along with the adjacent vegetation and land as the transition zone between aquatic and terrestrial ecosystems. The riparian vegetation plays a significant role in sustaining these ecosystems. Riparian vegetation supports many functional conditions that include: in-channel and floodplain roughness for hydraulic resistance, channel and streambank stability, shade for regulating stream water temperatures, input of organic carbon for ecosystem processes, LWD recruitment, mesohabitat maintenance, habitat cover, terrestrial and aquatic biodiversity, and water quality protection by buffering pollutants from entering the stream (Naiman et al. 1993; Fischer and Fischenich 2000; Covdova et al. 2006; Mayer et al. 2006; Atkinson et al. 2010). The tree canopy structure in the riparian corridor quantifies, directly or indirectly, the degree in which these functional conditions support the ecosystems (Shugart et al. 2010). Structure has been measured by the standard method, measuring tree diameter at breast height (Magarik 2021). Maintaining riparian corridors is essentially important in urban ecosystems (Atkinson and Lake 2020). Invasive species in the riparian corridor limit vegetation diversity and reduce habitat quality (Morgan et al. 2008; Aronson et al. 2017; Zelnik et al. 2020). Riparian vegetation is impacted by various human caused disturbances including development, leaving areas susceptible to overgrowth of invasive species (Shafroth et al. 2002). Many invasive species have been brought in from Europe and other continents as ornamentals that have spread. The Riparian Corridor parameter consists of four metrics; they are: 1) Riparian Width, 2) Canopy Cover, 3) Average Diameter at Breast Height (DBH), and 4) Percent Invasive Species (Table 2.1).

Riparian Corridor Width. The reference standard for the Riparian Corridor Width metric is based on support documents that include the TDEC NPDES stormwater permits and the TDEC (2014) guidance manual on permanent stormwater management. Many of the Tennessee municipal ordinances on riparian corridor width are based on the guidebook by Wenger and Fowler (1999). A maximum riparian corridor width of 200 feet equates to an index score of one (Figure 3.17). A project site with no riparian vegetation receives an index score of zero. A width of 50 feet equates to an index score of 0.6. A width of 100 feet equates to an index score of 0.8 and is considered fully functional to meet the stream conditions maintaining a healthy ecosystem.

Canopy Cover. The reference standard for the Canopy Cover metric is a measure of forest overstory density, which directly relates to the functional conditions within the riparian corridor. The densiometer tool and methodology was originally developed by Lemon (1956), which quantifies canopy density of the forest cover. The methodology was standardized and described by Strickler (1959). The reference standard for the Canopy Cover metric is a 1:1 relationship, where 0% cover equates to an index score of zero, and a 100% cover equates to an index score of one.

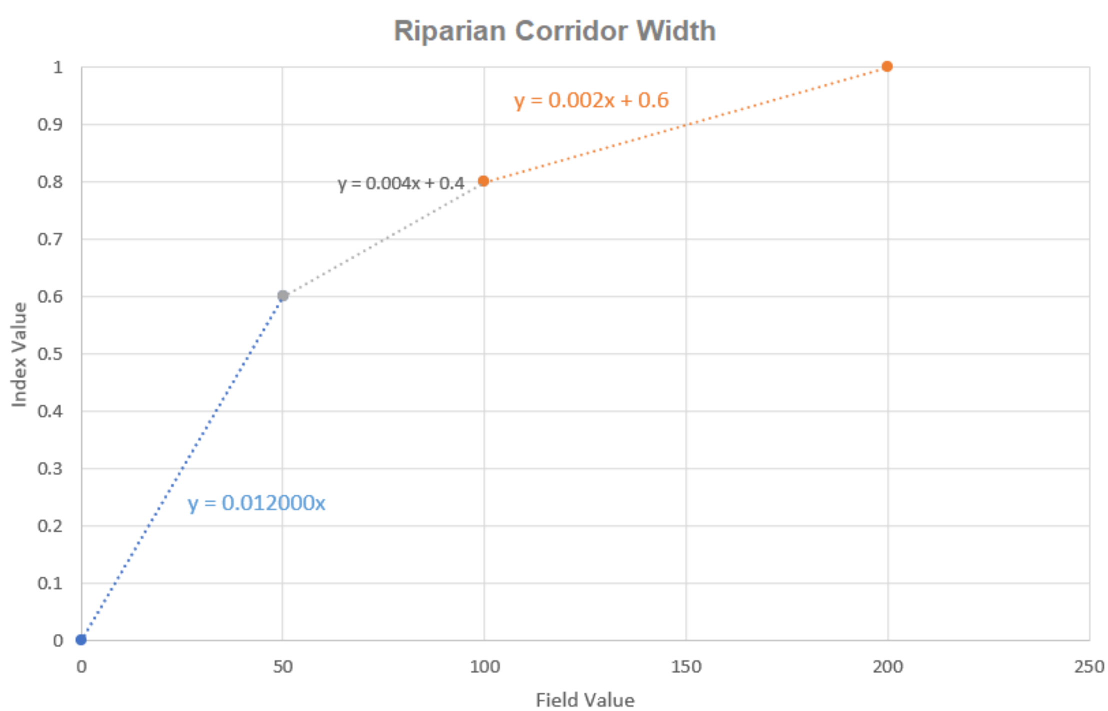


Figure 3.17. Reference standard for the Riparian Corridor Width metric.

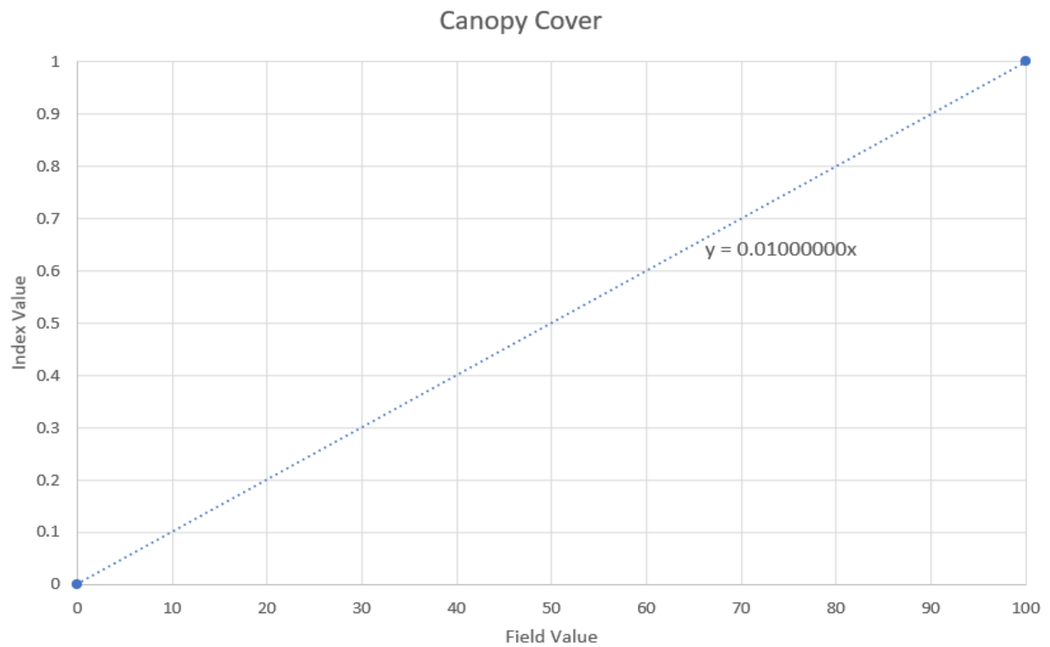


Figure 3.18. Reference standard for the Canopy Cover metric.

Average DBH. The average diameter at breast height (DBH) is a measure of the forest structure in age and biomass for plots along the riparian corridor (USFS 2023). In the TMAT this metric quantifies tree age structure indirectly related to canopy cover within the riparian corridor. Protocols for quantifying the reach average DBH use a minimum of six plots sized 13 m by 13 m square, or a minimum area coverage equal to 2% of total riparian area (Lee et al. 2008). The minimum number of plots as six consists of three plots on each side of the bank. Rather than measuring diameters of all trees in each plot, an analysis was conducted to determine the mean (average) of the three largest DBH values using the US Forest Service Forest Inventory Analysis (FIA) database (https://research.fs.usda.gov/products/dataandtools). The analysis of data from FIA applied over 8000 locations across Tennessee for a monitoring period 2016 to 2020. Our analysis found no statistically significant difference in values between Level III ecoregions, so one curve was generated. The reference standard was derived from this analysis conducted and a best-fit line through the x,y origin (0,0) and the four data points as thresholds (Figure 3.19). The DBH field value of 5.5 cm equates to an index score of 0.3; a field value of 6.9 cm equates to an index score of 0.5; a field value of 9.1 cm equates to an index score of 0.7; and field value of 23.0 cm or greater equates to an index score of 1.0.

Percent Invasive Species. The Percent Invasive Species metric is a measure of non-native vegetation in the riparian corridor. In Tennessee, exotic invasive riparian species are a significant issue across most of the state, as streams are ideal conduits for transporting seeds and other propagules throughout watersheds (Cooper et al, 2003). Invasive species have been noted as a *broad* threat to the health of riparian zone vegetation communities (Busch and Smith, 1995; Matlack, 2002; Richardson et al 2007; Huddle et al, 2011; Nunuz-Mir et al, 2019).

Field data is obtained at the same plots used to obtain DBH data, as visual estimates of percent invasive woody species in the plot and then averaged over the all the plots surveyed. The reference standard was derived after review of several documents from the Tennessee Invasive Species Council and the Tennessee Department of Agriculture describing the most common and problematic invasive species. These information sources included:

1) https://www.tnipc.org/invasive-plants/;
2) https://www.invasive.org/south/seweeds.cfm; and
3) https://wiki.bugwood.org/Archive:SEEPPC/List_of_Invasive_ExoticPest_Plants/

The reference standard based on these documents comprises of an index score of one for a field value of no invasives, an index score of 0.8 when the plot average is equal to 5%, and linearly decreases to an index score of zero at 80% invasives (Figure 3.20).

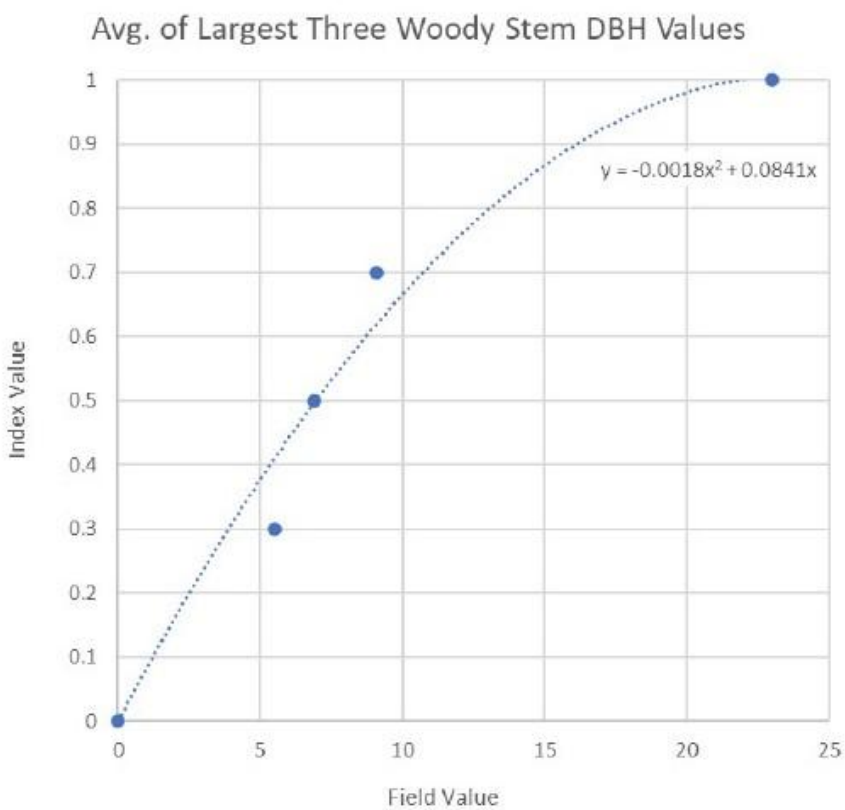


Figure 3.19. Reference standard for the Average DBH metric.

3.7 Geomorphology II Functional Category: Channel Stability and Physical Habitat

3.7.1 Channel Stability metrics

Channel stability refers to a stream or river's ability to maintain its form, pattern, and profile over time, transporting sediment and flow without significant changes in its dimensions or shape. A stable channel effectively carries water and sediment from its watershed without excessive aggradation or degradation. It is founded on the concept of a dominant or channel-forming discharge and a "graded" river (Section 3.2.3). Stable streams are considered ones that are in dynamic equilibrium. The time periods for natural adjustments to channel and following a physical disturbance are dependent of the morphological classification of different spatial scales

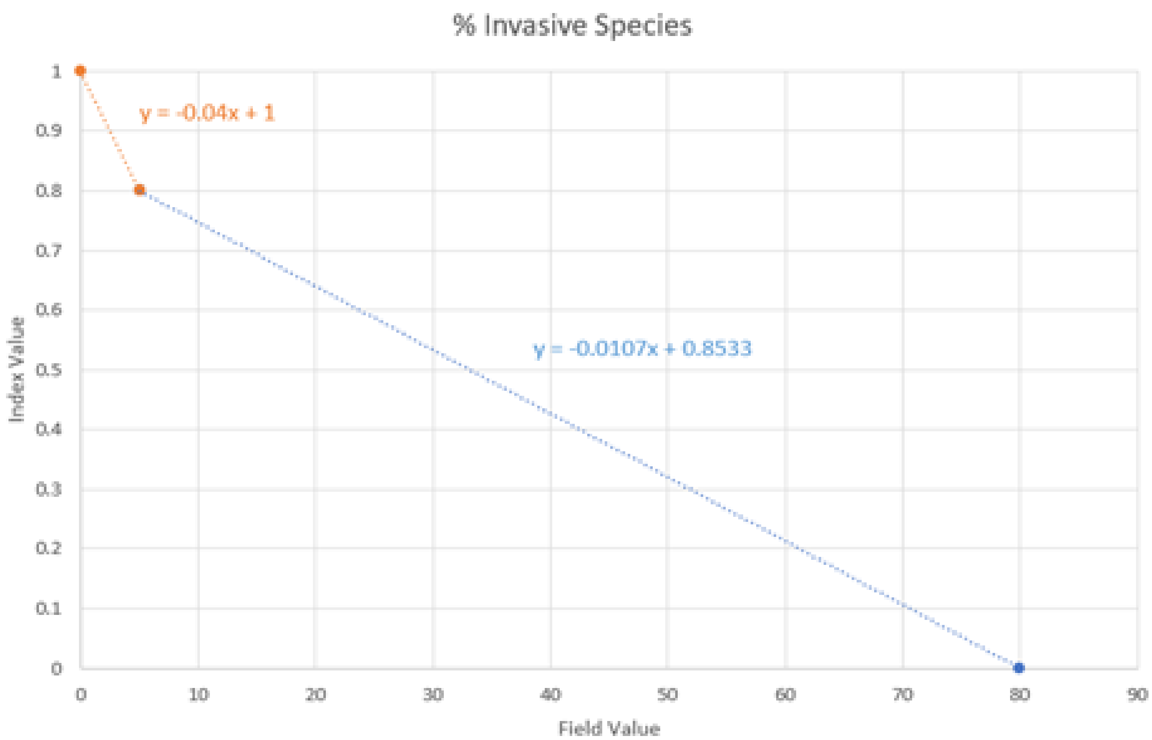


Figure 3.20. Reference standard for the % Invasive Species metric.

(Figure 3.4). For stream assessments and restoration practices, the relevant spatial scales are reach-scale (planforms), the bar unit (pools-riffle-bar bed morphology), and the bed substrate (Figure 3.2). Channel forms at these scales are stable when local erosive forces are balanced with boundary resistance forces (Simon 1992, 1995; Simon and Rinaldi 2000; Shields et al. 2003).

Erosive forces are the hydraulic forces from moving stream water in channels open to the atmosphere (Sturm 2021). Steady-flow discharge (Q) is most commonly computed by the Manning equation, which is a function of channel cross-sectional area (A), hydraulic radius (R_h), hydraulic roughness (n), and channel slope (S). The R_h is the area divided by the wetted perimeter. The equation is expressed as: $Q = 1.486/n * A * R_h * S^{0.5}$. The force versus resistance balance is embedded in this equation where force or energy is from slope or gravity and resistance is the moving water over the channel boundary and its roughness characteristics. Flow discharges, thus velocities, are based on the channel form and slope, which govern shear stresses (τ_0) at the channel boundary. Estimates of τ_0 are derived from fluid momentum and expressed as $\tau_0 = \gamma * R_h * S$ (where γ is the specific weight of water, a standard water property). Permissible shear stress is not a hydraulic property but rather a property of the boundary resistance to flow. It is expressed as the critical shear stress τ_C whereby a channel begins to erode and sediment is entrained (Fischenich 2001; Rhoads 2020). Deposition occurs when the weight of the sediment in transport is greater that the hydraulics forces keeping the particles suspended. These fundamental fluid physics govern that balance between local erosive forces and boundary resistance, where excessive “force” from hydraulic shear stresses (τ_0) cause erosion along the channel boundary both bed and bank. These principles are used in the TMAT to measure fluvial erosion along streambanks and quantified by the Percent Streambank Erosion metric. In addition, these principles are applied for the stability of both channel bed and bank, and quantified by the Rapid Geomorphic Assessment (RGA) metric.

The RGA follows the systematic adjustments to a channel following some physical disturbance as described by the CEM (Section 3.2.4). Figures 3.7 and 3.8 define six stages (classes) of the CEM. Cluer and Thorne (2014) expanded on the original adjustment stages adding a Stage 0 for anastomosing channel and providing feedback loops for multiple disturbances, however the basic geomorphic processes of excessive sediment aggradation and degradation remain. The RGA accounts for two bank retreat process, fluvial erosion as described above and bank mass failure (Simon et al. 2000). Mass failure differs from fluvial erosion in that it is a geotechnical process whereby different forces cause the bank to collapse along a shear plane and deposit a soil mass into the channel (Amiri-Tokaldany et al. 2003; Rinaldi and Darby 2007; Simon and Rinaldi. 2000; Simon et al. 2011). There are different mechanisms for mass failure that have been described by Thorne and Tovey (1981) but all are based on the force balance. The main driving force leading to bank collapse is the soil weight. Vegetation and soil properties are key factors to bank erosion and mass failure (Wynn and Mostaghimi (2006).

The RGA, as an index for channel stability, accounts for these two bank erosion processes, bank vegetation, and channel morphology as a channel incises to a physical disturbance (Simon 1989, Simon and Darby 1999). The original foundation for the RGA was a classification scheme developed by Downs (1995) that describes the relationships for channel adjustments and settings. The index was developed at the USDA National Sedimentation Laboratory by Simon (2004). It includes nine sub-metrics: 1) primary bed material, 2) bed/bank protection, 3) degree of incision, 4) degree of constriction, 5) stream bank erosion, 6) stream bank instability, 7) established riparian woody-vegetation cover, 8) occurrence of bed/bank accretion, and 9) CEM stage. These stages are fully described in Section 6.4.1.3 for the field data collection methodology. The RGA has been effectively used in numerous studies to assess channel stability (Simon and Klimetz 2008; Simon et al. 2009; Heeren et al. 2012; Habberfield et al. 2014). Comparing channel stability to habitat quality and response to aquatic biota, RGA index scores have been correlated with biological integrity (Williams 2005; Schwartz et al. 2011).

Channel armoring is the alteration of stream banks by concrete, gabion-baskets, and rip-rap. Armoring is the result of a human intervention to arrest excessive channel erosion. While the armoring of streambanks provides increased channel stability and reduction of fine sediment into the channel, it can reduce shade to the water affecting water temperature, limit carbon inputs to the stream, and harm a healthy riparian ecosystem (Fischenich 2003; Fleming et al. 2017). Toe rock is beneficial to prevent excessive fluvial erosion and reduce the risk of bank mass failure (Simon et al. 2000). The NRSC (2007) design manual provides several alternatives using natural materials and hybrid designs using both toe rock and vegetation.

The Channel Stability parameter in the TMAT consists of three metrics: 1) Percent Streambank Erosion; 2) Percent Streambank Armoring, and 3) Rapid Geomorphic Assessment (RGA) index metric. The reference standards for these three metrics follow.

<u>Percent Streambank Erosion</u>. The Percent Streambank Erosion metric is the average from a visually assessment of both left and right banks. A field value 5% equates to an index score of one, and a field value of 15% equates to an index score of 0.7 representing a "natural" level of fluvial erosion and functional. A field value of 30% equates to an index of 0.3 at the threshold of not functioning (Simmons 2014). Fluvial erosion greater than 50% equates to an index score of zero.

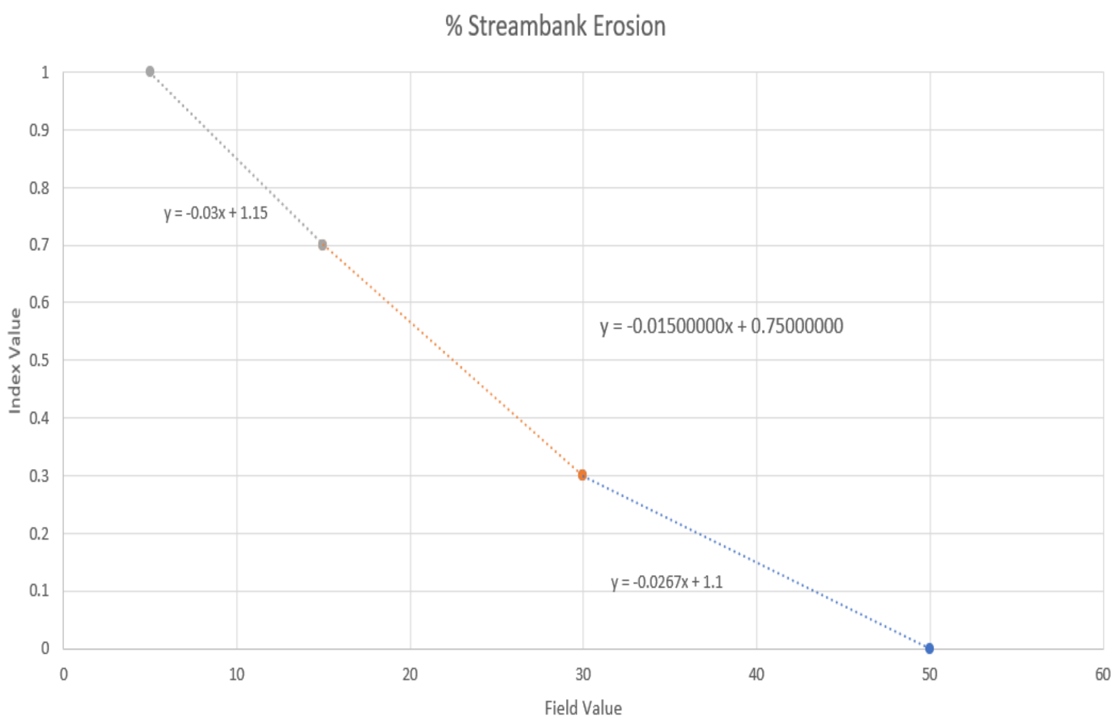


Figure 3.21. Reference standard for the % Streambank Erosion metric.

<u>Percent Streambank Armoring</u>. The reference standard for Percent Streambank Armoring metric considers ecological impairment when it equals or exceeds 30% as the average from both left and right banks; the index score is equivalent to zero (TDEC 2018). No armoring equates to an index score of one.

<u>Rapid Geomorphic Assessment</u>. The modified RGA consists of eight of the nine sub-metrics applied in the Simon (2014) protocols. The ninth metric, the CEM stage, was removed; however, it is still reported with the field protocols (Section 6.4.1.3). Each sub-metric is equal to 4 points, thus for eight sub-metrics the total possible field value is equal to 32 (Figure 3.23). Based on Simon (2014), the reference standard for the RGA index consists of these threshold values: 1) 10 or less is a stable channel, 2) between 11 and 17 is conditionally stable, and 3) greater than 17 is

unstable. These thresholds relate to index scores: 1) one for RGA values of 7 or less; 2) 0.7 equates to for RGA value of 10; 3) 0.5 equates to for RGA value of 17; and 4) 0.0 equates to for RGA value of 32.

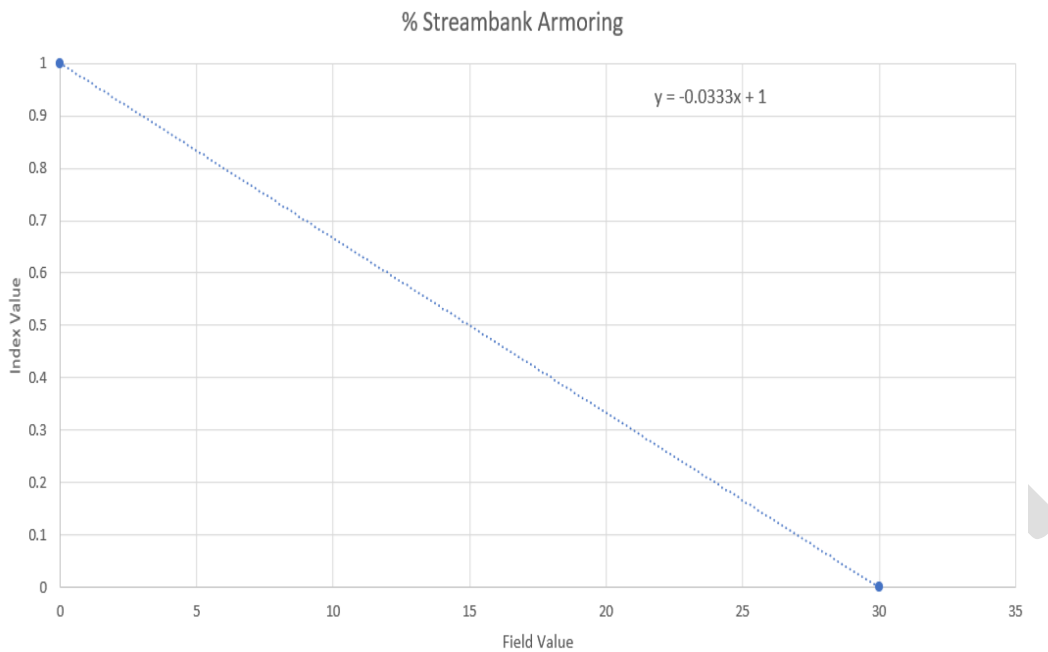


Figure 3.22. Reference standard for Percent Streambank Armoring metric.

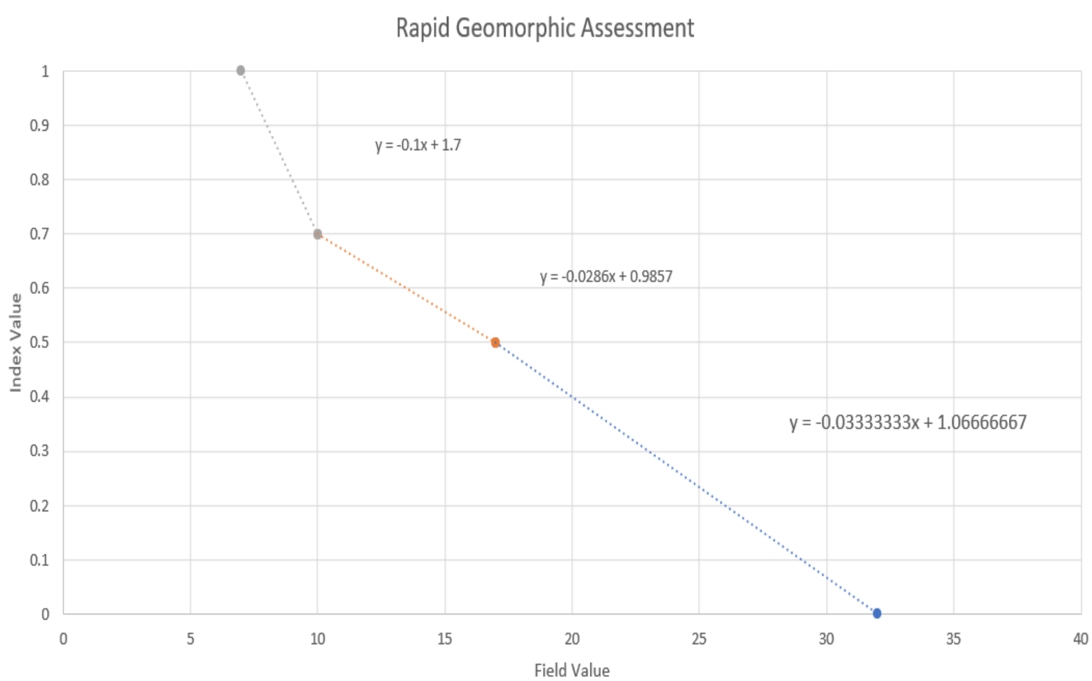


Figure 3.23. Reference standard for the Rapid Geomorphic Assessment (RGA) metric.

3.7.2 Physical Habitat metrics

Stream physical habitat refers to the structural characteristics and features of a stream channel that provide living space and resources for aquatic organisms (Allan and Castillo 1998; Mathon et al. 2013). Functional conditions of physical habitat are scale dependent; the hierarchical organization is shown in Figure 3.3. The most relevant scales for stream restoration and used in the TMAT are the bar unit (pools and riffles) and bed substrate. Pool-riffle sequences are ecologically key habitat structures in which fish, benthic macroinvertebrates, and other aquatic biota have evolved such that each species have adopted life histories (Rabeni and Jacobson 1993; Townsend et al. 1997; Clifford et al. 2006; Tullos et al. 2009). Schwartz (2002, 2016) describes the dominant functions that pools and riffles provide as: feeding, cover/evasion (escape from predation, resting, reproduction (spawning), and refugia from high temperatures and flood flows. Macroinvertebrates also have evolved to partition pool and riffle habitat use, though riffles are where the highest diversity occurs (Merritt et al. 2019). Macroinvertebrates in riffles are a dominant food source for fish (Angermeier 1982). Habitat quality for these bedforms is characterized by its complexity (number of different habitat types) and heterogeneity (spatial distribution of habitat types), and these qualities relate to supporting biodiversity (Southwood 1977). In ecology, the variability in space and time in which these habitat features are favorable for different species are important in maintaining rich biodiversity (Pringle et al. 1988). This ecological function is termed the Patch Dynamics Concept.

Habitat units within the reach scale are chiefly identified as: pools, riffles, glides, and runs (Hawkins et al. 1993; Bisson and Montgomery 1996; Arend 1999; Kemp et al. 1999). Arend (1999) describes and illustrates these habitat units (Figure 3.24). Other habitat units in steep-sloped channels may include rapids and cascades. Kaufmann et al. (1999) describes how to map these units longitudinally along the stream corridor. Section 3.2.2 describes the geomorphic processes that maintain these key habitat bedforms.

The rhythmic spacing of pools and riffles is a natural feature of rivers and streams (Knighton 1998). Depending on in-channel roughness elements and slope, riffle spacing has been reported to range from 1.5 to 23.3 channel unit widths with an average in the range of 5 to 7 channel unit widths (Keller and Melhorn 1978; Wohl et al. 1993). Pools are maintained by bed scour and sediment transport at high flows whereas riffles are maintained by sediment deposition (Dietrich 1987; Clifford 1993; Gregory et al. 1994; Sears 1996). Pools in a bar unit are termed a geomorphic pool and they differ from local scour holes in their formation and maintenance (Rhoads 2020). In general, a geomorphic pool's length will be equal to or greater than the active channel or bankfull width. Geomorphic pools can be formed by various channel conditions caused by narrowing of the channel width, scour on the outside of a meander bend, and a flow obstruction (Hawkins et al. 1993; Myers and Swanson 1997). Overall, the geomorphic processes that maintain stable bedforms are essential for maintaining healthy ecosystems.

As noted above, riffles are depositional units in a channel and when present the characteristics of their bed substrate is an indication of whether a channel is in dynamic equilibrium and stable (Gregory et al. 1994). Riffle substrate provides valuable ecological functions including fish and macroinvertebrate habitat, and hyporheic exchange of stream nutrients (Allan and Castillo 1998;

Huang and Chui 2022). The standard technique to characterize bed sediment is by the Wolman (1954) pebble count. This method describes collection and unbiases measurement of 100 sediment particles, and has been modified in various ways over the years by others but the fundamentals remain the same. For the TMAT, the methodology is described by TDEC (2017).

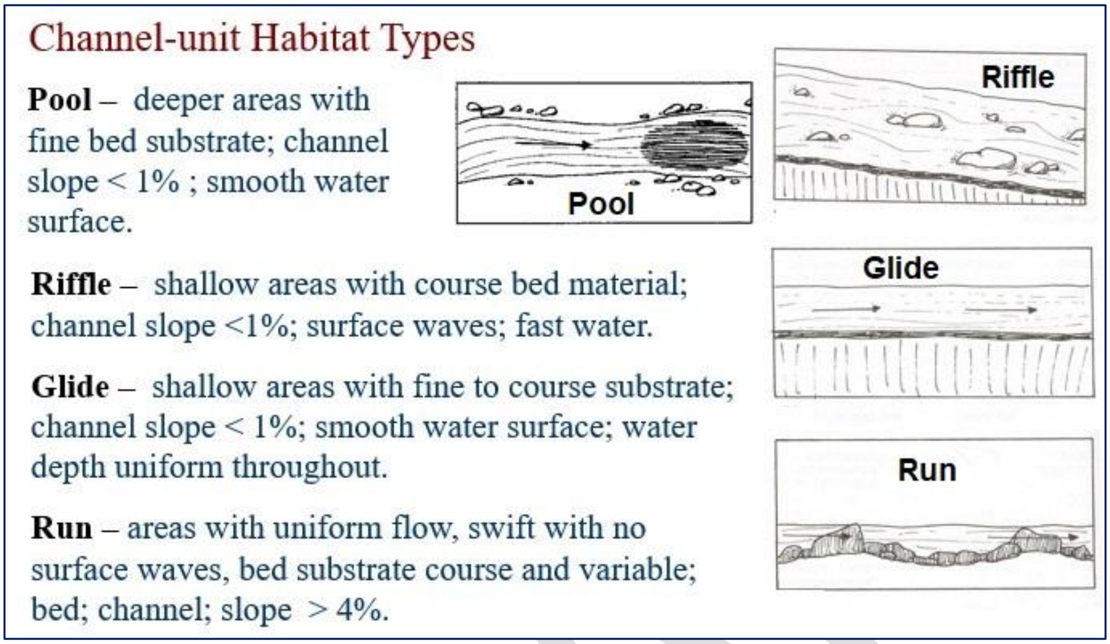


Figure 3.24. Pool, riffle, glide, and run habitat units in a stream as defined by Arend (1999).

Quantifying the functions for the Physical Habitat parameter, the TMAT consists of four metrics. They are: 1) Wolman Pebble Count, 2) Percent Riffle, 3) Pool-to-Pool Spacing Ratio, and 4) the Pool Depth Ratio. If bankfull indicators are not present or adequate, then the “active channel width” is used for the Pool-to-Pool Spacing Ratio, and the Pool Depth Ratio is not used. The reference standards for these metrics follow.

<u>Wolman Pebble Count</u>. The Wolman Pebble Count metric applies the field methodology to collect 100 sediment particles as described in TDEC (2017) deriving a particle size distribution (PSD). The PSD is entered into the USFS (2007) Size Class Pebble Count Analyzer. The Size Class Pebble Count Analyzer metric is a statistical comparison between the percent of fines in bed material samples from the study reach and a reference reach (Bevenger and King 1995). It tests the whether the percent of fines in the study reach is the same as the percent of fines in the reference reach. The statistical p-value provided by the Analyzer is the field value for the reference standard. A small p-value (< 0.05) represents a statistically significant difference between the study reach and reference reach, thus indicating that is it highly unlikely that the study reach percent fines is the same as the percent fines in the reference reach. The reference PSDs consist of three regionally-derived distributions from pebble count data collected in East, Middle, and West Tennessee. The PSDs for the reference conditions are provided in Section 6.4.2.1 (Table 6.11). Practitioners can collect and develop a reference PSD if conditions suggest the PSD in Table 6.11 is not applicable for their project site. The reference standard for this

metric in Figure 3.25 is based on typical statistical confidence intervals of 90%, 95% and 99%, corresponding to p-values of 0.10, 0.05 and 0.01 (Haldar and Mahadevan 1999). The reference standard is from TDEC (2018).

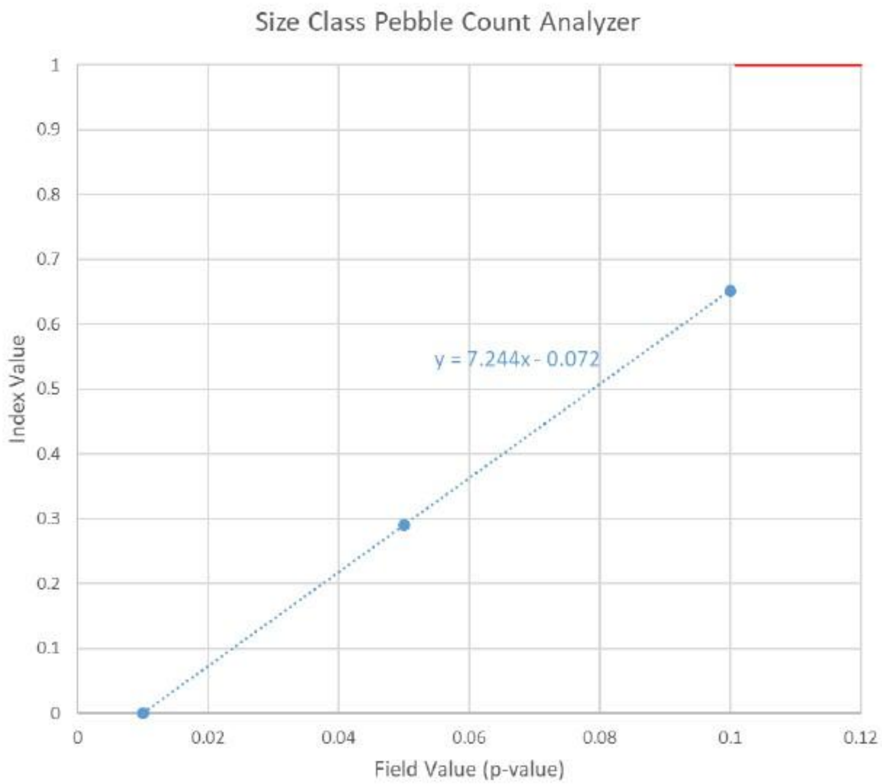


Figure 3.25. Reference standard for the Wolman Pebble Count metric.

<u>Percent Riffle</u>. The Percent Riffle metric is the longitudinal length of riffle habitat reported as a percentage of the total project reach. The field value for this metric is the percent riffle (Figure 3.26). The reference standards are derived from field data collected by Jennings Environmental (2017) for the different ecoregions in Tennessee. Some ecoregions use the same reference standard (TDEC 2018).

<u>Pool-to-Pool Spacing Ratio</u>. The Pool-to-Pool Spacing Ratio metric is a measure of rhythmic spacing of pools along the longitudinal profile reflecting geomorphic conditions of pool-riffle sequences and their maintenance as a stable bedform feature (Figure 3.4). It also is a measure of habitat quality at the bar unit scale (Figure 3.3). This metric's field value is an average of pool-to-pool spacing length along the longitudinal profile in the project reach and normalized by bankfull width. If bankfull indicators are absent or not adequate, then the pool-to-pool spacing length is normalized by the active channel width. Active channel width is defined in Section 6.4.2.3, and its use will not differ significantly from a bankfull measure. Only geomorphic pools are used for this metric. The reference standards are derived from field data collected by Jennings Environmental (2017) and compiled for channels with slopes less than or greater than 2% (TDEC 2018).

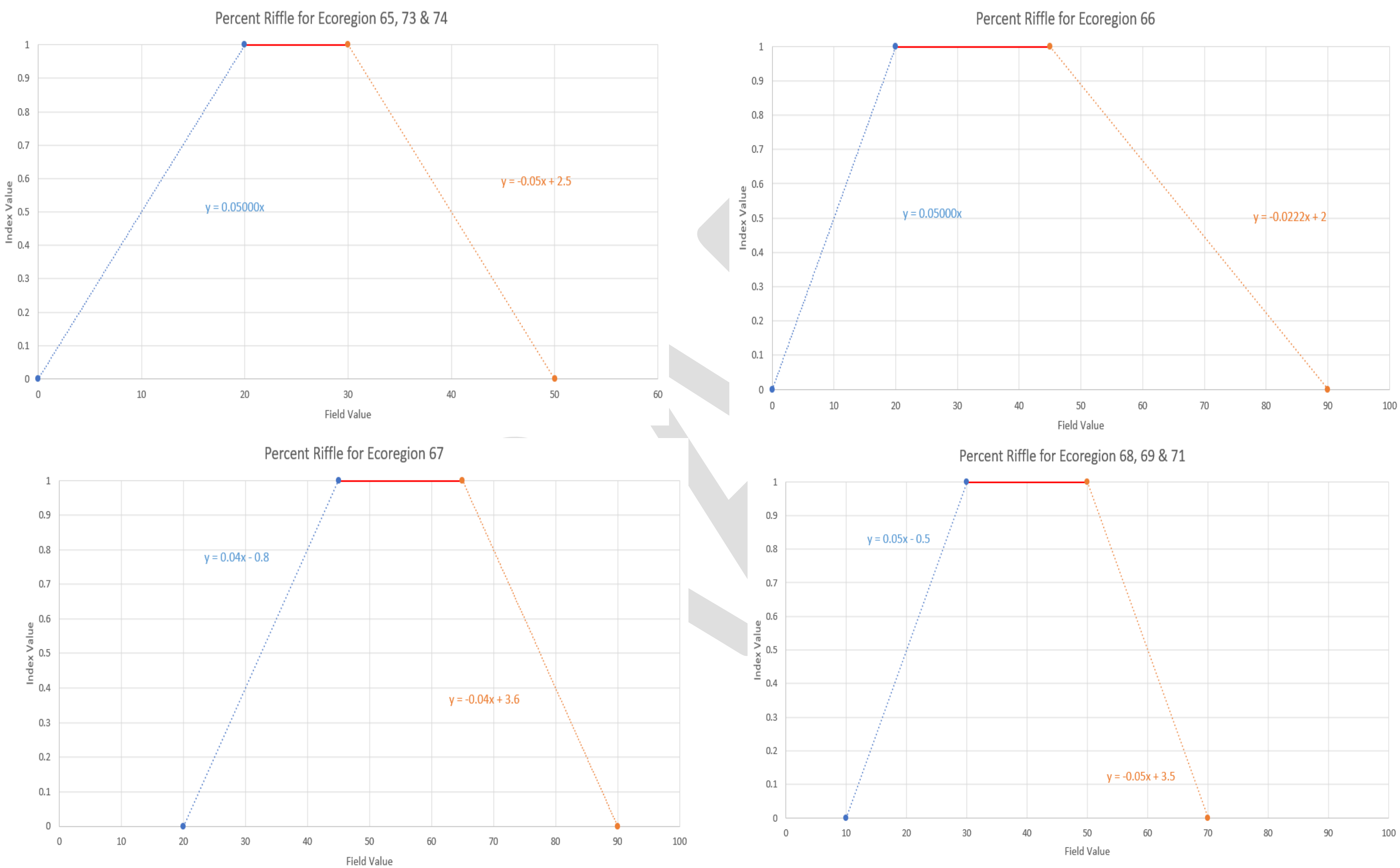
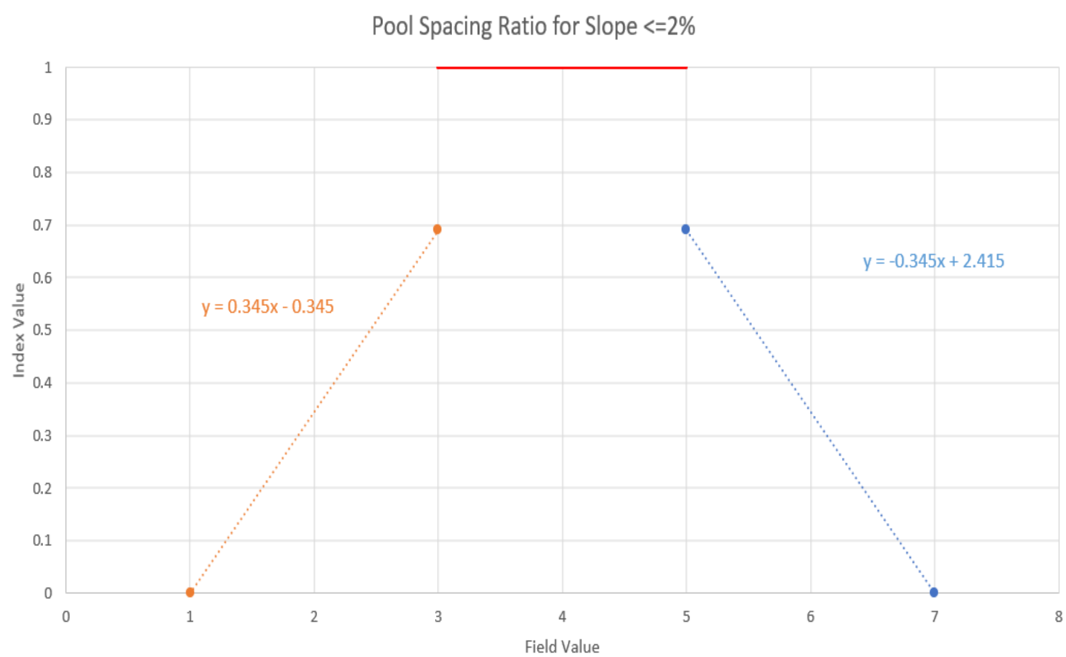


Figure 3.26. Reference standards for the Percent Riffle metric, for different Tennessee ecoregions.



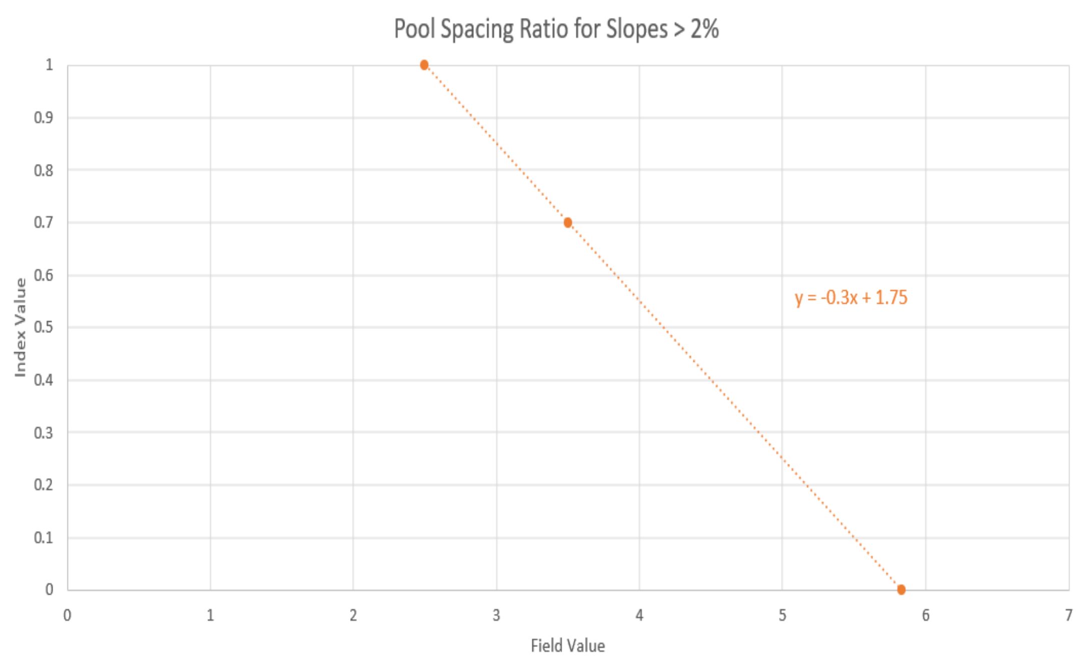


Figure 3.27. Reference standards for the Pool-to-Pool Spacing Ratio metric for channel slopes of less than or greater than 2%.

<u>Pool Depth Ratio</u>. The Pool Depth Ratio metric is a measure of the average bankfull depth at the deepest point of each pool within the project reach. The reference standards are derived from field data collected by Jennings Environmental (2017) in Tennessee. The reference standard is in Figure 3.28 (TDEC 2018). This metric is only used if bankfull indicators are present.

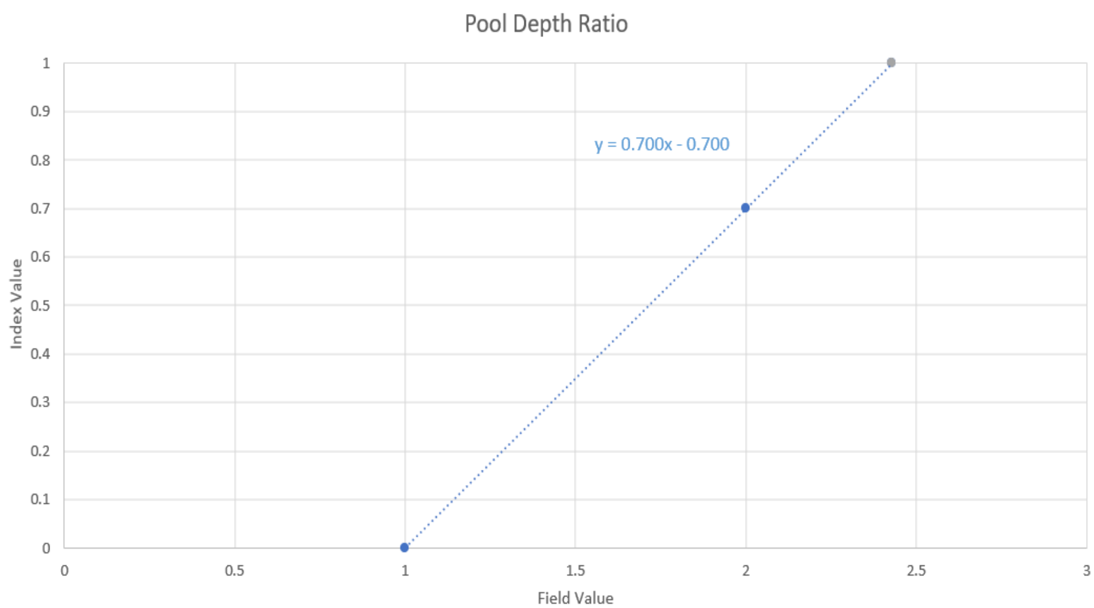


Figure 3.28. Reference standard for the Pool Depth Ratio metric.

3.8 Biology / Water Quality Functional Category

In the Biology / Water Quality category functions are combined because biological assessments using IBIs were developed as a surrogate measure of water quality (Karr et al. 1985). IBIs measure multiple functional conditions of streams as illustrated in Figure 3.1 which includes chemistry along with other factors as flow regime (hydrology and hydraulics) and physical habitat. Water quality impairment can be caused by many different sources of pollutants resulting in harm to aquatic biota; these pollutants include both point and non-point sources of pollutants (USEPA 2008). The dominant non-point sources of pollutants are in-stream excessive fine sediment causing siltation and habitat alteration, fecal bacteria, and nutrients (TDEC 2022). Typically, these pollutants are considered watershed-scale stressors thus restoration practices to improve water quality are limited from these pollutants because projects are implemented at the reach-scale. However, reach-scale restoration projects may result in incremental improvements to biological integrity locally. Even with impaired water quality, habitat-focused restoration projects can improve fish and macroinvertebrate communities (Schwartz and Herricks 2007; Schwartz et al. 2015; England et al. 2021). Other researchers have not found this improvement to be the case (Tullos et al. 2009; Stowe et al. 2023).

The CWA and state water quality statutes required states to develop IBIs for their biomonitoring program and incorporate IBIs into their water quality standards (USEPA 1990, Barbour et al. 1999). Tennessee uses macroinvertebrates for their IBI, which is the Tennessee Macroinvertebrate Index (TMI), and measurement protocols described in TDEC (2017). Macroinvertebrate IBIs typically measure local stream conditions, whereas water quality (chemical) sampling measures cumulative contributions of upstream pollutant sources. With the limited potential to improve water quality because upstream pollutant sources may be outside the project area, Water Quality metrics are optional. The Biology and Water Quality parameters and metrics for this functional category used in the TMAT are listed in Table 2.1.

3.8.1 Biology metrics

For Biology parameter, the TMI score is the primary metric used. The reference standard for the TMI score is based on Tennessee Water Quality Standards (TDEC Rules 0400-40-03). TMI scores range from 0 to 42, with higher scores indicating healthier streams. A score of 32 or lower generally indicates some degree of impairment, while a score of 32 or higher is considered a stream with functional conditions (Figure 3.29).

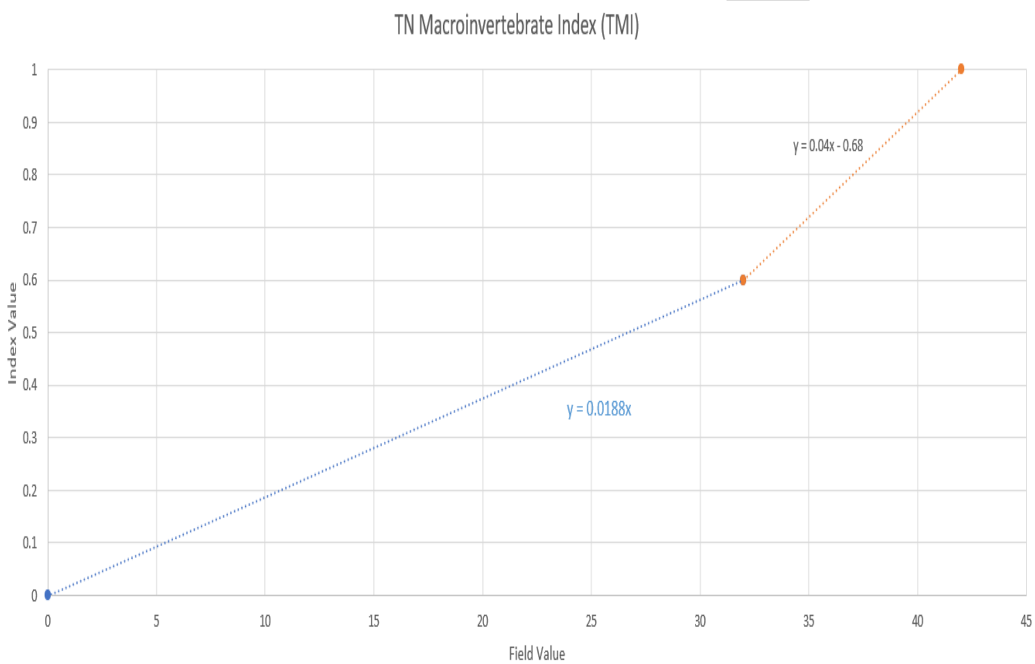


Figure 3.29. Reference standard for the TMI metric.

An alternative is to use only a subset of biometrics, which are: percent Clingers, percent EPT-Cheumatopsyche (% EPT-Cheum), and percent Oligochaeta and Chironomidae (% OC). Reference standards for these sub-set biometrics are based on differences in ecoregion, drainage area size, and season collected. These reference standards are in Appendix 9.3.

3.8.2 Water Quality metrics

Assessment of the Water Quality parameter is optional, however if used all metrics within this categorical parameter must be measured. Macroinvertebrates data are obtained by a TMI Semi-Quantitative Single Habitat (SQSH) sample. The four metrics are: % Nutrient Tolerant Macroinvertebrates, mean Nitrate-Nitrite, mean Total Phosphorus, and geomean *E. coli*. References standards are based differences in ecoregion and drainage area size. These reference standards are in Appendix 9.4.

4. Stream Mitigation Functional Loss and Lift

Section 4 of the User's manual provides general guidance on the use of the TN Debit Tool for computing loss of stream function associated with authorized impacts (debits), and the TMAT for computing lift to stream functional capacity from restoration practices (credits). Section 4.1 provides an overview of mitigation debit and credit calculations utilizing the TN Debit Tool and TMAT workbooks. Sections 4.2 and 4.3 provide general procedural guidance on debit calculations (functional loss) and credit calculations for mitigation projects (functional lift).

4.1 Overview: Stream Mitigation Debiting and Crediting Procedures

The TMAT worksheet is used to quantify the condition score at the reach scale prior to a permitted impact or restoration project as the ECS (Sections 2.1 and 2.2). After the ECS has been computed for a site reach, the TMAT is then used to quantify a condition score as a PCS either as functional loss from a proposed impact, or functional lift from a proposed stream restoration project. Collected desktop/field data are entered into the *Data Entry* worksheet of the TMAT workbook (Section 7), where the spreadsheet automatically calculates an ECS or PCS. ECS and PCS use the same assessment metrics in the TMAT worksheet (Table 2.1).

An ECS for a project reach is multiplied by its stream length to convert linear feet units to functional feet (FF) units. Stream length is measured along the centerline of the channel. For a stream reach with permitted impacts, the PCS is multiplied by the impacted stream length to compute FF. For a mitigation project reach, the PCS is multiplied by the length of the proposed restoration site to compute FF. A debit is the relative difference between the existing stream FF and the proposed stream FF from a permitted impact (ΔFF), whereas a credit is the difference between the existing stream FF and the proposed stream FF from a mitigation project. All functional feet values should be rounded up to the nearest tenth. Debit/credit calculations are demonstrated as follow.

- Existing Stream FF = ECS * Existing stream length
- Proposed Stream FF = PCS * Proposed stream length
- Change in FF (ΔFF) = Proposed FF – Existing FF; where:
  a negative ΔFF = debit; and a positive ΔFF = credits

Mitigation debits are calculated using two primary tools: the TMAT to quantify the ECS and existing FF, and the TN Debit Tool to quantify stream functional loss depending on severity of impact type (Section 4.2). Mitigation credits are calculated using the TMAT workbook to quantify the ECS and existing FF, and used to quantify the PCS to calculate stream functional lift from stream restoration projects and monitoring post-construction (Section 4.3).

4.2 Determining Stream Functional Loss (Debits)

The TMAT was developed in part to provide an objective, consistent, and transparent method for quantifying the functional loss associated with unavoidable permitted stream impacts. If the assessment objective is to generate debits for unavoidable impacts, then planning for the TMAT data collection is simplified because the stream reach is pre-determined as the impact area. Section 1.3 summaries some potential impacts caused by human disturbances on or near streams. In many cases an impact reach may be short such as bridge and culvert road crossings, or a development on a small parcel. However, for longer reaches that differ in stream functional characteristics that affect ECSs, a reach may need to be segmented per the guidelines outlined in Section 5.4. Longer reaches for example may be an impact from a major new road development disturbing hundreds of feet in stream length. A segmented reach will have multiple ECSs generated for each delineated stream reach.

4.2.1 TN Debit Tool

The TN Debit Tool workbook consists of separate worksheets that are used to compute FF of loss. The worksheets include a data entry worksheet, debit project assessment worksheet, the debit calculator, TMAT worksheet, a worksheet for documenting site photos, and the reference standards use in the TMAT. The TN Debit Tool file wr_nru-tmat-debit-tool-workbook-V.2 can be downloaded from TDEC's web page for *Compensatory Mitigation for Stream and Wetlands*:

> https://www.tn.gov/environment/permit-permits/water-permits1/aquatic-resource-alteration-permit--arap-/permit-water-arap-compensatory-mitigation.html.

A general description of using the TN Debit Tool workbook follows in Section 4.2.2. Detailed guidance on using the six worksheets within the TN Debit Tool workbook are described in Sections 7.1 to 7.3.

4.2.2 TN Debit Tool Calculation Procedures

A procedural flowchart for computing debits in FF is shown in Figure 4.1. Reaches with unavoidable impacts are delineated based on the disturbance, with locations identified by latitude/longitude and a unique ID number. Each reach location and its impact description are summarized in the debit project assessment worksheet. This information is also entered into the first two (left) columns in the Debit Calculator worksheet (Table 4.1).

The Debit Calculator worksheet as shown in Table 4.1 requires ECS and PCS and their respective stream length to compute FF loss. The Debit Calculator uses the user-supplied ECS selected from three options where the ECS can be computed using the TMAT worksheet applying measured metrics or using a default value (Section 4.2.3). The option applied is defined in the third column (from the left). Options applying the Debit Calculator worksheet require procedures fully described in Sections 5 and 6 of this User's Manual. Applying the ECS the linear footage of existing stream length is used to determine existing FF (fourth and fifth columns from the left). The stream length of proposed impact reach is measured then scaled by a numeric factor associated with the Impact Severity Tier (sixth and seventh columns from the left). Impact Severity Tiers are summarized in Section 4.2.4. This calculation results in a PCS (eighth column), which when combined with proposed linear footage of stream, determines the FF loss (ninth column). As noted in Section 4.1, debits are the difference between existing FF and the proposed FF.

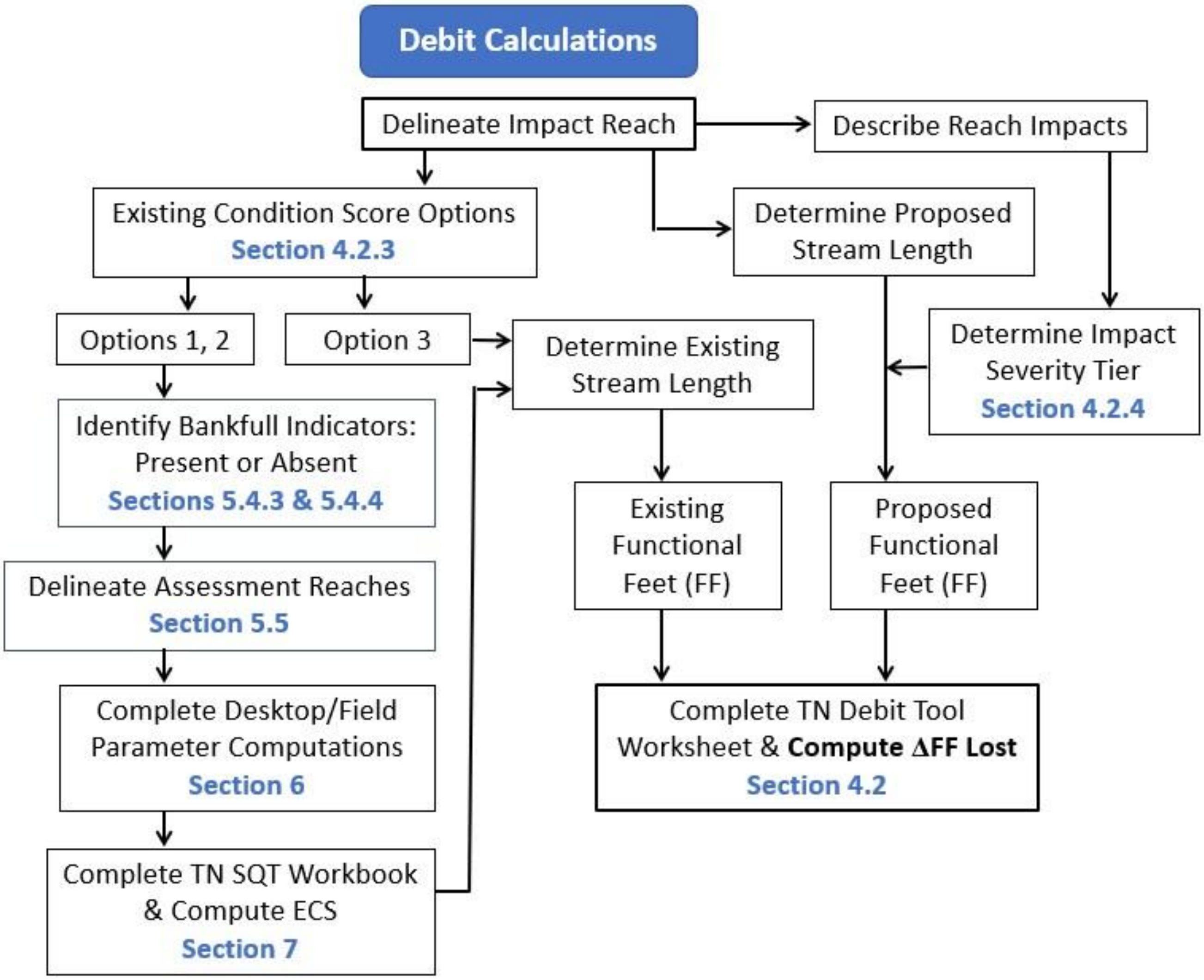


Figure 4.1. Flow chart showing general procedures for debit calculations.

4.2.3 Existing Condition Score Options

Using the TN Debit Tool there are three options provided in the *Tennessee Stream Mitigation Guidelines* (TDEC DWR-NR-G-01) for determining an ECS (Table 4.2). The three options are described as follows:

Option 1 requires the user to measure the existing condition of the proposed impact reach by quantitatively assessing all required metrics in the TMAT worksheet (Table 2.1). Once the desktop/field assessment has been completed and the data processed, the user will enter the data into the Data Entry worksheet within the Debit Tool, and the TMAT Existing Condition worksheet to calculate an ECS for the reach.

Table 4.1. Debit calculator worksheet in the TN Debit Tool.

Name:
Date:

TMAT DEBIT TOOL v. 1.0

Project ID/ Permit Number:	**0**		Users Input Values	
			Users select values from a pull-down menu	

DEBIT TOOL TABLE

Stream ID by Reach	Impact Description	Option	Existing Stream Length	Existing Condition Score	Proposed Length	Impact Severity Tier	Proposed Condition Score	Change in Functional Feet
0	0							
0	0							
0	0							
0	0							
0	0							
0	0							
0	0							
0	0							
0	0							
0	0							
0	0							
0	0							
0	0							
0	0							
0	0							
0	0							
0	0							
0	0							
0	0							
0	0							
0	0							
							Total Functional Loss (Debits in FF):	**0.0**

Table 4.2. User-chosen options 1, 2, or 3 to determine the existing condition for a stream reach with proposed impacts to functional condition.

TN Debit Tool Option	Existing Condition Score (ECS)	Proposed Condition Score (PCS)	Recommended Use
1	Applicants complete an existing condition assessment of all the required parameters and metrics.	Use Debit Calculator	Permit applicants who have the staff and expertise to perform the assessments. Typically used for larger impacts
2	Applicants estimate the existing condition score by assessing some, but not all, of the required metrics included in the assessment.	Use Debit Calculator	Permit applicants who only want to assess a subset of the required parameters.
3	Applicants use a standard existing condition score (1.0 for ETWs or ONRWs and 0.8 for other waters as a default value).	Use Debit Calculator	Permit applicants who do not want to perform an assessment.

<u>Option 2</u> is for users that do not want to measure all of the required metrics in the TMAT worksheet per the Existing Conditions tab of the TN Debit Tool. The user enters the measured values into the Data Entry worksheet in the TN Debit Tool. For all required parameters that the applicant chooses not to measure, a default index score of 0.80 is used for each unmeasured metric, unless the stream is an Exceptional Tennessee Water (ETW) or Outstanding National Resource Water (ONRW), in which case the default score is 1.0. Because the metrics are not being measured, the Debit Tool assumes these metrics are functioning. This approach acknowledges it is possible that some metrics can and often do score high where other condition scores may be functioning at a lower capacity.

<u>Option 3</u> allows permit applicants to use a standard reach-scale existing condition score, i.e., no measured values are entered. In most cases, the DWR will apply an ECS of 0.80. The 0.80 value assumes that the existing stream is a functioning intermittent or perennial stream. Ephemeral channels are assumed with a 0.32 default ECS. The exception to this is for ONRWs, or waters designated as ETWs, in which case a standard condition score of 1.0 is used. The ARAP rules require that the determination of existing conditions shall ensure at least minimal protection for all streams notwithstanding prior degradation. Therefore, as described in the *Tennessee Stream Mitigation Guidelines*, for activities that propose impacts to highly degraded streams, the ECS will not be assessed as any less than 0.40 for intermittent and perennial streams, and where applicable, a lower limit ECS of 0.16 for highly degraded ephemeral streams. This lower limit to the ECS does not apply to degraded streams proposed for compensatory mitigation and aimed at providing functional lift. In addition, stream relocations may have an existing condition score lower than 0.40. This lower limit for impacted streams recognizes that even

degraded streams have values outside of the TMAT evaluation that must be offset if lost. Resource values are the benefits provided by a water resource that help maintain its classified uses established under State's Water Quality Standards. The TN Debit Tool and TMAT measure functions of streams such as the physical, chemical and biological processes that are primarily associated with maintaining habitat for fish and aquatic life. However, a stream's current condition may provide little to no habitat while still providing other resource values that help maintain additional classified uses such as irrigation, recreation, and wildlife and livestock watering. In this regard, a permanent or significant loss of stream water resource value must be balanced by compensatory mitigation to ensure an overall no net loss of resource value.

4.2.4 Impact Severity Tiers

A primary challenge with measuring the functional loss caused by a permitted stream impact is that long-term monitoring of a permitted stream impact condition over time is typically infeasible for both regulators and permittees. Unlike compensatory mitigation projects, the DWR will not typically require permittees to monitor a site after the impact to calculate the change in stream function. Therefore, Impact Severity Tier categories were developed by evaluating the affects a particular activity would have on stream habitat conditions and the likely amount of loss that would result from an impact regardless of the stream conditions existing prior to the impact. These activities were then grouped by activities with similar functional loss. The Impact Severity Tiers were based on stream project design documents, modeling, literature reviews, previous post- project evaluations, and best professional judgment. Thus, these Tiers are categorical determinations of the amount of adverse impact to stream functions, ranging from no loss to total loss, resulting from a proposed activity, and used to determine the proposed condition of the stream after the impact occurs.

The amount of functional loss a specific Impact Severity Tier directly correlates to an Impact Factor, which is used by the Debit Calculator to calculate stream functional loss. (Figure 4.1). Impact Severity Tiers range from 0 to 6 where Tier 0 impact represents no appreciable permanent loss of stream functions and therefore would not require compensatory mitigation, while a Tier 6 impact would result in significant loss requiring compensatory mitigation (Table 4.3). Some impact project proposals may have impacts with activities that fall into different tiers depending on the magnitude of the impact. For example, a small bank stabilization project may be a Tier 1 impact if only riparian vegetation and/or lateral migration parameters are impacted. However, if the project is large enough to impact water quality and/or biological functions, then the project would be at least a Tier 3 impact.

Applicants will be required to select an impact severity tier based on the proposed activity which is needed to estimate a PCS. Calculations for both the PCS and proposed FF loss are described next in Section 4.2.5. The Debit Calculator Tool automatically computes the PCS and Proposed FF (Table 4.2).

4.2.5 Proposed Condition Score and Loss Functional Feet

This section summarizes debit calculation procedures for an impacted reach as described in Section 4.2.2 and outlined in the Figure 4.2 flow chart. Section 4.2.2. defines where the proposed stream length and condition score are entered into the Debit Calculator (Table 4.1). As noted above in Section 4.2.4, after the ECS, existing stream length, post-impact stream

Table 4.3. Impact Severity Tiers and descriptions with function-based parameters being impacts.

Tier	Functional Loss Descriptions: Impacts to Stream Resource Values
0	No appreciate permanent loss of stream functions individually or cumulatively at any scale.
1	Minimal loss of stream functions. Impacts to reach runoff, lateral migration and/or riparian vegetation. Minor impacts to water quality, and macroinvertebrate and fish communities. Activities in this tier represent an 11% functional loss.
2	Partial loss of stream functions. Impacts to reach runoff, lateral migration, bed form diversity, and riparian vegetation. Minor impacts to water quality, and macroinvertebrate and fish communities. Activities in this tier represent a 20% functional loss.
3	Permanent loss of some of stream functions. Impacts to reach runoff, floodplain connectivity, lateral migration, riparian vegetation, and bed form diversity. May also include impacts to large woody debris. Minor impacts to water quality and moderate impacts to macroinvertebrate and fish communities. Activities in this tier represent an 48% functional loss.
4	Permanent loss of most stream functions. Impacts to reach runoff, floodplain connectivity, lateral migration, riparian vegetation, and bed form diversity. May also include impacts to plan form and/or large woody debris. Significant impacts to water quality and macroinvertebrate and fish communities. Activities in this tier represent an 68% functional loss.
5	Permanent loss of most of stream functions. Removal of all aquatic functions except for hydrology. Activities in this tier represent an 88% functional loss.
6	Total and permanent loss of all stream functions. Activities in this tier represent a 100% functional loss.

length, and Impact Severity Tier have been selected and entered into the Debit Calculator Tool, the PCS and proposed FF loss are automatically calculated. The absolute value of the change in FF total is equal to the debits required to offset the proposed impacts (Section 4.2.1). Multiple stream impacts can be reported on a single spreadsheet. In addition, an applicant can assess the ECS for multiple stream reaches proposed to be impacted. Embedded in the spreadsheet cells, the Debit Calculator computes the PCS and FF loss by the following steps.

Step 1: Manually calculating the Existing FF using the following equation.

Existing FF = ECS x Existing Stream Length.

Step 2: Manually calculating the PCS using the following equation, and loss percentages to be used are in Table 4.4.

PCS = Impact Severity Tier x ECS.

Step 3: Manually calculating the Proposed FF using the following equation.

Proposed FF = PCS x Proposed Stream Length.

Step 4: Manually calculate functional loss (debit) using the following equation.

Debit = Proposed FF – Existing FF.

Note with these calculations, the ECS cannot be lower than 0.40.

If the stream will be straightened by the permitted activity, the proposed length will be less than the existing length. The debit calculator will highlight the cell if the existing stream length is longer than the proposed stream length. This project situation may occur when encapsulation and channel straightening occur on a meandering stream channel. Commonly, an impact activity may shorten a stream length by pipe encapsulation. Thus, for a proposed project impact of existing 300-foot pipe along 275 feet of stream, the impact is only 275 linear feet of stream. The proposed length is the length of the pipe at a minimum. In some situations, an impact activity may actually lengthen stream footage. Within the TN Debit Tool, it is not appropriate for stream lengths to be increased via impacts to the resource. The proposed stream length should never exceed the existing stream length in the TN Debit Tool. Streams cannot be lengthened by pipes. For example, if a project encapsulates 100 feet of stream with a 110-foot pipe, the total existing stream length would be 100 feet, and the total proposed stream length would also be 100 feet within the TN Debit Tool. As another example, if a 100-foot pipe is removed and replaced with 60 feet of open channel and 50 feet of new pipe, the total existing stream length would be 100 feet, and the total proposed stream length would be 100 feet within the TN Debit Tool. This ensures that stream mitigation credit is not awarded for activities that typically do not qualify for mitigation credits. Overall, stream length loss has a negative impact on the function of a system and will be accounted for in debit totals.

Table 4.4. Percent loss calculations for Impact Severity Tiers from Proposed Condition Score (PCS) equations as a function of reach assessed Existing Condition Scores (ECS).

Impact Severity Tier	PCS Equation	Percent Loss
0	PCS = 1.0* ECS	0%
1	PCS = 0.89* ECS	11%
2	PCS = 0.80* ECS	20%
3	PCS = 0.52* ECS	48%
4	PCS = 0.32* ECS	68%
5	PCS = 0.12* ECS	88%
6	PCS = 0.0* ECS	100%

4.3 Determining Functional Lift (Credits)

4.3.1 TMAT and Mitigation Crediting

The TMAT may be used as a calculator to quantify the numerical differences between an ECS and the PCS (Section 2.2). This numerical difference is termed as functional lift and computed in FF units. It is part of the Tennessee stream credit determination method as defined in State rules and guidance, and by the federal 2008 Mitigation Rule. It provides a method to review how restoration activities change or improve stream functions and resource values. This is done through focusing on quantitative parameters and measurement methods that directly relate to stream functions and can be assessed by stream restoration practitioners and regulators. It also links restoration goals to restoration potential, encourages assessments and monitoring that matches the restoration potential, and incentivizes high-quality stream mitigation by calculating functional lift associated with enhancement to physical habitat and riparian corridors, and improvements to biological integrity.

TDEC and the USACE use the TMAT worksheet as a component of the mitigation project review process to calculate mitigation credits through quantification of functional lift. The TMAT may also be used as to assess a project proposal's suitability, its project goals and objectives, and its overall potential success over time. If the project objective is to assess whether a stream site could be used to generate mitigation credits, a more extensive effort is needed. Potential sites must be assessed to the feasibility for restoration. This effort requires data collection for watershed characteristics upstream of the possible restoration site, and for the project reach. Feasibility reflects justification that potential mitigation site results in functional lift and credit generation. If a potential mitigation site is deemed feasibility and approved by the IRT, the TMAT is applied to determine the FF gained. Detailed information concerning how to collect the required data, access data, and input the data into the TMAT worksheet are described in Sections 6 and 7 of this User's Manual.

Although a project may propose functional lift, ecological lift from the restoration project must be demonstrated through monitoring. Actual credit generation may vary through time based on-site performance and will be based on the documented lift in functional feet. Permittee-responsible mitigation projects may be required to perform corrective action or additional mitigation, if at the end of the monitoring period, the stream condition does not adequately offset the resource value lost. This outcome may occur if the projected lift as originally proposed was never fully achieved, therefore reducing the amount of actual functional feet of stream generated. Mitigation bank and In-lieu fee projects will be awarded credits based on performance and success determined by the USACE in conjunction with the IRT. Four key stream conditions consisting of the measured metrics in the TMAT for floodplain connectivity, riparian corridor, channel stability, and bedform diversity for physical habitat should at the conclusion of the monitoring period be functional for any stream channel proposed for functional lift. Measured parameters for these four conditions are summarized in Section 3, and desktop/field procedures for parameter measurement is in Section 6. This includes stream relocation projects. Urban projects and unique sites that deviate from this goal will be evaluated on a case-by-case basis. Additional guidance can be found in the *Tennessee Stream Mitigation Guidelines* (TDEC DWR-NR-G-01).

4.3.2 TMAT Workbook

The TMAT workbook consists of separate worksheets that are used to compute FF of lift. The worksheets include: a data entry, project assessment, and repeated for five project reaches the quantification tool, monitoring data, and data summary; and reference standards. The TMAT file wr_nru-tmat-workbook-version-2.0 can be downloaded from TDEC's web page for *Compensatory Mitigation for Stream and Wetlands*:

> https://www.tn.gov/environment/permit-permits/water-permits1/aquatic-resource-alteration-permit--arap-/permit-water-arap-compensatory-mitigation.html.

A general description of using the TMAT workbook follows in Section 4.3.3. Detailed guidance on using the TMAT worksheets within the TMAT workbook are described in Sections 7.1, 7.2, and 7.4. The data entry methodology into the worksheet provided and described in Section 7.2 includes both the desktop and field data required for input into the TMAT worksheet.

4.3.3 TMAT Calculation Procedures

The TMAT is a stream quantification tool that can be utilized in various ways. A procedural flowchart for computing mitigation credits in FF is shown in Figure 4.2. The initial step for computing mitigation credits is to assess whether the project reach site has sufficient potential to generate credits and if a project completed will be successful in maintaining long-term functional capacity. An initial assessment for a proposed restoration project consists of describing its objective, project measures, and potential lift. This restoration potential effort includes compiling basic information on watershed and reach characteristics (Sections 5.3 and 5.4). If there is the potential for a successful mitigation project, upstream and downstream boundaries are delineated based on criteria outlined in Section 5.5. A project may have multiple reaches depending on the reach characteristics.

Within each reach, metrics are collected for the five categories as summarized in Table 2.1 and Figure 2.3. Section 2.2 describes two pathways and different suite of metrics for computing the ECS when bankfull indicators are present or when indicators are absent or not adequate. Once the reach(es) are delineated, bankfull indicators are investigated. Guidance on the criteria to make this pathway determination is in Section 5.4.4. Some metrics in the TMAT are collected for the entire project reach, however most field-based metrics are collected for an assessment reach (Table 5.7). Assessment reaches within the project site reach need to be delineated for the TMAT metrics where the measurement method specifies a shorter stream length to be assessed than the entire project stream length. Field-based metrics Section 5.5.3 provides guidance on delineating the assessment reach.

Desktop/field data per project site reach are collected to complete an ESC. Within the TMAT workbook, the Data Entry worksheet in Section 7 provides the user a logical sequence of compiling data following the data needs for the TMAT worksheet. A stream length is required to be entered into the worksheet in order to compute existing FF.

Based on the proposed project description, the TMAT worksheet is used to compute a PCS. Enter proposed site data into the provided worksheet, in addition to the proposed stream length. Guidance is provided in Section 7.4. The worksheet computes the proposed FF. The worksheet takes the difference between the existing and proposed FF to compute FF of ecological lift, i.e., the Δ between the existing and proposed FF (Section 2.2).

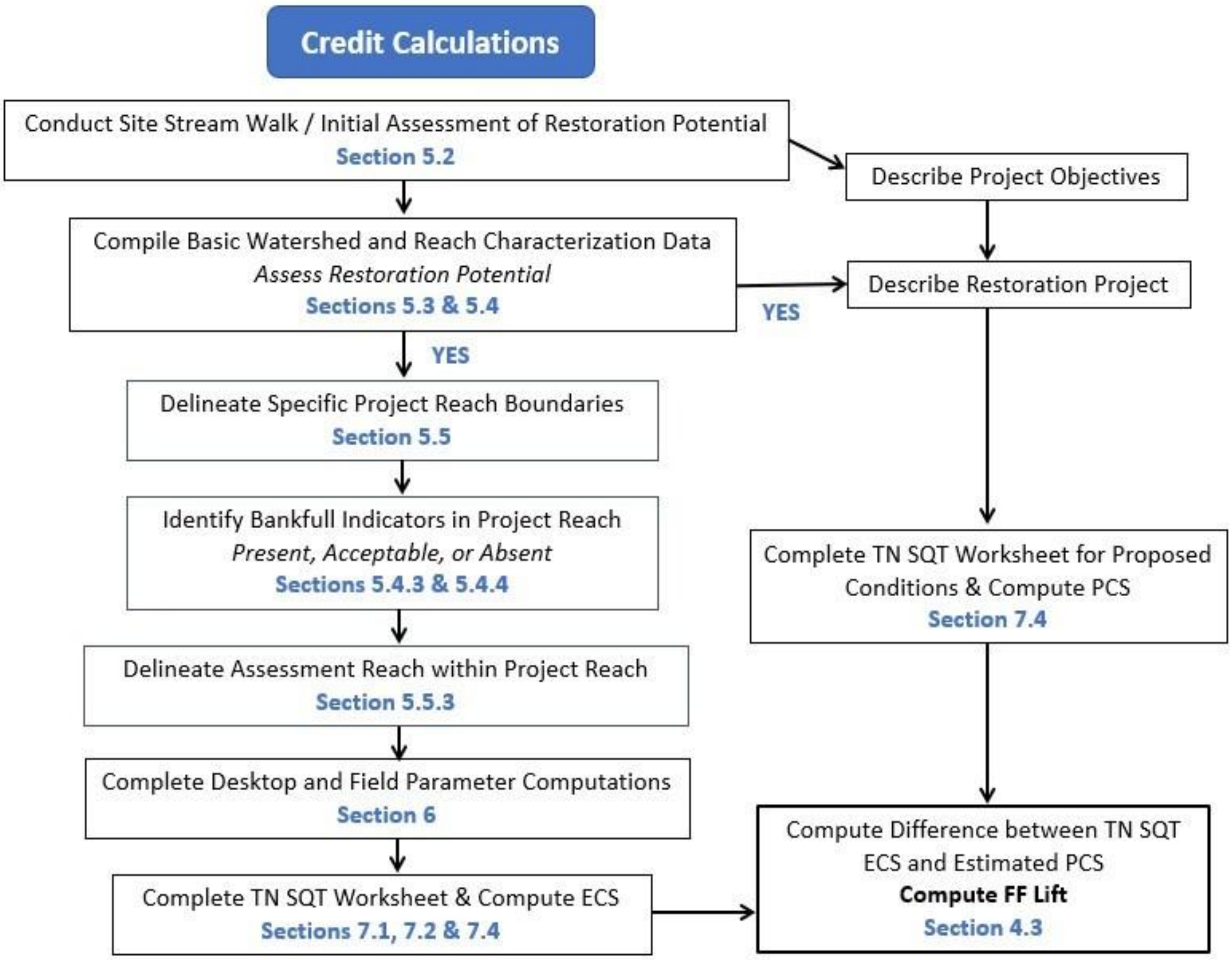


Figure 4.2. Flow chart showing general procedures for mitigation credit calculations.

Unlike the TN Debit Tool, there is no lower limit to the ECS calculated for purposes of mitigation credit assessments. As a project example, a stream restoration project on a cattle farm proposes to restore a channel to increase its functional capacity. The current stream reach was historically straightened where the channel morphology has greatly incised disconnecting the channel from its floodplain. The straightened channel has no riparian vegetation, degraded water quality and poor biological integrity. The stream banks are eroding causing siltation and the main cause of biological impairment. The ECS of a 3,000 linear foot stream reach is calculated to be 0.21. The proposed restoration project will reduce bank erosion, improve the riparian corridor, create in-channel habitat, and reconnect the channel to a floodplain. The proposed condition score will be a 0.53, and the newly meandering channel will be 3,500 feet long. The credits generated will be 1,225 functional feet by the following calculations:

- 3,000 linear feet of stream (x) ECS of 0.21 = 630 existing functional feet.
- 3,500 linear feet of restored stream (x) PCS of 0.53 = 1,855 proposed functional feet.
- Credits = proposed functional feet (1,855 ft) – existing functional feet (630 ft)
- Total credits for project = 1,225 functional feet

5. Project Site Assessment, Data Collection and Field Preparations

Section 5 provides the guidance for site assessments and metric data collection using the TMAT worksheet. TMAT metrics within the functional categories and parameters were summarized in Table 2.1. Guidance is provided for both debit and credit calculations. Though much of the basic information to be collected at an impact site or a mitigation project site are the same, some procedural differences were described in Section 4 and shown in Figures 4.1 and 4.2. Pre-project assessments for selection of a mitigation project require information gathering at both watershed and reach scales to evaluate the potential for restoration and credit generation. General guidance on resources for watershed information gathering, identifying watershed stressors, and evaluating restoration potential are in Sections 5.2 and 5.3.

Reach characterization including flow type classification, Rosgen stream type determination, and bankfull indicator identification and verification are summarized in Section 5.4. Section 5.5 describes procedures for reach segmentation, and determining boundaries of assessment reaches within project reaches. Some metric index scores utilize data from the entire project reach whereas several field-based metrics are based on a sub-section of the project reach, termed the assessment reach. Measurement methods for the TMAT worksheet metrics by either desktop and/or field procedures are described in Section 6.

5.1 Data Needs Guidance for Debit and Credit Calculations

Basic site information is required to be compiled and reported for both impact and mitigation project reaches. Sites require a general name with latitude and longitude coordinates of the upstream and downstream reach boundaries. A general description of the site along with photos are to be included in TMAT reports. The following information is reported on the TMAT datasheet (Section 7).

- Project Name; Reach ID Name and Number
- Reach Upstream and Downstream Latitude and Longitude
- Ecoregion (Level III)
- ETW/ONRW Designations
- Drainage area (sq. mi) (above downstream reach boundary)
- Regional Curve and Dimension
- Field Data Collection Dates (physical, water quality and/or biological data)
- Valley Type
- Reach Flow Type
- Rosgen Stream Type
- Channel Evolution Model (CEM) Stage
- Reach Site length (feet)
- Channel Slope (%)
- Bankfull Indicators: Presence or Absence
- Flow Statistics (peak flow return frequencies from USGS StreamStats)
- Macroinvertebrate Field Collection Method

5.2 Restoration Potential for Mitigation

The TMAT can be used to evaluate the restoration potential for each stream in a project (Section 4.3). Restoration potential is defined as the highest level of return of functional conditions that can be achieved based on results of the watershed assessment and identification of any site constraints (Section 5.3). Restoration potential is determined by the degree to which physical, chemical, and biological processes at both watershed and reach scales are maintained or restored. The key goal is to improve water quality and biotic integrity to meet classified uses with the general aim to remove impaired stream reaches from the Section 303(d) list based on unavailable parameters. Practitioners should evaluate the potential of each stream by weighing watershed stressors and site constraints to develop a proposal for either full or partial restoration. Once the site potential has been determined, practitioners can develop complementary project function-based goals and objectives.

Stream restoration projects, whether for compensatory mitigation or not, can be complex and practitioners often encounter many challenges depending on the site. The potential for a project to be successful short-term and be resilient long-term may have little to do with the restoration of the stream reach but more with the upstream watershed conditions. Project planning by practitioners is crucial for a successful and resilient project. Planning starts with selecting a stream site and evaluating the project's restoration potential to achieve functional lift, including development of clear objectives aligned with the project proposal (Figure 4.2).

Project planning requires practitioners to carefully evaluate all conditions within the project watershed that may help or hinder the restoration efforts. When planning a project, it is recommended that the TMAT be used to gauge conditions that influence the potential functional lift of a site. This effort includes identifying watershed stressors and reach site constraints (Section 5.3). Once these conditions have been evaluated, practitioners can then select reach-scale functional conditions that can be improved given the site condition and any constraints. Once the restoration potential has been determined, practitioners can develop specific function-based objectives for a project indicating whether partial or full restoration can be achieved.

The potential for a stream reach to achieve full or partial restoration should be evaluated through each functional category and parameters of the TMAT. A stream reach with full restoration potential would restore functions back to a reference condition within all categories which include: Hydrology, Hydraulics, Geomorphology, and Water Quality/Biology (Table 2.1). It is consistent with the 'full-restoration' concept described by Beechie et al. (2010), where actions restore habitat-forming and ecological processes returning the site to its natural or reference standard range. By contrast, reach-scale projects with limited potential for improvements to all functional conditions are considered as partial restoration.

Partial restoration is the most commonly applied project design practice. These projects result in the partial reestablishment of the structure and function of stream ecosystems, where restored streams are geomorphologically stable promoting physical habitat maintenance and ecological processes. However, the reference condition can't be obtained because some watershed stressors or reach-scale constraints prevent the site from reaching its full potential.

These types of projects can improve floodplain connectivity, channel stability, bed form diversity, and riparian vegetation closer to a reference condition, but may result in limited functional lift for water quality and biological functions. The description for a proposed project and its stated goals for restoration should include what watershed stressors and/or site constraints from anthropogenic impacts will likely limit restoration potential. Some general guidance follows in Sections 5.3 with information on watershed stressors and site constraints, in addition to some resources for watershed characterization.

Project goals and objectives must align with restoration potential, however potential alone cannot determine the amount of functional lift a project will achieve within the time required by the regulatory program. All projects require detailed post-construction monitoring and evaluation of each parameter proposed for lift to gauge the level of success a restoration has achieved. It is important to note that a project may have good potential for partial restoration, but throughout the monitoring years never reach the proposed functional condition. This outcome does not mean a project failed but it represents incremental improvement to the functional condition. Also, some functional attributes may achieve their design goal long after the post-construction monitoring period has ended, i.e., growth of the riparian tree canopy.

5.3 Watershed Assessment

5.3.1 Watershed Stressors

Watershed stressors are land surface and riparian corridor disturbances degrading the physical, chemical and biological processes within a watershed's streams. In general, stressors that exist outside the project boundaries and within the lateral drainage area of a stream may limit functional lift, and therefore, restoration potential. Watershed-scale stressors typically include land cover/use conversions to developed lands causing changes to hydrology and channel morphology impacting physical habitat (Figure 3.2). Developed land uses can cause hydromodification from increased impervious surfaces resulting in greater stormflow runoff volumes and peaks, and reduced infiltration (Booth and Jackson 1997; Violin et al. 2011). Also, land development and construction activities can cause sediment erosion where excess fine sediment (clay and silt) enters the stream resulting in siltation impacts. Land use patterns causing habitat fragmentation and low levels of habitat connectivity may impact aquatic organism survival and limit migration necessary for a species to reproduce (Figure 3.5). Riparian corridor disturbances can promote dominance of invasive aquatic species impacting native ecosystems. Low-head dams or poorly designed road culverts create passage barriers where aquatic biota cannot migrate upstream impacting recruitment for certain species. The Tennessee Macroinvertebrate Index (TMI) is used as an indicator measure of water pollution in which low index scores may be a result of stream eutrophication from excessive nutrients, siltation from stormwater runoff fine sediment, and other sources of pollutants such as combined sewer overflows, failed septic tanks, and illegal dumping. Useful information on stream impairment and possible sources of pollution can be investigated using TDEC's Data and Map Viewer (Section 5.3.3). *Watershed Assessment* includes descriptions of watershed processes and stressors, as noted above, that are outside of the project reach that may limit functional lift. Table 5.1 summarizes examples of stressors and their functional category.

Table 5.1. Watershed features that may cause stressors of aquatic ecosystems that can be assessed to evaluate the potential functional lift from stream restoration.

Watershed Feature and (Functional Category)		Feature Description
1	Impervious Cover in Watershed (Hydrology)	Percent of catchment upstream of the restoration site that is impervious surface.
2	Percent Land Use Change in Watershed (Hydrology)	Rapidly urbanizing versus rural and primarily forested.
3	Road Density in Watershed (Hydrology)	Proximity of existing and planned roads to the restoration site.
4	Percent Forested (Catchment) (Hydrology)	Percent of catchment that is forested upstream of the restoration site.
5	Catchment Impoundments (Hydrology)	Presence and size of impoundments upstream of the restoration site likely to limit flow in the reach. These include small low-head dams, headwater farm ponds, and large impoundments.
6	Catchment Forested Riparian Corridor (Geomorphology)	Presence or lack thereof of riparian corridors on streams contributing to the restoration site.
7	Stream Channelization (Geomorphology)	Straightened channel from development reducing habitat diversity.
8	Fine Sediment Deposition (Geomorphology)	Extent of fine sediment present in the project reach. This category is used to assess excessive fine sediment supply embedding the channel at the site.
9	Streams within the Catchment Area Assessed as Impaired (Water Quality)	Extent of streams contributing to the restoration site known to be impaired. Streams are on the state's 303(d) list.
10	Agricultural Land Use (Water Quality)	Livestock access to stream and/or intensive cropland in the catchment likely to impact restoration site conditions. Lack of riparian corridor vegetation and buffer strip runoff filtering of sediment.
11	Process Wastewater Outfalls in Watershed (Water Quality)	Proximity of Process Wastewater Outfalls (PWOs) and NPDES permits to the restoration site.
12	Stormwater Outfalls from Urban Lands (Water Quality)	Pollutants from untreated stormwater runoff from streets and other developed land surfaces.
13	Aquatic Organism Barriers (Biology)	Proximity of impoundments impacting fish passage to the restoration site, both upstream and downstream.
14	Organism Recruitment (Biology)	Potential for and availability of the desired taxa to be recruited to the restoration site.

Understanding the watershed stressors coupled with careful evaluation of site constraints relies in part on qualitative professional judgement as to the site potential for mitigation credits. Overall, a watershed assessment can aid the user in determining the overall watershed condition of a stream, assisting users in defining the restoration potential and function-based goals and objectives of the project.

5.3.2 Project Site Constraints

Many factors influence the amount of functional lift a project can reasonably achieve, including watershed stressors as described above in Section 5.3.1. Watershed stressors may result in site constraints having a direct effect on the restoration potential of a site (Table 5.1). Applicants for potential mitigation projects need to explore all conditions as site constraints that may limit a project from meeting its stated objectives. It is important to note that site constraints as it pertains to restoration potential, are anthropogenic and not natural conditions (Bond and Lake 2003). Examples of anthropogenic constraints include: land use practices generating runoff pollutants, current and proposed urban development, stream channel realignment, adjacent sewer and utility lines; existing utility easements; roads, buildings and other infrastructure. Lack of conservation easements is a form of site constraint. Wide conservation easements in the riparian corridor can provide protection for systems against current and future impacts or changes in the watershed. Although greenways and public parks are protected and may seem to partner well with restoration activities, park management missions, active use parcels, and simple landscaping and maintenance activities can limit functional lift.

Some natural stream features such as bedrock channels and waterfalls may limit a project's capacity for functional lift, thus limit an index score in the TMAT worksheet. Such features are not considered project constraints, and a practitioner will need to describe these features to the IRT during project development assessing restoration potential. Other natural landform features such as multiple channels in lowland areas, also not a project constraint, may limit an index score in the TMAT worksheet and therefore must be explained as to why the suite of TMAT metrics may not reflect the important ecological functions for a site's unique conditions. The IRT may accept alternative measures for quantifying functional lift in these site conditions.

Final site selection is critical to the success of stream restoration projects and requires a thoughtful assessment of whether the site will be able to achieve both programmatic and project goals given land use restrictions, utility easements, financial constraints, and a myriad of other factors. Even though the assessment of restoration potential can aid in the site selection process, the site selection process can depend on many factors and is not limited to this assessment alone. Once a site has been selected, understanding the potential for full or partial restoration based on functional condition allows a permit applicant to define restoration objectives, as well as a monitoring plan, to focus on appropriate and achievable functional lift.

5.3.3 Watershed Characterization

Drainage networks of watersheds are hierarchically organized and watershed physiographic controls govern geomorphic and habitat maintenance processes at the reach scale (Section 3.3.2). Understanding watershed processes and the cumulative impacts from land and channel disturbances is critical to summarizing the watershed stressors that may affect the potential for functional lift from a restoration project. As summarized in Table 5.1, watershed stressors typically include land use conversion from undeveloped to developed lands possibly causing hydromodification and channel incision, and the physical alterations of stream channels (channelization) and riparian vegetation.

Once the project site has been identified, the list of required watershed information for mitigation permitting is summarized in Section 5.3.1. In addition to this basic information, the permit applicant should compile as much information available to assess restoration potential. All useful information describing the stream restoration potential for functional lift should be submitted to the IRT for a proposed mitigation project, and information included in the prospectus report. In general, the basic information for a watershed and project site includes the following: ecoregion, surficial geology, drainage area above downstream boundary of project reach, largest stream order, terrain/average slope, soil hydrological classification, land cover/use composition including impervious surface, road density, impoundments, floodplains, and Section 401 permitted discharges. Useful resource information and web links to obtain watershed characterization data follows. Other resource information sources are also available (Appendix 9.2).

Level III Ecoregions are shown in Figure 5.1. Level IV Ecoregion designations should be identified from the state map. Identification of the Level IV Ecoregions in which the project site is located can be obtained from the TDEC Division of Water Resource public data viewer at the following web link: https://tdeconline.tn.gov/dwr/

https://gaftp.epa.gov/EPADataCommons/ORD/Ecoregions/reg4/reg4_eco.pdf

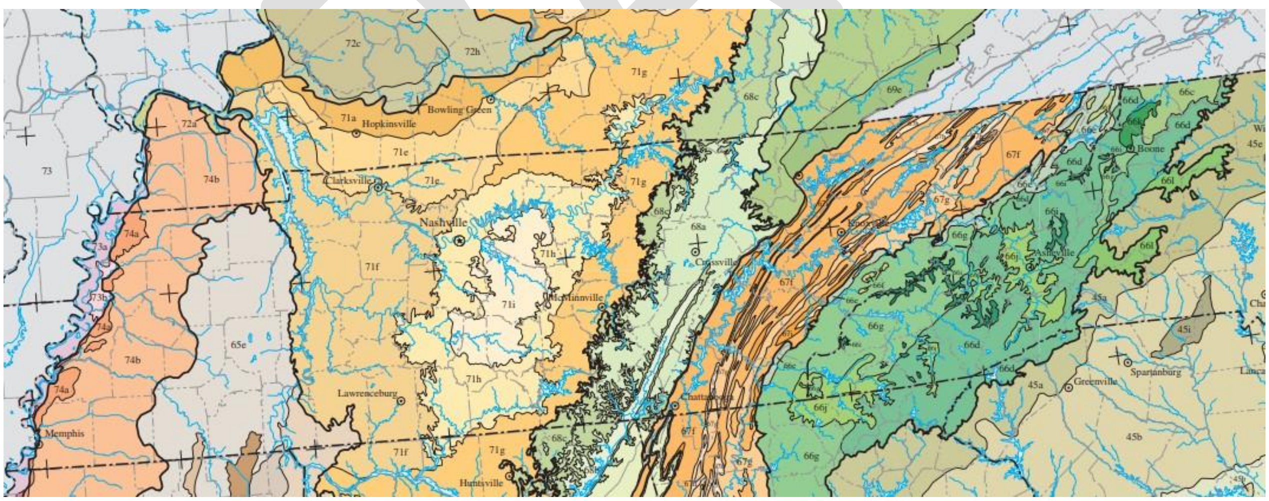


Figure 5.1. Level III ecoregions in Tennessee. *Ecoregions*: 65 = Southeastern Plains; 66 = Blue Ridge Mountains; 67 = Ridge and Valley; 68 = Southwestern Appalachian; 71 = Interior Plateau; and 74 = Mississippi Valley Loess Plains.

Surficial Geology for the state of Tennessee can be obtained at the following web site:

https://www.tn.gov/content/dam/tn/environment/geology/images/geology_geologic-map-lg.jpg

Surficial geology provides useful data on the character of stream morphology and the dominant type of bedload supply. Bedload supply directly relates to channel bed and sediment. For example, the Precambrian strata of eastern Tennessee (Blue Ridge) will be dominated by resistant sandstones and igneous/metamorphic rocks whereas middle Tennessee is dominated by Paleozoic limestones. West Tennessee is much different with Cenozoic/Mesozoic soft sandstones and recently deposited alluvial material. Surficial geology closely follows ecoregions because ecoregions are based on geology, soils, and vegetation (Omernik 2004, Omernik and Griffins 2014).

<u>Terrain</u> of the watershed consists of the topographic configuration spatially mapped primarily by elevation contour lines. This information can be obtained from the USGS topoView web link:

https://ngmdb.usgs.gov/topoview/viewer/#4/39.98/-100.06

Maps downloaded from USGS topoView also includes bluelines of the drainage network and land use features, i.e., buildings and roads (road density). Information on building and roads shows the relative degree of development in a watershed which can cause hydromodification.

<u>Watershed drainage area</u> can be delineated using various GIS-based interface tools available on the web. The tool suggested for use is *Model My Watershed*® supported by the Stroud Water Research Center, and open assess can be found at:

https://modelmywatershed.org/

Use of *Model My Watershed*® can delineate the drainage area above the project site and summarize key characteristics, including: 1) drainage area size in mi^2 or km^2, 2) stream lengths by order, 3) average watershed slope, and 4) present area of hydrological soil groups (A, B, C, and D). Average watershed slope indirectly provides information on erosion potential with steeper slopes more prone to channel erosion when land surfaces are disturbed. Hydrological soil group provides useful information on the general infiltration capacity of the soils within the watershed.

<u>Watershed's Composition Land Cover/Use</u> is important to understanding the potential for restoration achieving a desired level of functional lift due to stressors imposed onto aquatic ecosystems. Output from *Model My Watershed*® includes a summary of percent land cover/ use types. Types can be grouped into broader, relevant classes for assessment purposes. They are: 1) % Developed consisting of urban lands; 2) % Agriculture consisting of pasture/hay and cultivated crops; and 3) % Forested. Examining land cover/use patterns in a watershed allows for a qualitative assessment of the degree of potential impacts from development and areas that provide resilience to potential impacts. Forested lands with good riparian cover may mitigate impacts from adjacent developed lands on hydrological and ecological processes. Watershed land cover/use information can also be obtained from the USGS Multi-Resolution Land Characteristics Consortium (MRLC). The MRLC web link is:

mrlc.gov/viewer

The MRLC database provides the National Land Cover Database (NLCD) for multiple years, and a Land Cover Change Index. The Land Cover Change Index is useful to assess the degree of land conversion which may correspond to rapid geomorphic adjustments to stream channels. The

MRLC database also includes a spatial layer for *tree cover* and *impervious surfaces*. The tree cover layer provides qualitative information on the quality of the existing riparian corridor. The impervious surface layer provides qualitative information on the density of development in a watershed. In general, land cover patterns and land use features (buildings and roads) can be inspected using Google Earth Pro. The web link is:

https://earth.google.com.

Using Google Earth Pro of the watershed allows for a general inspection of possible stressors and reach-scale site constraints limiting restoration potential for functional lift. Possible constraints include identifying low-head dams and impoundments upstream and downstream of a proposed project site. Low-head dams can create an aquatic organism barrier to migration, necessary for many fish species to fulfil their life history needs. Road crossings need to be identified as possible culvert locations also potentially creating an aquatic organism barrier to migration. Road crossings with bridge abutment protections create watershed locations of hydraulic (vertical) grade controls, which provide important geomorphic data to assess the potential for channel downcutting (incision).

Soil Types and Soil Hydrological Classes for a watershed's area of interest (AOI) can be obtained from the USDA Web Soil Survey web site:

https://websoilsurvey.nrcs.usda.gov/app/

The USDA Web Soil Survey site summarizes soil types in the AOI within a watershed in which data on soil hydrological classes and hydraulic connectivity are reported. These parameters relate to the soil's ability to infiltrate precipitation. It includes HUC 8 boundaries, and summarizes the information contained in the Soil Survey Geographic (SSURGO) database. Soil data from this site may be useful to assess the survival of vegetation plantings for a project's riparian corridor. Also, it can provide information on whether wetland hydric soils may be present in the watershed and within the riparian corridor.

Floodplains and Flood Hydrology at the project site provide spatial information on hydrological processes and the attenuation of flood waters, and can be used for stream power estimates for assessing the potential for geomorphic channel incision. The best data source for floodplains is the FEMA flood maps web site, which displays the 100-year and 500-year floodways. The USGS StreamStats site provides flood flow frequencies in terms of a return period, i.e., a 2-year return frequency (Q2), a 5-year return frequency (Q5), etc. It provides the Q2, Q5, Q10, Q25, Q50, and Q100 flow return frequencies. Floodplains and flood hydrology information can be obtained from the FEMA flood maps and USGS StreamStats web sites, respectively. The web links are:

https://streamstats.usgs.gov/   https://www.fema.gov/flood-maps

Pollutant Sources potentially causing water quality impairment can come from point and non-point sources. Protection of water quality from point source pollutants is regulated under Section 402, National Pollutant Discharge Elimination System (NPDES) discharge permits issued in the watershed upstream of a project site. NPDES permits are issued by the DWR which define pollutant discharge limits from municipal and industrial wastewater treatment plants and stormwater outfalls, and active construction activities. Physical alterations to properties of waters of the state require an ARAP or a §401 Water Quality Certification. To identify whether an NPDES permit has been issued upstream of a project site, in addition to an ARAP, the TDEC Data and Map Viewer can be used to identify permit locations and their information, and it can be found at the web link:

https://tdeconline.tn.gov/dwr/.

This link also displays whether a stream reach has been assessed for meeting water quality standards, shown as fully supporting, not supporting, and not evaluated, as well as where TDEC monitoring stations have been established. If the stream reach is shown as not supporting that reach will be on the *Section 303(d) list*. The Tennessee §303(d) list will identify the *unavailable parameters* and causes for the water quality and/or biotic integrity impairment. The Tennessee 303d list can be downloaded from the web site:

https://www.tn.gov/content/dam/tn/environment/water/watershed-planning/wr_wq_303d-2022-final.xlsx

This information is critical to developing restoration project goals and objectives because removing streams from the §303(d) list meets the CWA's overarching goals of restoring water resource values of streams. Water resource values are defined by physical, chemical, and biological functions. For example, if the stream reach is §303(d) listed for siltation and habitat alternation, a restoration project objective would be to 1) identify the source of excessive fine sediment on the bed and focus on eliminating the sources, and 2) enhance aquatic habitat. In general, excessive fine sediment in streams either come from land surface erosion that may require stormwater control measures (SCMs), or from stream bank erosion which requires bank stabilization. Another example may include a stream listed for *E. coli*, with the source listed as cattle grazing, where a project would consist of fencing the cattle out of the stream and repairing the riparian vegetation.

Water Quality data from any of the TDEC 's monitoring stations (using the station code number found on the TDEC Map Viewer) can be obtained from the Ambient Water Quality Monitoring Data Viewer at:

https://dataviewers.tdec.tn.gov/dataviewers/f?p=2005:34510:4148526613363.

It is also advisable to contact TDEC with any questions as to the suitability of use of existing data in an TMAT calculation, based on proximity or age of existing data.

5.4 Reach Site Characterization

Site characteristics of channel reaches are governed in part by upstream watershed characteristics due to the hierarchical nature of drainage networks (Figure 5.2). Site characteristics to be collected and used for project assessment include: drainage area (sq. mi) (above downstream reach boundary), stream order, ETW/ONRW designations, land uses adjacent to the project site, floodplain surfaces, flow Statistics (peak flow return frequencies from USGS StreamStats), water quality and biological data, 303d segment listing, NPDES permits, soil hydrological classification in floodplains, artificial hydraulic grade controls, and utilities and built infrastructure in riparian corridor. Information collected within the project reach site provides the essential data needed to identify site constraints and to assess restoration potential.

Several data sources for watershed characteristics as described in Section 5.3.3 can also provide information for reach-scale characteristics of a project site.

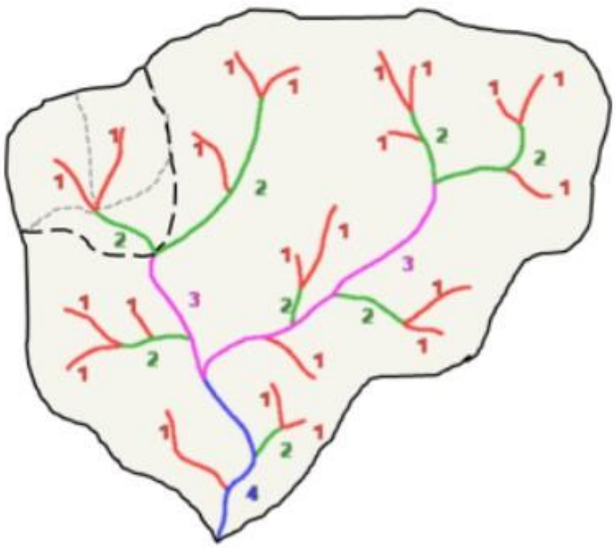


Figure 5.2. Watershed drainage network delineated by Strahler stream order (Strahler, 1957) where 1st order headwater streams shown in red, 2nd order in green, 3rd order in pink, and 4th order in blue.

Specific reach characterization information is required for the mitigation and impact permitting and entered into the TMAT worksheet and debit tool, respectively (Section 5.1). Other than the basic location data, reach characterization information includes: 1) flow type, 2) Rosgen valley and stream classifications, channel evolution model (CEM) stage, and channel slope. Determining flow type and Rosgen valley and stream classifications are described below in Section 5.4.1 and 5.4.2. Rosgen stream types rely on five parameters, two of which require bankfull measures. Field methods for determining CEM stage, channel slope and other reach-scale geomorphic features are described in Section 6.

Bankfull identification and verification, and whether bankfull indicators are appropriate for use are described in Sections 5.4.3 and 5.4.4. If bankfull indicators are present at a project site through verification procedures, bankfull channel dimensions are used for computing several TMAT metrics s as described in Section 6. Both watershed- and reach-scale characterizations are necessary for completing reach segmentation procedures for a project site. These reach segmentation procedures are described in Section 5.

5.4.1 Flow Type Classification

Flow type classification consists of whether the stream is perennial, intermittent, or ephemeral. Determine the flow type for the reach. *Perennial streams* maintain baseflow throughout the year and are often connected to groundwater as their continued source of flow. Intermittent streams are those with an episodic hydrologic connection to groundwater that sustains baseflow only seasonally (generally in the late winter and early spring). Ephemeral streams only flow for short duration in direct response to a precipitation event and are not connected to the water table. All of these stream types may be considered WOTUS and should have jurisdictional evaluations submitted to the USACE. TDEC's regulations reflect a similar distinction in flow regimes but use differing terms and hydrologic determination procedures.

Under TDEC's Rule Chapter 0400-40-17.01 a hydrologic determination is required to determine the WOTS jurisdictional status of aquatic features. Watercourses are either a "*Wet Weather Conveyance*" or a "*Stream*" where a wet weather conveyance is defined in state statute as generally analogous to that for an ephemeral stream but not identical. Note, if the watercourse is determined not to be a wet weather conveyance, then it is a stream as defined by the state statutes. Procedures for conducting a hydrological determination can be found at the following link, which includes the guidance SOP document and field data sheet: https://tnhdt.org.

Hydrologic determinations are submitted to TDEC for evaluation. Trainings and certification are required to become a qualified hydrologic professional to submit hydrologic determinations with the "presumption of correctness" to TDEC's ARAP program.

Only a subset of the standard TMAT metrics are applicable in calculating an Existing or Proposed Condition Score. The TMAT spreadsheets will automatically lock-out all metrics not used in calculating a Condition Score when "ephemeral" is chosen as the Flow Type. Only data that is applicable to ephemeral streams should be collected and entered into the field data sheet and calculation spreadsheet for such a channel.

5.4.2 Rosgen Valley and Stream Classifications

Rosgen valley types that may occur in Tennessee include: unconfined alluvial, confined alluvial, and colluvial valleys. Rosgen (1996) specifically defines these valley types and their relation to stream classifications. Valley types relevant to Tennessee are summarized in Table 5.2 with illustrations shown in Figure 5.3. Locations of the different types are highly dependent on geology, for example steep colluvial valleys will occur in mountainous regions of eastern and middle Tennessee, confined alluvial gorges may occur in the Cumberland Plateau, and unconfined alluvial will occur throughout Tennessee including western Tennessee. Middle Tennessee may have bedrock-controlled valley floors.

Rosgen stream classification is required for mitigation and permit applicants and type reported. Stream type is one reach-scale characteristic used in the reach segmentation process (Section 5.5). Stream types are based on five parameters (Figure 5.4). They are: 1) entrenchment ratio, 2) bankfull width/depth ratio, 3) sinuosity, 4) channel slope, and 5) dominant bed sediment. Using these five parameters the following stream types are classified: A+, A, B, Bc, C, D, DA, E, F, and G (Figures 5.5 and 5.6, Table 5.3). The original work describing this classification scheme was published in Rosgen (1994). More information can be found on the Wildlands Hydrology Consultants web site (https://wildlandhydrology.com/). Of the main stream types noted above, the capitalized alphabetic designations are based on entrenchment ratio, width/depth ratio, and sinuosity. A number follows these designations based on dominant bed sediment: 1 = bedrock, 2 = boulders, 3 = cobble, 4 = gravel, 5 = sand, and 6 = silt/clay (Figure 5.6). A non-capitalized alphabetic designation follows the number based on slope ranges. For example, a

C4b stream is single-thread meandering channel with a slope between 2.0-3.9% and consists of a gravel bed.

The entrenchment and the width/depth ratios require identifying bankfull indicators and estimating bankfull width and depth. Field methods for identifying bankfull indicators and verifying bankfull dimensions can be found in Section 5.4.3. It is possible that no consistent bankfull indicators are present within the site reach (Section 5.4.4). If no bankfull indicators are present, bankfull width and depth dimensions can be estimated by "active" channel measures.
Table 5.2. Rosgen (1996) valley types with summary descriptions and associated stream types.

Valley Type	**Summary Description**	**Stream Types**
Steep Colluvial	Elevational relief is high with rejuvenated side slopes, valley floor slopes are greater than 2% but generally would be above 5% with step-pool morphology. Bed substrate predominantly composed of colluvial material with some bedrock.	Aa+, A, G
Moderately-sloped Colluvial	Moderate relief and side slope gradients, relatively stable, valley floor slopes generally less than 4% with bed substrate dominantly composted of colluvium but mixed with some alluvial deposits. Channel bed with rapids and scour pools.	B, G
Confined Alluvial Gorge	Entrenched or deeply incised, and confined landforms directly observed as gorges with gentle elevation relief and valley-floor gradients often less than 2%, often meandering.	C, F
Unconfined Alluvial	Broad valleys with gentle, down-valley elevation relief consisting of floodplains with the valley floor predominantly composition of alluvium. Channel slopes less than 2% and consisting of pool-riffle morphology. May consist of single- or multi-tread channels depending on the floodplain soils, bedload supply, and slope.	C, E, F, D, DA
Unconfined Terraced Alluvial	Incised channel with a broad valley with gentle, down-valley elevation relief consisting of floodplains and terraces. Single-tread channel slopes less than 2% with pool-riffle morphology. Presence of terraces indicate geological periods of geomorphic downcutting, may be anthropogenic caused.	C, E, F, G

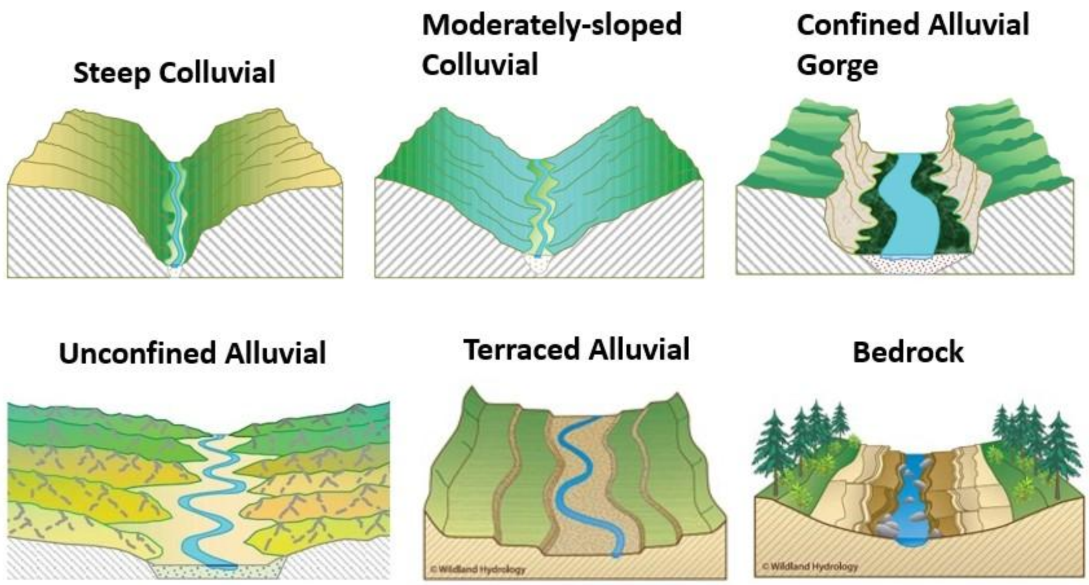


Figure 5.3. Valley type illustrations from Rosgen (1996) relevant to Tennessee watersheds.

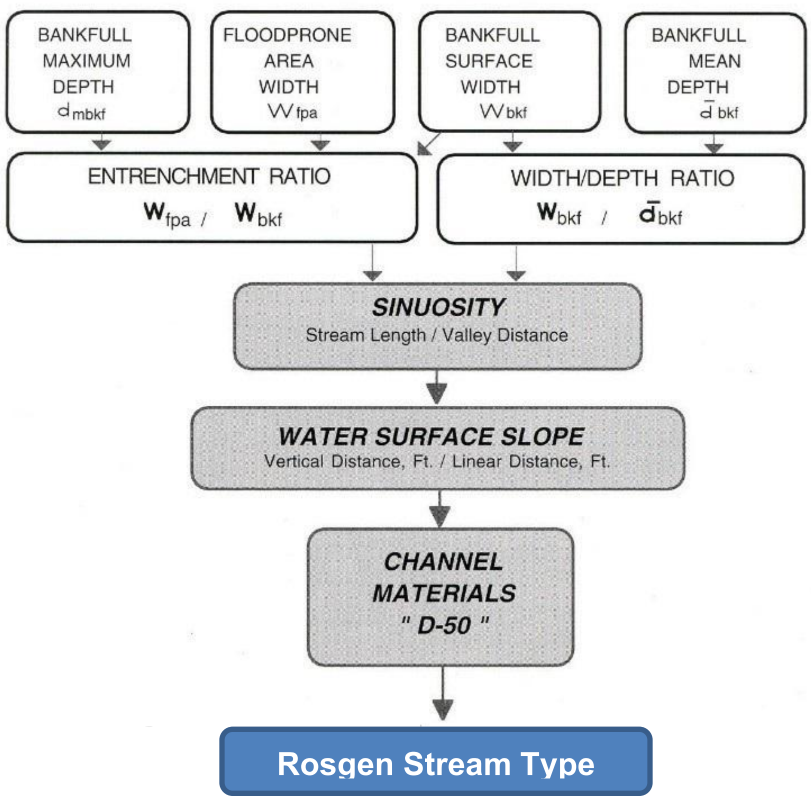


Figure 5.4. Measurement flow chart for Rosgen (1996) stream type classifications.

Active channel measures are based on the lower limit of perennial vegetation (Schumm 1960), and/or evidence of scour lines on the bank and/or from continued flood flows exposed root hairs (Rosgen 1994). Alternatively, less accurate but acceptable only for stream type determinations is use of published regional curves to obtain bankfull width and depth. TDEC provides regional curves for the state's ecoregions at:

https://www.tn.gov/content/dam/tn/environment/water/natural-resources-unit/wr_nru_tennessee-ref-stream-morphology.pdf

After a site reach has been classified with a Rosgen stream type, the result should be compared to the general type descriptions in Table 5.3 to confirm the stream type matches.

Once bankfull dimensions have been estimated from field data collection, the entrenchment ratio and width to depth ratio are calculated. Additional field measures needed include sinuosity, slope, and dominant bed substrate. Overall, the parameters are computed as follows.

1. Entrenchment Ratio is computed by dividing the flood prone width by the channel bankfull width. The flood prone width is obtained by measuring the width in the channel or onto the floodplain by taking that measurement at a height two-times the maximum bankfull depth (Figure 5.7).
2. Bankfull Width/Depth Ratio is dividing the bankfull width by the bankfull average depth.
3. Sinuosity is the ratio of channel length divided by valley length (Figure 5.8).

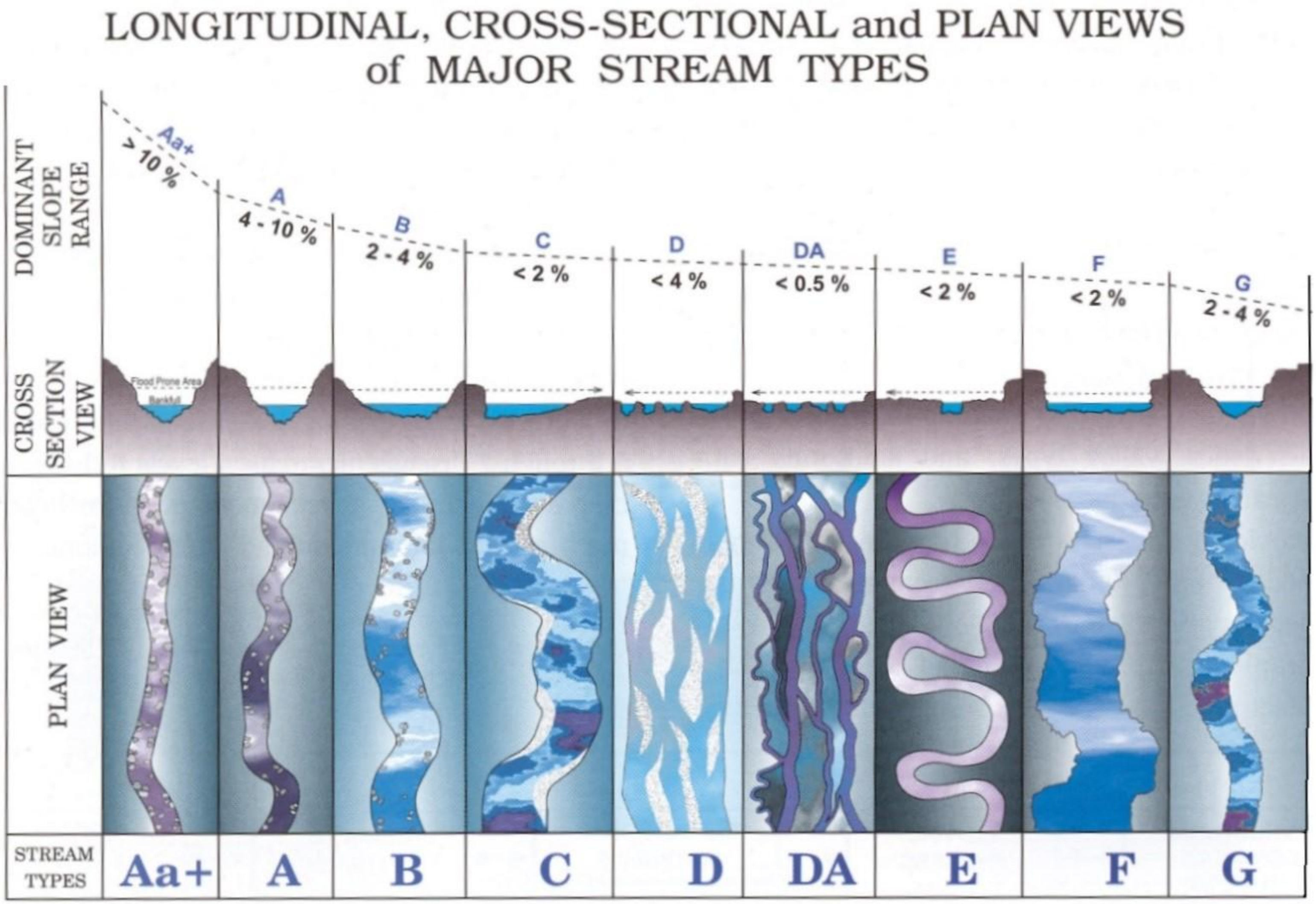


Figure 5.5. Major stream types shown by longitudinal, cross-section, and plan views per Rosgen (1996) reach-scale classification scheme.

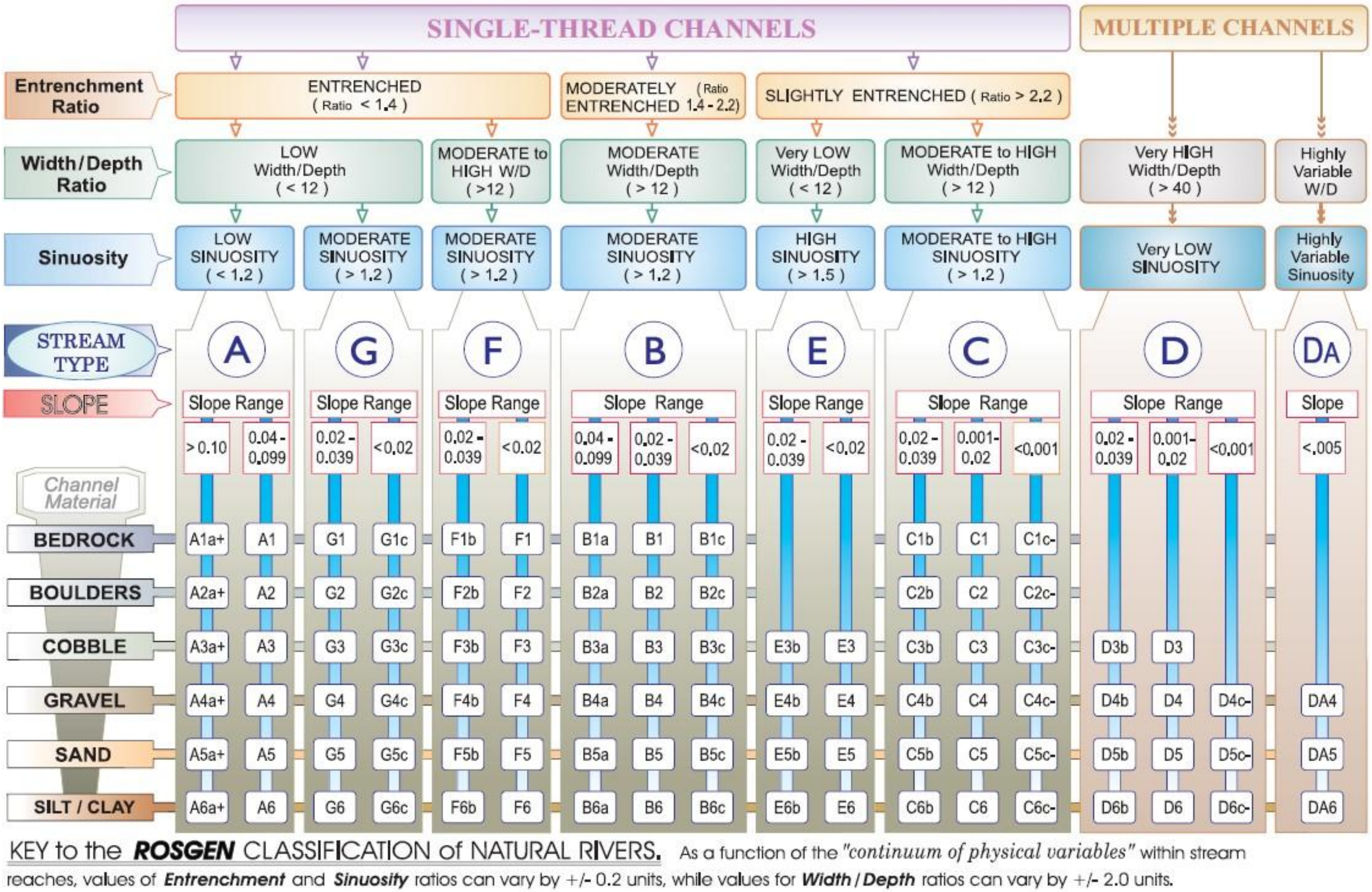


Figure 5.6. Stream classification flow-chart key for Rosgen (1996) stream type.

Table 5.3. Stream type descriptions and general delineative criteria for broad-level classification (Rosgen, 1994, 1996).

Stream Type	General Description	Entrench-ment Ratio	Width/Depth Ratio	Sinuosity	Slope	Landform Features
Aa+	Very steep, deeply entrenched, debris transport, torrent streams	< 1.4	< 12	1.0-1.1	> 10%	Very high relief. Erosional, bedrock or depositional features; debris flow potential. Deeply entrenched streams. Vertical steps with deep scour pools; waterfalls.
A	Steep, entrenched, cascading, step/pool streams. High energy/debris transport associated with depositional soils. Very stable with bedrock- or boulder bed.	< 1.4	< 12	1.0-1.2	4-10%	High relief. Erosional or depositional and bedrock forms. Entrenched and confined streams with cascading reaches. Frequently spaced, deep pools in associated step/pool bed morphology
B	Moderately entrenched, moderate gradient, riffle-dominated channel with infrequently spaced pools. Very stable plan and profile. Stable banks.	1.4-2.2	> 12	>1.2	2.0-3.9%	Moderate relief, colluvial deposition and/or structural. Moderate entrenchment and width/depth ratio. Narrow, gently sloping valleys. Rapids predominate with scour pools.
C	Low gradient, meandering, point bar, riffle/pool, alluvial channels with broad, well-defined floodplains	> 2.2	> 12	> 1.2	< 2%	Broad valleys with terraces, in association with floodplains, alluvial soils. Slightly entrenched with well-defined meandering channels. Riffle/pool bed morphology.
D	Braided channel with longitudinal and transverse bars. Very wide channel with eroding banks.	n/a	> 40	n/a	< 4%	Broad valleys with alluvium, steeper fans. Debris and depositional features. Active lateral adjustment with abundance of sediment supply. Multiple bar bed features, aggradation processes, high bedload and bank erosion.
DA	Anastomosing (multiple channels) narrow and deep with extensive, well-vegetated floodplains and associated wetlands. Very gentle relief. Very stable streambanks.	> 2.2	Highly variable	Highly variable	< 0.5%	Broad, low-gradient valleys with fine alluvium and/or lacustrine soils. Anastomosed (multiple channel) geologic control creating fine deposition with well vegetated bars that are laterally stable with broad wetland floodplains. Very low bedload, high washload sediment
E	Low gradient, meandering riffle/pool stream with low width/depth ratio and little deposition. High meander width ratio. Stable channel.	> 2.2	< 12	> 1.5	< 2%	Broad valley/meadows. Alluvial materials with floodplains. Highly sinuous with stable, well-vegetated banks. Riffle/pool morphology with very low width/depth ratios.
F	Entrenched meandering riffle/pool channel on low gradients with high width/depth ratio.	< 1.4	> 12	> 1.2	< 2%	Entrenched in highly weathered material. Gentle gradients with a high width/depth ratio. Meandering, laterally unstable with high bank erosion rates. Riffle/pool morphology.
G	Entrenched “gully” step/pool and low width/depth ratio on moderate gradients.	< 1.4	< 12	> 1.2	< 3.9%	Gullies, step/pool morphology with moderate slopes and low width/depth ratio. Narrow valleys or deeply incised in alluvial or colluvial materials; i.e., fans or deltas. Unstable with grade control problems and high bank erosion rates.

4. Channel Slope is the elevation difference between reach site boundaries divided by its channel length. A level and rod set-up, slope laser range finder, hand-held clinometer, or another device can be used to estimate slope.
5. Dominant Bed Material is obtained by visual inspection within the project reach. Other than a bedrock channel bed, the bed material is the sediment that dominates and represents that which is transported during bankfull events.

The practitioner should only characterize the channel as "Bedrock" if the bed material is dominated by exposed, solid bedrock in the bed of the stream. Bedrock may be located underneath other substrate (such as having some areas of solid bedrock bed material, but also with some riffles and pools, where the bed material is composed of cobble or other materials underlain by bedrock). In such cases, the practitioner should categorize the existing bed material based upon the bed material that is exposed in the bed of the stream; the underlying geologic layers below the stream bed are not categorized within the assessment. "Bedrock" should only be a classification when it dominates the channel to such as extent that it precludes the development and ability to characterize bed load substrate.

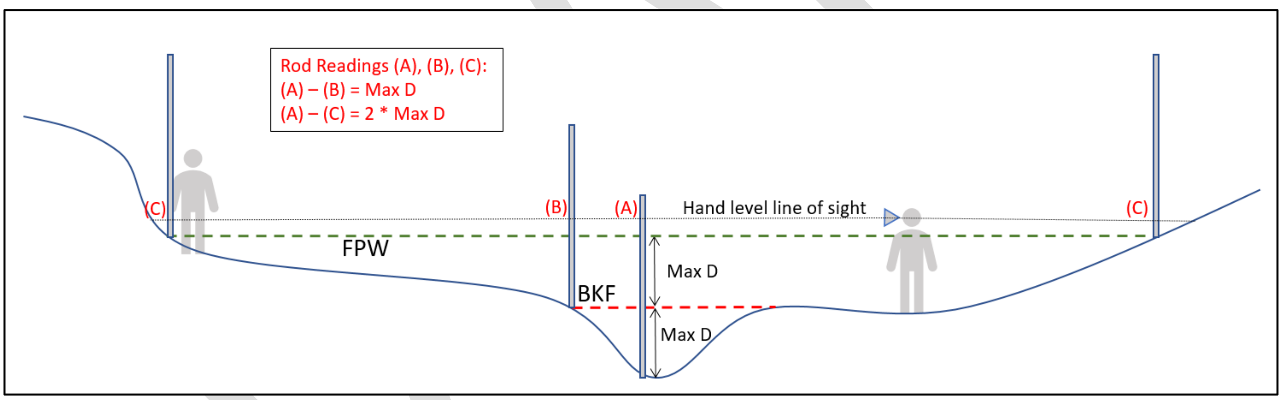


Figure 5.7. Illustration for bankfull and Entrenchment Ratio field measurements (Rosgen 2014). FPW = Flood Prone Width; BKF = Bankfull; Max D = Maximum BKF Depth

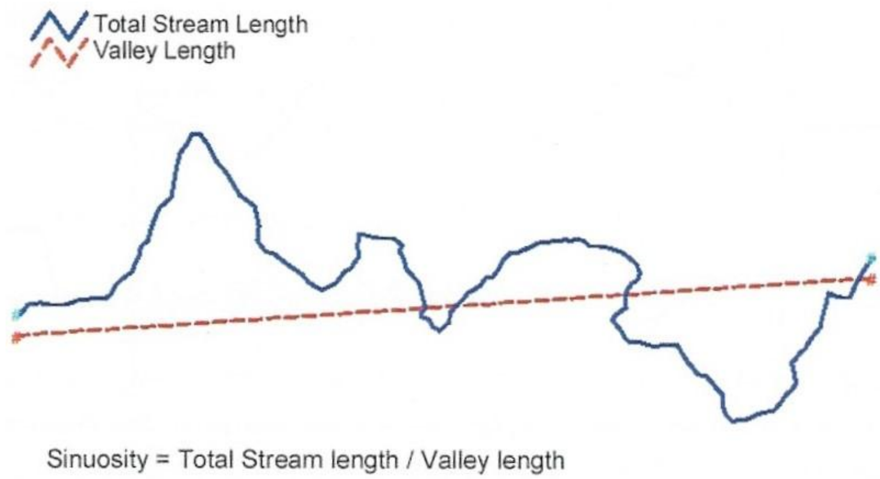


Figure 5.8. Plan-view illustration for computing channel sinuosity (FISRWG 2001).

5.4.3 Bankfull Indicator Identification and Verification

Bankfull discharge has been equated to the dominant discharge where the channel's cross-sectional area is maintained within a geomorphic dynamic equilibrium (Section 3.2.3). It represents a flood discharge with a recurrence interval (return frequency) of 1.5 to 2.0 years on average in which discharge transports the greatest amount of bedload and suspended sediment over time (Knighton 1998). Bankfull has also been referred to as the "effective discharge" or "channel forming flow", where this flow stage is sufficiently effective and sufficiently frequent to perform the greatest amount of geomorphic work maintaining channel cross-sectional shape. Most stream systems are in a continual cycle of change, termed dynamic equilibrium, but channel dimensions are maintained over the long-term, many years.

Bankfull indicators are many as summarized in the USDA Natural Resources Conservation Service (NRCS 2007), National Engineering Handbook Part 654 (Table 5.4). This table matches that in Table 3.3, as published in Soar and Thorne (2011). As can be observed over the years, ideas to what constitutes bankfull indicators for the dominant, or channel-forming flow has changed.

Table 5.4. Summary of bankfull indicators from the NRCS (2007) National Engineering Handbook, Part 654, Table 5-11 in Chapter 5 on Hydrology.

Bankfull indicator	Reference
Minimum width-to-depth ratio	Wolman (1955) Pickup and Warner (1976)
Highest elevation of channel bars	Wolman and Leopold (1957)
Elevation of middle bench in rivers with several over-flow sections	Woodyer (1968)
Minimum width-to-depth ratio plus a discontinuity (vegetative and or physical) in the channel boundary	Wolman (1955)
Elevation of upper limit of sand-sized particles in boundary sediment	Leopold and Skibitzke (1967)
Elevation of low bench	Schumm (1960); Bray (1972)
Elevation of active flood plain	Wolman and Leopold (1957) Nixon (1959)
Lower limit of perennial vegetation	Schumm (1960)
Change in vegetation (herbs, grass, shrubs)	Leopold (1994)
A combination of: • elevation associated with the highest depositional features • break in bank slope • change in bank material • small benches and other inundation features • staining on rocks • exposed root hairs	Rosgen (1994)

Rosgen (1994) relies on a combination of indicators. Every site is unique, thus no single indicator of bankfull can always give you an acceptable measurement (https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd753759.pdf). Typically, several indicators can help identify bankfull stage, and you should consider all that are present at any given site. They include:

i. Depositional Feature - Point Bars: Nearly flat top of developing point bars as the channel migrates across the valley it builds the active floodplain in its wake through the development of point bars. The top of the point bar is considered an active floodplain. Often point bars occur on the inside of meander bends, the stream will build up a bar of sediment from the eddy current created by the bend. The top of such a point bar is the minimum height of bankfull.

ii. Benches: Flat depositional benches or remnant lateral bars. May consist of a concave bank bench. On straighter sections of river will often exist as lateral bars where these bars may also represent the active floodplain. For incised channels with a developing floodplain, bankfull can be the back of a sloping bench; the bench front is the inner berm.

iii. Bank Slope Break: In stream channels with natural riparian areas and a low, flat floodplain, the bankfull edge is located at the edge of this plain and the tops of marginal deposits define the active floodplain. It is the location of inflection from steep to a gentler slope.

iv. Bank Undercuts: On the outside of meander bends, the stream will undercut the bank and expose root mats. Highest elevation of undercut bank may be a bankfull indicator.

v. Vegetation: The bankfull edge is often indicated by a demarcation line between lower areas that are either bare or only have annual vegetation and higher areas with perennial vegetation such as shrubs and trees. If using vegetation, you should also look at soils.

vi. Soils: The bankfull edge is at a transition where particle sizes change vertically up the bank, typically from cobble/gravel to sand/silt to soil. Above bankfull level, you should find old leaf litter forming into soil with organic matter.

A summary of recommended field procedures to identify and verify bankfull are as follows:

1. Look for and identify all bankfull indicators on both sides of the channel and in-channel point bars or other bar structures. Figure 5.9 provides some helpful illustration photos.
    a. If a bar structure is present, bankfull is the highest elevation on the top of the bar surface. Point bars as depositional features typically occur at “stable” riffles.
    b. Check the bank for a break between depositional processes and channel formation processes such as a slope break. Examine bank soil characteristics vertically up the bank and identifying changes in composition.
    c. For incised channels post rapid adjustment with a bench surface, bankfull is typically the back of a sloping bench. The front of the bench is typically the inner berm.
    d. Least reliable but can be used to reinforce indicators from depositional features is by examining vegetation and scour lines; typically termed the “active channel.”
    e. Oftentimes when looking for bankfull, you will find wrack lines at multiple elevations. It is important to remember that the bankfull discharge typically occurs at a 1.5-2 year return interval, which will help in determining bankfull elevations.
    f. During dry years, tree roots can be below the bankfull elevation.
    g. Scour cannot be the sole bankfull indicator

2. Move up the bank from the channel, observing all indicators identified per criteria ‘a’ through ‘d’ above. When you conclude your bankfull demarcations are reasonably accurate, mark that level with a flag or stick. Working with another person with both agreeing on demarcations will result in better accuracy.

3. Verification consists of completing a *bankfull profile survey* where bankfull indicator elevations are plotted along the longitudinal distance. A regression line is drawn through at least three bankfull demarcations to obtain a slope line and an average bankfull stage. Adjust bankfull demarcations as needed because elevations will likely vary along the profile due to local geomorphic processes. Stable riffles as defined below provide the ideal location to measure bankfull dimensions. Additional method information follows.

Lateral Point Bar (*Credit*, VNR 2004)

Slope Break Change (*Credit*, IUPUI FEH, 2023).

Deposition on Bench
(*Credits*, IUPUI FEH, Web download 2023).

Active Channel No Perennial Vegetation

Top of Point Bar (*Credits*, Michigan DNR 2020 Document)

Figure 5.9. Example illustration photos of bankfull indicators.

4. Further verification can be conducted by comparing your field demarcations plotted on ecoregion-specific regional curves. If the indicator points fall within the range of scatter of the regional curves, it provides confidence that they are reasonable. To note, if the bankfull indicator points fall outside the regional range of scatter they should not be used and non-bankfull procedures are used (Section 5.4.4). Regional curves for Tennessee ecoregions can be obtained from TDEC's web site:
5. https://www.tn.gov/content/dam/tn/environment/water/natural-resources-unit/wr_nru_tennessee-ref-stream-morphology.pdfHydrology and hydraulic (H&H) modeling to can also be used to assess the accuracy of bankfull demarcations. This verification method requires skills many practitioners may not have thus it is only mentioned here as a resource to be comprehensive. Based on a 2-year return frequency discharge (Q2) obtained from USGS StreamStats, a hydraulic model is used to generate the water surface profile. Field-based indicators should align with this water surface profile based on the Q2.

<u>Water Surface and Bankfull Profiles</u>: Detailed assessments require longitudinal profiles of thalweg, water surface or bed elevation, bankfull, and top of low bank within the stream reach using a tape and level, laser rangefinder/ hypsometer, total station, or other survey equipment. Methods for identifying the bankfull stage are described above. Those procedures are based on documents from Harman (2000), Harrelson et al. (1994), and Rosgen (2014). As described in Step 3 above, a best-fit-line is plotted through the bankfull indicator elevations versus longitudinal distance.

Although a consensus value for the difference between the bankfull (BKF)stage and water surface may be obtained from the multiple measurement points. In order to document that this critical step has been completed, the practitioner must document multiple bankfull indicators and horizontal distance to water surface elevation on the field form. Additionally, by providing this documentation it assists the agencies in expediting field reviews.

If the bankfull slope is different from the water surface slope (or channel bed elevation slope if channel is dry), and/or if the best-fit line through the bankfull points has a low correlation coefficient, the stream reach is not in geomorphic dynamic equilibrium (Rosgen 2014). If the stream is not in dynamic equilibrium, bankfull determinations may not be appropriate for use of those TMAT metrics that require bankfull dimensions (Section 5.4.4).

<u>The Stable Riffle</u>: If possible, a "moderately stable" to "stable" riffle cross section should be located within each stream reach. The primary purpose of this cross section is to assist in verifying bankfull. Prior to surveying the cross section, the practitioner should select a bankfull feature with the strongest indicators, based on multiple observations throughout the reach as field procedures are outlined above. A stable riffle meets the following criteria:

- The bankfull W/D ratio is near the low end of the range of all riffles within the reach. This represents a hydraulically efficient channel.
- Minimal signs of bank erosion.
- Bed sediment deposited across channel with bar development, and *not* local sediment deposited immediately downstream of a flow obstruction.
- Minimal headcutting .

- Cross-sectional area plots within the range of scatter of a representative regional curve.

A stable riffle cross section measurement should not be collected at a riffle that is immediately adjacent to a culvert or other in-stream structures. Geomorphology is often unstable and not representative in locations where a stream enters or exits a structure, such as a culvert or bridge.

If your completed measurements of the stable riffle cross section results in a measured bankfull area that is not close to the regional curve bankfull area, you should first review the additional procedures, tips, and solutions for determining bankfull dimensions provided in this manual. The chosen bankfull elevation may need to be reviewed, or you may need to choose a different stable riffle to complete your cross section measurements. The field data for the site should fall within the range of scatter of the regional curve in order for bankfull to be verified, and typically the cross-sectional area curve is used to make this determination. If the field data are outside the range of scatter used to develop the regional curve, the user will need to determine if the wrong indicator was selected. If the wrong indicator was selected, then the user can review the bankfull indicators identified in the reach walk to determine if the bankfull indicator at the selected riffle needs to be revised and bankfull dimensions recalculated. The user may need to choose a different stable riffle outside of, but very close to, the project reach, which has a measured bankfull area within the range of data scatter of the regional curve bankfull area. If the reach is degraded such that bankfull indicators are scarce or cannot be found, the dimensions predicted by the regional curves are used to quantify the departure of the stream from a stable condition, and is an indicator that the non-bankfull alternate metrics may be appropriate to use.

Bankfull identification in the field should be performed by professionals with a background in geomorphology and the necessary experience to accurately complete the methods described above. Any bankfull discharge modeling to support bankfull identification and used to verify indicators should be completed by professionals with a background in H&H modeling, ideally with experience with Tennessee streams.

The use of bankfull methodology is the preferred and default protocol for the TMAT and should be used wherever bankfull indicators are available and appropriate. The non-bankfull metrics should only be applied where bankfull is not available and channel conditions are appropriate for the non-bankfull protocol as described in 5.4.4 below. Any use of the non-bankfull protocol that does not clearly meet the criteria for non-bankfull in 5.4.4 must be pre-approved by the permitting agencies or the IRT.

5.4.4 Channels Conditions Limiting Bankfull Methods

Various stream conditions can occur where bankfull indicators are not evident or are not stable features within the stream corridor. These conditions are generally due to a stream that is no longer in geomorphic dynamic equilibrium due to a prior disturbance from channelization and/or land use conversion causing hydromodification (Section 3.2.3). In general, there are a number of stream conditions where identifying bankfull indicators need to be carefully assessed for use in the TMAT. They include reaches with severe alterations such as: engineered channels, straightened channels, and urban streams. These conditions may result in riffle bedforms that no longer exist or may be rapidly changing over time due to hydromodification. The USDA NRCS, National Engineering Handbook Part 654 provides a summary table when bankfull indictors are impacted by non-equilibrium geomorphic processes (Table 5.5).

Fundamentally, the non-equilibrium conditions represent a lack of balance among water discharge, sediment discharge, channel slope, and sediment particle size (Lane 1955). Rosgen (2014) identifies this non-equilibrium condition when the profile slope line of bankfull indicators

Table 5.5. Summary of stream conditions that affect bankfull indicators (NRCS 2007 National Engineering Handbook, Part 654, Table 5-11).

Reach condition	Process	Effect on bankfull indices
Threshold	Sediment transport capacity of the reach exceeds the sediment supply, but the channel grade is stable	Bankfull indices may be relics of extreme flood events, and may indicate a bankfull flow that is too high
Degrading	The sediment transport capacity of the reach exceeds the sediment supply to the reach, and the channel grade is lowering	The former flood plain is in the process of becoming a terrace. As a result, bankfull indices may indicate a flow that is too high
Aggrading	The sediment transport capacity of the reach is less than the sediment supply	The existing flood plain or in channel deposits may indicate a flow that is too low
Recently experienced a large flow event	Erosion and/or deposition may have occurred on the bed and banks	Bankfull indices may be missing or may reflect the large flow event
Channelized	Sediment transport capacity may not be in balance with sediment supply. The channel may be aggrading or degrading. The reach may be functioning as a threshold channel	Bankfull indices may be relics of previous channel, artifacts of the construction effort, embryonic, or missing altogether

is different from the water surface or channel bed elevation slope and/or if the best-fit line through the bankfull points have a low correlation coefficient.

The TMAT recognizes that bankfull indicators may be absent or not reliable indicators of a stable geomorphic channel in a reach site. Several metrics in the TMAT require bankfull dimensions. They are the Entrenchment Ratio (ETR) and Bank-Height Ratio (BHR) in the Hydraulics functional category, and Pool-to-Pool Spacing Ratio in the Geomorphology II category (Tables 2.1 and 2.2). The TMAT provides a non-bankfull alternative for these metrics (Figures 2.3). Examples of situations where use of the non-bankfull alternative metrics may be appropriate include the following conditions:

- No bankfull indicators present, and/or no stable riffles present.
- The slope difference between the water surface (or channel bed) and bankfull stage elevations along longitudinal section do no exceed 10% (Rosgen 2014).
- Channelized straightened reaches / earthen and concrete engineered channels.

· Bedrock channels with no bankfull indicators or indicators highly variable in elevations along profile.

· Bankfull indicators are only a result of a recent large flow event.

· Rapidly urbanizing watershed causing unstable, non-stationary bankfull indicators.

There are no reaches near to the survey area having a measured bankfull area within the range of scatter of the regional curve bankfull area.

· Other non-equilibrium channel conditions, scientifically justified.

Any use of the non-bankfull metrics that do not meet the above criteria must be pre-approved by the permitting agencies or IRT. It is recommended that the permitting agencies be consulted in any situation where the use of the non-bankfull metrics are being considered.

Barring unusual circumstances, pre- and post-assessments will have to be conducted using the same methodology. The choice of bankfull vs non-bankfull protocols must be made based upon the criteria listed in this section and the preceding one. Practitioners may not choose between them based on the amount of lift produced.

5.5 Reach Segmentation

5.5.1 Reach Segmentation for Debit vs. Credit Calculations

Stream reaches to be assessed for debits or mitigation credits can vary substantially in channel length. Procedures for reach segmentation differs whether the site length is “short”, typical for debit calculations, versus a site length that is “long”. Reach length as “short” versus “long” is somewhat arbitrary. An example for a debit calculation of a “short” reach would be an impact to a stream from installation of a road culvert. Projects requiring debit calculations from an unavoidable impact on “short” reaches are generally less than 15-20 times the bankfull or active channel width. As described in Section 5.4.2, the active channel width is defined as the cross-sectional distance traversing the channel generally observed by the lower limit of perennial vegetation on the bank and/or evidence of scour from frequent flood events (Table 5.4). In cases where the impacted site reach is designated as a “short” length, reach segmentation is simply determined by the upstream and downstream boundaries of the impacted stream length. Data collection for the TMAT may extend upstream or downstream of the impact to quantify functional capacity.

Large projects with “long” reaches, either for debits or mitigation credits may require multiple delineated project reaches where site conditions do not exhibit consistent functional attributes. Long project reaches typically will be greater than 15-20 times the bankfull or active channel width. Reach site characteristics described in Section 5.4 provides supporting information to delineate the reach upstream and downstream boundaries so that a unique ECS can be generated with the use of the TMAT. Large projects in thousands of linear feet most likely will have multiple site reaches for which ECS are generated with the use of the TMAT. Large projects may include both main-stem channels and tributaries. Some headwater projects can encompass all or many stream channels within a catchment.

If the practitioner is unable to collect complete or representative data for various metrics due to access restrictions or other site constraints, they may choose to either complete the measurements during more favorable field or access conditions, or in the case of calculating ECS for debit considerations, may utilize the default value for these metrics. (See Section 4.2.3 *Existing Condition Score Options*)

5.5.2 Procedures for Reach Segmentation

Reach segmentation is accomplished by an initial review of desktop data followed by a stream walk, and observation of any changes in functional conditions (Section 5.1.3). Basic information and data collection sources for watershed and reach scales can be found in Sections 5.3 and 5.4. From a desktop analysis using USGS topoView, Google Earth Pro, *Model My Watershed®*, and FEMA maps, compile these four characteristics at the proposed project site:

1) stream order;
2) hydraulic grade controls at road crossings with bridges or culverts, or other;
3) presence of a floodplain; and
4) riparian corridor and adjacent land cover/land uses.

Stream order methodology is defined by Strahler (1964) as a numeric number to indicate stream size within a hierarchically-organized drainage network watershed, where 1st order is a headwater stream and consecutively larger order numbers increase in stream size (Figure 5.2). Stream order generally corresponds with stream power (a function of dominant discharge and channel slope). Model My Watershed® can generate this information.

Hydraulic grade controls are bed structures that prevent vertical downcutting of the channel, and arrest upstream migrating headcuts. They can be both artificial or natural features. Artificial hydraulic grade controls commonly are road crossings and culverts but may include low head dams, buried utility pipelines, and concrete/rip-rap rock used to protect the channel bed from erosion. Natural hydraulic grade controls are bedrock channel beds that are resistant to vertical downcutting, which include cascades and waterfalls. Hydraulic grade controls should be ground-truthed during a stream walk as functioning as a hydraulic grade control. The distance between the controls determines channel vulnerability to channel incision (Simon and Darby 2002).

Floodplains occur in larger streams typically above 2nd order with a slope less than 2% where alluvial sediment can be deposited forming floodplain surfaces (Section 3.4.3). However, valley-constrained canyon reaches can occur in higher-order streams with steeper slopes not lending to floodplain development (Figure 5.3). Floodplain width is examined using FEMA maps, USGS topoView and/or Google Earth visually inspecting for horizontal riparian surfaces between valley walls varying along the stream corridor. This floodplain measure is associated with the floodplain connectivity metrics in the Hydrology and Hydraulic categories (Table 2.1, Figure 2.3).

Riparian cover and adjacent land cover/land uses largely influence the functional metrics in the

Geomorphology II category associated with recruitment of large woody debris (LWD) and riparian vegetation quality (Table 2.1, Figure 2.3). A desktop analysis providing preliminary information on forested riparian width and canopy cover can be accomplished by a visual inspection using Google Earth. However, site riparian condition metrics need to be investigated through a stream walk and field measured on-site.

After review of the compiled desktop information, a stream walk is used to determine flow type (ephemeral, intermittent, and perennial), and any changes in flow type. A stream walk can result in observations of substantial changes in riparian corridor characteristics, channel slope, Rosgen stream type, and bankfull indicators. Rosgen stream types relate to planform types as: straight (A), meandering (B, C, E), braided (D), and anastomosed (DA). As shown in Figures 5.4-5.6, Rosgen stream types are classified for multiple geomorphic forms based on entrenchment ratio, width/depth ratio, sinuosity, slope, and bed substrate. Methods to obtain the parameters needed to determine Rosgen stream type are described in Section 5.4.2. For the project scoping phase, reach-scale channel slope can be roughly estimated by a desktop procedure using USGS topoView or available GIS digital elevation model (DEM) identifying contour line elevations crossing the stream channel, and measuring the distance along the longitudinal profile between two points with elevations. Slope is computed by the elevation difference divided by the stream length. Field measurement of channel slope is recommended during the stream walk.

As noted above in Section 5.5.1, large projects may have multiple streams and/or multiple stream reaches with different functional conditions. The reach segmentation procedure identifies whether there are multiple reaches along the stream based on differences in riparian corridor and stream physical characteristics. Each site reach delineated by upstream and downstream boundaries within a project area is evaluated separately in the TN Debit Tool and TMAT. An example segmentation is as follows.

> The main-stem stream channel is broken into five site reaches, two unnamed tributaries broken into two reaches each, and the remaining two unnamed tributaries as individual reaches (Figure 5.10, Table 5.6). This project has a total of eleven streams, therefore the project requires eleven field data sheets and TMAT worksheets.

Delineating project reach upstream and downstream boundaries is accomplished so to accurately complete reach segmentation where delineated reaches have consistent functional conditions. Professional judgement is applied during the reach segmentation process requiring knowledge of watershed science fundamentals and the TMAT metrics. A practitioner is required to provide justification for the final reach breaks in their permit application.

General guidelines for reach segmentation are summarized below considering the riparian corridor and stream physical characteristics.

- Identify a reach's <u>stream order and transition tributary junctions</u> including tributary junctions not increasing the downstream reach to higher order, e.g., a 2nd order stream enters a 3rd order stream. Greater significance is given to tributary junction where downstream order is increased because these locations are where drainage area and stream power increase, e.g., two 2nd order streams merge to form a 3rd order stream (Figure 5.2).

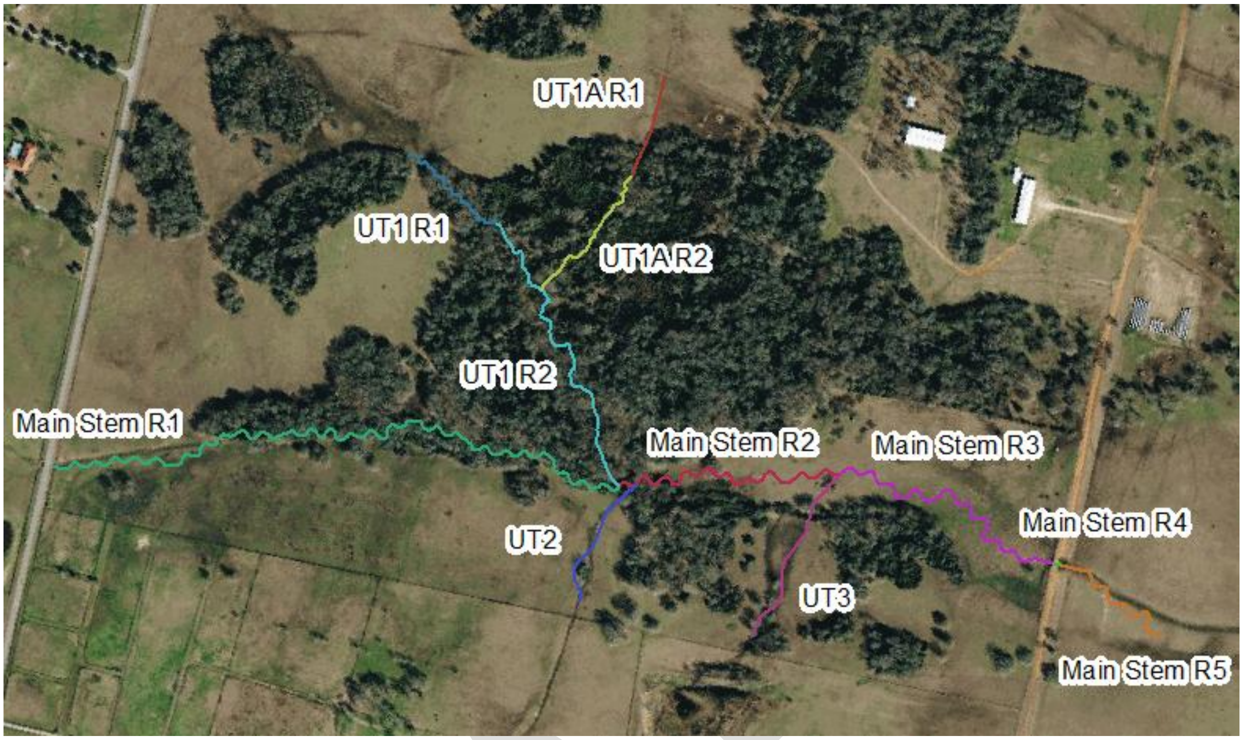


Figure 5.10. Example of reach segmentation from noted below in Table 5.6 (TDEC 2018).

Table 5.6. Description of reaches identified in the Figure 5.12 example of reach segmentation.

Reach	Reach Break Description
Main Stem R1	Beginning of stream to UT1 confluence where drainage area increases by 25%.
Main Stem R2	To UT3 confluence where there is a change in slope.
Main Stem R3	To a perched culvert that is ponding water in reach 3. Bed material is finer and bedform diversity is impaired as a result of the culvert.
Main Stem R4	40 feet through the culvert.
Main Stem R5	From culvert to end of stream.
UT1 R1	Property boundary to the last of a series of headcuts caused by diffuse drainage off the surrounding agricultural fields.
UT1 R2	To confluence with Main Stem. Restoration approach differs between UT1 R1 where restoration is proposed to address headcuts and this reach where enhancement is proposed.
UT1A R1	Property boundary to edge of riparian vegetation. Reach is more impaired than UT1A R2, restoration is proposed.
UT1A R2	To confluence with UT1. Enhancement is proposed.
UT2 & UT3	Beginning of stream to confluences with mainstem. Reaches are actively downcutting and supplying sediment to the mainstem.

· Segments need to have approximately similar stream power values (dominant discharge times channel slope) at the upstream and downstream points. In urban streams, a major stormwater outfall (pipe > 3 ft diameter) should be considered as a reach break location due to the potential increase in stream power.

· Tributaries are not included in main stem surveys.

· Hydraulic grade controls both natural and artificial controls need to be identified as reach boundaries, i.e., bedrock channel beds and road crossing bridges and culverts, respectively. Major flow barriers such as low-head dams and some utility pipeline crossings form significant obstacles and convenient reach boundary break points. Stable riffles should be for used for reach boundaries, and if available multiple stable riffles are to be included within the project reach for use in the TMAT.

· Changes in Rosgen stream type constitutes separate reaches. Rosgen stream classifications recognize the physical form characteristics of entrenchment ratio channel slope, sinuosity, width/depth ratio, and dominant bed materials (Section 5.4.2). Any changes of the individual parameters may also be used to delineate project site reach boundaries.

Changes in bankfull cross-sectional area, which is defined as bankfull width divided by mean depth at bankfull. Some tributaries do not demonstrably influence changes in channel morphology in the receiving streams. If there is a notable and consistent change in the cross-sectional bankfull area due to the influence of a tributary, a reach break is required.

· Floodplain surface areas and their width are to be inspected along the project reach and substantial changes in floodplain width are used to delineate reach boundaries. Inspection of floodplain width, also referred to as the valley floor width is accomplished by desktop inspection of topographic maps and/or aerial images, and field reconnaissance. The absence of floodplains may represent locations in headwaters and constrained alluvial valley or canyon reaches (Figure 5.3). A valley floor width greater than or less than two times the active channel width constitutes a transition point where floodplains with greater surface area have more potential for infiltration and wetlands development.

· Changes in riparian corridor vegetation from land use differences should be considered for delineation of project site reach boundaries. For example, a change in forested land cover to an urbanized land such as a subdivision, or to active agriculture use. Reach boundaries may be based on channel constraints such as roads and buildings adjacent to streams.

· Changes to mitigation approach based on site conditions should require a reach break. This typically occurs where channel form, impacts, or land practices change, e.g., restoration versus enhancement, or Rosgen Priority 1 versus Priority 3 (Rosgen 1997).

5.5.3 Difference between Project Site Reach and Assessment Reach.

Each *project reach* will be assessed to obtain a total ECS for the project site as a whole using the TMAT metrics within the functional categories and parameters. Some metrics in the TMAT are computed based on assessed characteristics for the entire delineated project reach. Whereas some metrics are evaluated for a representative “sub-reach” within the project site reach, termed the *assessment reach*. In the TMAT metrics where desktop procedures are applied, the entire project reach will be used to compute an ECS/PCS for each designated reach. Some field-based metrics require the application of an assessment reach because the measurement protocols for such metrics typically specify a length of 15-20 active channel unit (bankfull) widths. Whether a full *project reach* or an *assessment reach* is used for TMAT metric computations by functional parameters is defined in Table 5.7.

The assessment reach must consistently contain the key functional conditions as used to delineate the project reach. The assessment reach should begin and end at a riffle, if possible, but must be a location that is not subject to vertical channel down-cutting. Project reaches less than or equal to approximately 20 channel unit widths (active or bankfull) are equivalent to the assessment reach.

Table 5.7. Guidance on use of project site vs assessment reaches for TMAT parameters.

Functional Category	**Functional Parameters**	**Reach Length and Boundaries Determination**
Hydrology	Catchment Hydrology- Watershed Land Use Runoff, Reach Runoff/Stormwater Infiltration, Floodplain Storage Infiltration Potential	Full Project Reach
Hydraulics	Entrenchment Ration, Bank Height Ratio	Assessment Reach, approx. 20 channel unit widths
	Channel Incision; Floodplain Inundation Frequency	Assessment Reach, approx. 20 channel unit widths
Geomorphology I	Large Woody Debris, Riparian Width	Assessment Reach
	Riparian Canopy Cover	Assessment Reach - three locations within the reach
	Average DBH, % Invasive Species	Assessment Reach - Vegetation Plots in Riparian Corridor, left/right banks in the reach
Geomorphology II	% Streambank Erosion, Rapid Geomorphic Assessment, % Riffle, Pool Spacing Ratio, Pool Depth Ratio	Assessment Reach, approximately 20 channel unit widths
	% Streambank Armoring	Full Project Reach
	Wolman Pebble Count	Assessment Reach, approx. 20 channel unit widths
Biology / Water Quality	Tennessee Macroinvertebrate Index (TMI), and TMI sub-indices; NO_2^-/NO_3^-; TP; *E. coli*	Single location in a project reach best representing stream biota, or other data justified

5.5 Preparation for Field Data Collection

This section provides some basic information and guidance on field work preparation to complete stream walks for assessing project restoration potential, and to collect on-site field data needed for TMAT metrics. It includes field gear preparation, field datasheet familiarization and site map preparation, and field safety.

5.5.1 Field Gear Preparation

A recommended list of field gear and supplies are summarized in Table 5.8. It covers basic field gear needed to measure TMAT metrics. Waders or mud boots are needed depending on the stream size. A backpack to carry and organize gear is needed. All equipment requiring batteries need checking and/or replacement prior to a site's visit. Similarly, accomplish electronic equipment calibrations in accordance with the manufacturer's recommendations. Safety equipment/supplies are to be included (Section 5.5.3).

Table 5.8. Recommended field gear and supplies for TMAT field data collection.

Required	Optional
Survey Gear: automatic level & rod; total station; or rangefinder/hypsometer	Clinometer
Fiberglass measurement tapes (300- and 100-feet lengths)	Calculator
Camera	Compass
Clip board, site maps and field data sheets; pencils/pens; note pad	Machete, vegetation clipper
Flagging tape; marking pin flags; sharpie	Bug repellant
GPS Unit	Rain gear
Densiometer	Flashlight; batteries
DBH (diameter at breast height) tape	Drinking water bottle
Macroinvertebrate collection gear, D-net, bottles with preservative.	Water collection bottle (with preservation if required, sterilized for *E. coli* samples)
First aid kit	Chaining pins or stakes
Metric Ruler	

5.5.2 Field Datasheet Familiarization and Site Map Preparation

Field Datasheet Familiarization. The field datasheet and the TMAT worksheet should be reviewed in full by all practitioners prior to beginning the survey effort. A thorough understanding of field protocols and familiarity with the assessment parameters/metrics are critical to computing an index score.

Field Assessment Datasheets. The field datasheet is described in Section 7.1, and a copy provided in the Appendix. If using paper datasheets in the field, they should be printed on waterproof paper. Pre-programmed datasheets can also be loaded onto a hand-held device with maps for data entry. Initial header data, such as stream name, stream reach identification, date, time and crew member names, are completed upon arrival to the survey reach (Section 5.1). Site photos with reach identification, date, time, and GPS coordinates are collected along stream walks. In addition to routine photos, photos of any specific points of concern should also be taken with notes added to the datasheets.

Map Preparation. Maps of the project reaches and vicinity are needed for successful field data collection. Maps may consist of paper printouts through available local GIS databases, or the use of internet for on-line maps obtained from Google Earth, USGS topoView, TDEC Data Viewer, Google Maps, or other. Hand-held devices with GPS capability and predetermined site locations for collecting visual data can also be used. Maps should include a scale bar, north arrow, walking pathways, streams, and landmarks such as buildings, powerlines, parking lots, etc.

5.5.3 Field Survey Safety

Safety precautions are required during all field activities described in this document. Field survey crews should consist of two or more individuals for safety (Table 5.8). Common stream survey hazards include trips/falls, extreme temperatures, inclement weather, high velocities or flows, exposure to snakes, poison ivy, stinging insects, water-borne pathogens, etc. Safety protocols need to be implemented including the team to have a first aid kit, drinking water, safety vests if near a roadway, sunscreen and insect repellent, and other supplies as deemed necessary for safe field operations. Appropriate personal protection equipment may be required while conducting field work as well as a familiarity with basic first aid techniques. Private property access requires obtaining landowner permission, which should be completed prior to the stream survey and data collection.

6. TMAT Metrics: Data Collection Procedures

Metric data collection for the TMAT parameters utilizes both desktop and field assessment procedures, which are summarized in Table 2.1. TMAT metrics for the Hydrology functional category require only desktop procedures described in Section 6.1. Within the Hydraulics functional category, bankfull metrics are field-based assessment methods whereas the non-bankfull alternative require desktop and field data to complete the computations, which are described in Section 6.2. Metrics within the Geomorphology I and II functional categories and the Water Quality/Biology functional category require field assessment procedures and are fully described in Sections 6.3 through 6.5.

6.1 Hydrology Functional Category Parameters and Metrics

The parameters and allied metrics included in the Hydrology functional category are the Catchment Hydrology/Watershed Land Use Runoff, Reach Runoff/Stormwater Infiltration, and Floodplain Storage/Infiltration Potential (Table 2.1, Figure 2.3). These functional attributes reflect overall modifications to hydrology from land use conversion upstream of a project reach, and site reach conditions related to ground infiltration of surface water on floodplains along the stream corridor (Table 2.2). Benefits of enhancing infiltration on floodplains are to protect physical, chemical and biological functions, where these functions contribute to flood attenuation, filtering of runoff pollutants, maintaining baseflows during dry periods, and protecting/ enhancing riparian ecosystems. These metrics can measure improvements through land conservation, wetlands and side-channels enhancement on the floodplain, best management practices (BMPs) for enhanced floodplain infiltration, and installation of stormwater control measures (SCMs) for volume reduction through infiltration.

6.1.1 Catchment Hydrology: Watershed Land Use Runoff Metric

The Watershed Land Use Runoff (LUR) metric in the Catchment Hydrology parameter is a measure of land use composition upstream of an assessment or restoration project reach that governs runoff volumes and other hydrologic processes. It assesses watershed-scale impacts from land use/cover conversions potentially causing hydromodification which can result in increased runoff, reduced infiltration, and reduced stream baseflows. Compared to natural streams, stormwater runoff in urban catchments typically have higher peak stream flows and shorter flood flow durations. In general, greater peak and storm flow volumes can lead to stream channel erosion impacting habitat. Runoff from urban catchments and other intensively-used lands, i.e., agriculture, timber harvest, etc. may result in increased runoff pollutants. The dominant pollutant is fine sediment causing siltation and habitat alteration. Overall, land use conversion from a natural landscape cover can degrade the aquatic health of a stream. Therefore, the composition of the catchment land use upstream of a project site can have a direct effect on the site's functional condition.

Restoration projects that can affect large portions of a catchment and its hydrology may achieve functional lift. For example, lift for this metric may consist of purchasing areas of the catchment or the entire catchment and converting the land use from cultivated crops to wetlands, or pastureland to forest. It can represent a conservation approach to restoration. This mitigation approach is more likely suitable for smaller-sized headwater catchments.

The Watershed LUR metric consists of an index score based on a composite curve number (CN) used for the USDA Natural Resource Conservation Service (NRCS) rainfall-runoff methodology (NRCS 2021), adopted from TR-55 (NRCS 1986). Runoff after a precipitation event is a function of several hydrological processes, which includes the ability for a soil to infiltrate rainfall and the influence of vegetation to intercept, evaporate and transpire rainfall. The more impervious the land surface the greater the runoff enumerated by a higher CN. Vegetation attenuates the potential for runoff thus vegetated land surfaces are enumerated by a lower CN. The full range for CNs is 0 to 100, with 100 representing runoff volumes where the precipitation volume of a storm event is all converted to runoff, essentially 100% of a storm event rainfall volume equaling that of runoff volume. A paved parking lot has a CN of 98, where a very small volume leaves as evaporation thus the CN is not 100. The Watershed LUR metric applies CNs for eleven (11) land use types (Table 6.1). These land use/cover types and their percentages within a delineated watershed can be obtained from *Model My Watershed*® program.

The CNs for the land use/cover in Table 6.1 are based on the NRCS (2021) listed values corresponding to one hydrological soil group, Hydrological Soil Group B. Group B was selected because soils outside of the riparian corridor generally correspond to other hydrologic soil groups. In general, riparian land cover is proportionally smaller than non-riparian cover in a watershed. Hydrological soil group B, which is characterized by intermediate infiltration rates when wetted and is associated with moderately to well drained soils, was selected as a representative soil instead of A, which exhibits high infiltration rates when wetted and well to excessively drained soils (NRCS 2007). To simplify land cover descriptions, the CN corresponding to “good condition” (or average of CNs when applicable), were assigned for the simplified land use descriptions.

Table 6.1. Curve numbers (CN) for the catchment land use/cover types used in the TMAT.

Land Use	**Land Use CN**
Forest: Deciduous Evergreen, Mixed	45
Woody, Emergent Herbaceous Wetlands	30
Grassland/Herbaceous, Pasture/Hay	68
Shrub/Scrub	60
Open Water	0
Cultivated Crops	75
Barren Land (Rock/Sand/Clay)	88
Developed Open space	70
Developed, Low Intensity	65
Developed, Medium Intensity	75
Developed, High Intensity	95

In situations with an upstream catchment area that is rapidly developing which are not yet shown on available aerial imagery, users have the option to utilize the most currently available aerial imagery, and to the extent possible, account for the existing new impervious surface at the time you are establishing an ECS. This can be done from determining the amounts of new impervious surface from design plans or georeferenced field data. This would provide the most up-to-date accounting for developing the Watershed LUR Score. You should not develop the score with what could potentially occur in the future. This option is only to be used on a case-by-case basis and is more appropriate for significant categorical shifts in land use (e.g. from farmland to impervious surfaces).

The basic procedure to compute the Watershed LUR metric is as follows:

1. Delineate the watershed upstream of the project reach and summarize the land use types within the watershed. Land use types from applying the NLDC data source are easily obtained from *Model My Watershed*®. Other software programs can be used to obtain a summary of land use types within the watershed, but the user needs to specify what program was used if not *Model My Watershed*®.
2. Calculate the total upstream drainage area and the areas for each land use. Compute the percent area for each land use type and enter percentages into the datasheet. If using *Model My Watershed*®, these areas and percentage areas are compiled by the program.
3. Match each land use type with the CNs listed in Table 6.1 and enter CNs into the datasheet.
4. For each land use type, multiply the CN by its percent drainage area, and sum the products. The product sum is the composite CN, which is the index score for this metric.

The following desktop steps are for using *Model My Watershed*® should be followed to obtain data for the watershed land use score.

1. Access the *Model My Watershed*® website at: https://modelmywatershed.org/. Map appears on the right side of the web page, and program utilities are on the left.
2. Click "Get Started" to the Select Area web page; and "Delineate watershed" to access a dropdown menu and select "Continental US from NHDplus v2" and then zoom into displayed map locating the general area near the project reach.
3. Zoom into the watershed area and place the *marker* at the most upstream point on the stream for the project reach to delineate watershed boundaries and analyze data. Note, a latitude and longitude can be entered in the upper right to help pinpoint a site location.
4. A successful delineation will display the watershed boundary and data.
5. If a delineation is unsuccessful because the drainage area is too small, you will need to use the "Draw area" function and "Free draw" the drainage area upstream of the project reach to delineate the watershed and analyze that area for land use/cover data.
6. Once a watershed has been delineated, the data menu at the top of the page will show "Streams" which summaries the stream length by stream order. Click on "Land" and the land use/cover data will appear as a chart and a table.
7. Compile the land use/cover data, either as area (km^2) or coverage (% drainage area) per land use classes. To obtain the eleven-land use/cover types used for the TMAT, three forest categories (deciduous, evergreen, and mixed) are summed for a single forest land

cover type, two wetlands (woody and emergent herbaceous) are summed, and grassland/ herbaceous and pasture/hay are combined.

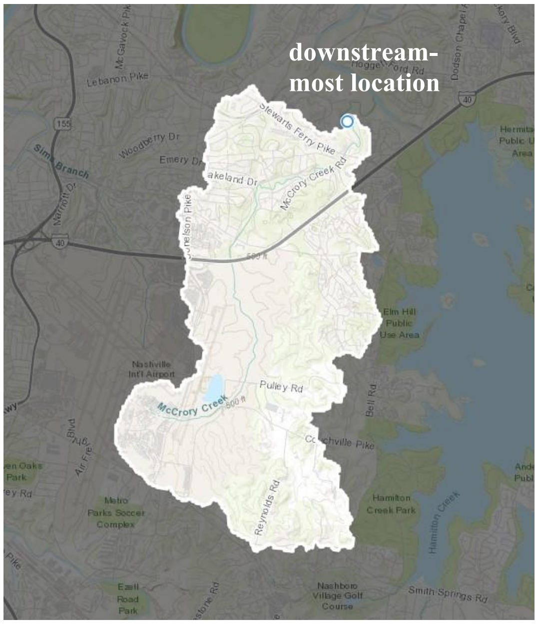
8. With the compile data follow instructions above to compute the watershed LUR score.

An example for computing the index score for the watershed land use runoff metric is demonstrated below using the *Model My Watershed*® website. McCrory Creek in Nashville is used for this example and output from *Model My Watershed*® is shown in Figure 6.1. The example datasheet is summarized in Table 6.2. Figure 6.1 shows a delineated map of the drainage area (upper left plot), a bar chart of land use percentages (lower left plot), and a summary table of land use areas (right-side plot). In this example the total area above a project site on McCrory Creek is 22.23 km^2. The three forest land cover types (deciduous, evergreen, and mixed) are summed into a % area for a single forest category. Likewise, the two categories for grassland/herbaceous and pasture/hay are summed; and the two wetland land cover types (woody and emergent herbaceous) are summed total for a single % drainage area.

Output for the McCrory Creek watershed upstream of the proposed restoration project site is shown in Table 6.2. Table 6.2 is the same table as required to be completed in the datasheet. The forest category is summed as 31.45% per deciduous, evergreen, and mixed forest types as 17.78%, 3.95%, and 9.72%, respectively. Grassland/herbaceous consisted of 0.89% and pasture/hay of 7.84% summed to 8.73%. Woody and emergent herbaceous wetlands of 0.06% and 0.03%, respectively, were summed as 0.09%. In Table 6.2, summarize the % areas for the watershed, which will be 100% if correctly entered. This summation should always be computed as a data entry check. For each land use/land cover the multiplied CN times % drainage area is entered in the right column. The product of these values for each land

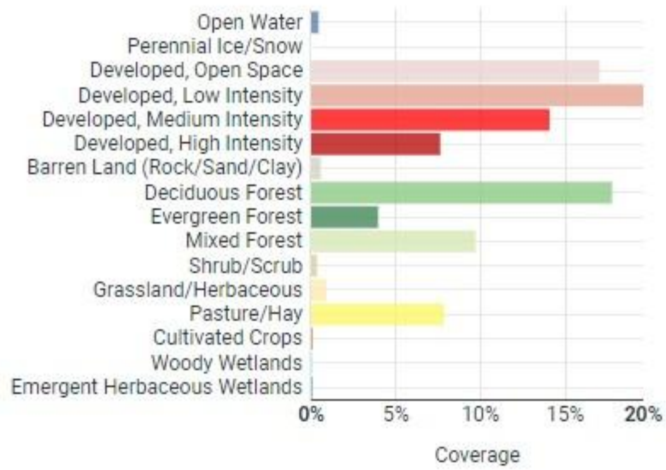
Table 6.2. Example computation for the watershed land use runoff score for McCrory Creek site at Nashville, Tennessee.

Land Use / Land Cover Type	**% Land Area**	**Land Use CN**	**% Land Area x CN**
Forest: Deciduous, Evergreen, Mixed	31.45	45	1,415.25
Woody, Emergent Herbaceous Wetlands	0.09	30	2.70
Grassland/Herbaceous, Pasture/Hay	8.73	68	593.64
Shrub/Scrub	0.34	60	20.40
Open Water	0.43	0	0.0
Cultivated Crops	0.0	75	0.0
Barren Land (Rock/Sand/Clay)	0.57	88	50.16
Developed Open space	17.05	70	1,193.50
Developed, Low Intensity	19.63	65	1,275.95
Developed, Medium Intensity	14.09	75	1,056.75
Developed, High Intensity	7.62	95	723.90
Composite Curve Number: (*Sum product of % Land Area x CN & divide by100)*			**63.1**



Delineated watershed area with downstream-most location of proposed project site shown at the top of the figure.

Land Use/Cover 2019 (NLCD19)
Related Layer: Land Use/Cover 2019 (NLCD19) ✔ Turn on
Source: National Land Cover Database (NLCD 2019)



Type	Area (km²)	Coverage (%)	River Area (km²)
Open Water	0.10	0.43	No Data
Perennial Ice/Snow	0.00	0.00	No Data
Developed, Open Space	3.79	17.05	No Data
Developed, Low Intensity	4.36	19.63	No Data
Developed, Medium Intensity	3.13	14.09	No Data
Developed, High Intensity	1.69	7.62	No Data
Barren Land (Rock/Sand/Clay)	0.13	0.57	No Data
Deciduous Forest	3.95	17.78	No Data
Evergreen Forest	0.88	3.95	No Data
Mixed Forest	2.16	9.72	No Data
Shrub/Scrub	0.08	0.34	No Data
Grassland/Herbaceous	0.20	0.89	No Data
Pasture/Hay	1.74	7.84	No Data
Cultivated Crops	0.00	0.00	No Data
Woody Wetlands	0.01	0.06	No Data
Emergent Herbaceous Wetlands	0.01	0.03	No Data
Total	**22.23**	**100.00**	**No Data**

Figure 6.1. Example of delineated watershed and land use data output from *Model My Water*shed® for a McCrory Creek site at Ben West Sports Complex, Nashville.

use/land cover type are summed, which equaled 6,311.83 for McCrory Creek. Dividing this product value by 100 and rounding to a tenth, the CN and watershed land use runoff score for the McCrory Creek is 63.1 (Table 6.2).

6.1.2 Reach Runoff: Stormwater Infiltration Metric

Infiltration of relatively small and frequent rainfall events on the landscape supports stream function by sustaining baseflow, replenishing soil moisture, and removing stormwater pollutants. The Reach Runoff/Stormwater Infiltration metric applies a measurement method that quantifies hydrologic infiltration and the amount of stormwater runoff treated by chosen Best Management Practices (BMPs) or Stormwater Control Measures (SCMs). BMPs are permanent practices and measures designed to reduce the discharge of pollutants from stormwater runoff in agricultural settings and SCMs are permanent practices and measures used in new development or redevelopment projects. These measures are integral to maintaining and improving the physical, chemical, and biological properties of water resources. BMPs and SCMs provide ecosystem services and resource values as they filter, settle, and eliminate pollutants; prevent the entry of pollutants into downstream waters; assist in flood prevention; provide habitat; and recharge stream baseflows and groundwater, ensuring both the quality and quantity of drinking water. TDEC provides design guidance for stormwater control measures in state's stormwater rules and NPDES MS4 permits at the link shown below. The Tennessee Permanent Stormwater Management and Design Guidance Manual (UTK/TDEC 2014) serves as an additional resource for designing SCMs on a project site. Municipal Separate Stormwater Sewer Systems (MS4) programs in the state also provide SCM design criteria. The TDEC reference is as follows.

> https://www.tn.gov/environment/permit-permits/water-permits1/npdes-permits1/npdes-stormwater-permitting-program/npdes-municipal-separate-storm-sewer-system--ms4--program.html

In order to calculate the ECS and PCS for the reach runoff/stormwater infiltration metric for the TMAT, the user must delineate the Runoff Source Area (RSA) within the lateral drainage area (LDA) and the drainage area that will be treated by BMPs and SCMs. The LDA is the portion of the stream's watershed that drains laterally to the project stream reach (Figure 6.2). The RSA is the portion of the LDA that significantly increases runoff or generates pollutants. For example, RSA consists of areas of agricultural and/or urban land uses that generate additional runoff due to severe soil compaction, excessive erosion, added impervious surface, or other pollutant generating activities. The RSA may also include areas where infrastructure concentrates runoff flow through a wet-weather conveyance or a stormwater outfall.

Method Steps to Obtain RSA

RSA within the LDA may be delineated using existing tools, such as GIS, GoogleEarth™, and Model My Watershed®. GoogleEarth™ and the polygon area measurement tool can be used to delineate polygons around each of the modified land covers to sum those areas. Model My Watershed® can be used with instructions described above in Section 6.2.1. The above-mentioned tools GoogleEarth™ and Model My Watershed® are freeware available to practitioners thus not needing advanced commercial products. These area calculations can also be accomplished with other GIS-based spatial analysis tools. The RSA must be determined by identifying all the areas with impervious, crop land agriculture, or other disturbed land covers that contribute to increased runoff or excessive pollutants within the project area. As noted above, Figure 6.2 illustrates LDA associated with a project reach.

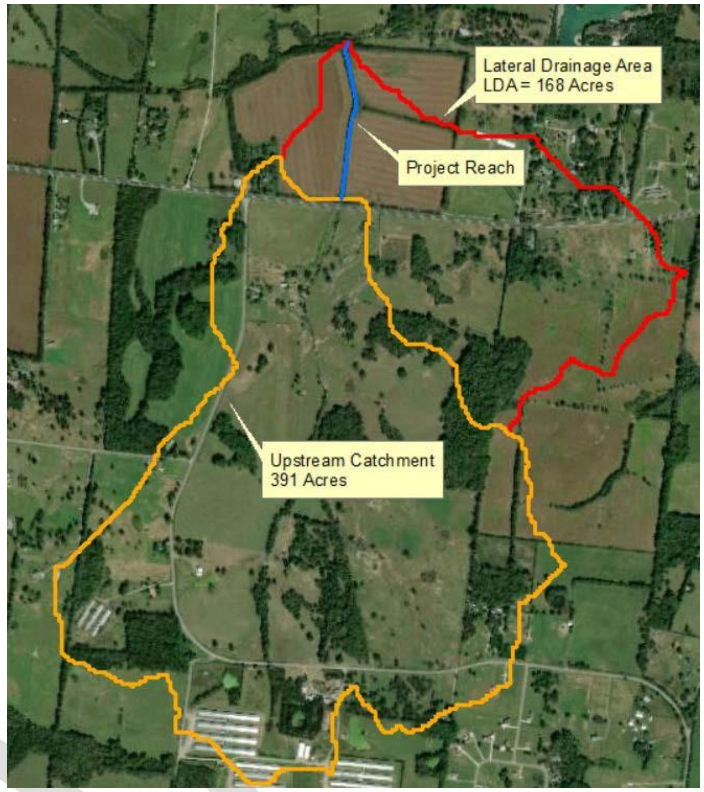


Figure 6.2. Example site with a project reach illustrating the lateral drainage area (LDA = red boundary) with the upstream catchment area shown (yellow boundary). The RSA is the area within the LDA generating excess runoff or pollutants, which can be seen as brown adjacent to the stream (blue line).

Computing Existing and Proposed Condition Scores

If the entire LDA consists of well-established vegetated land cover, there is no runoff source area and no infiltration best management practices or SCMs are needed. The RSA equals 0, thus the ECS for the reach runoff/stormwater infiltration metric will equal 1.0. If the entire LDA is impervious or disturbed or bare soils, then the reach runoff/stormwater infiltration metric will equal 0. If the LDA contains areas generating increased or polluted runoff, then there are two approaches that can be used alone or simultaneously to increase stormwater infiltration in the stream restoration project. In this case the metric's field value will range between 0 and 1. For this metric the field value and the ECS/PCS are the same.

The first approach consists of converting disturbed land to protected vegetative land cover, such as establishing a vegetative buffer, grassy waterway, or contour infiltration berm. The second approach involves retrofitting or constructing new SCMs to treat the RSA. Any land development within regulated stormwater community must install SCMs as required by TDEC stormwater NPDES permits and applicable municipal separate storm sewer system (MS4) ordinances. Calculations for both approaches are described next where the first approach is demonstrated in *Project Site Example 1*, the second approach demonstrated in *Project Site Examples 2-4*, and combined approaches demonstrated in *Project Site Examples 5-6*.

- The *first approach* includes a land use/cover conversion of the RSA to a protected vegetated area such reforested areas, unmanaged grassland, improved riparian corridors, designed infiltration areas, and constructed wetlands. This approach is most relevant for rural restoration projects where vegetated land cover can be established, or wide riparian zones can be vegetated and protected. The calculation for the Reach Runoff/Stormwater Infiltration metric for a field value, thus an ECS and PCS are as follow:

Reach Runoff/Stormwater Infiltration Field Value (RRSI) = [LDA – RSA + CA] / LDA, where

LDA = the lateral drainage area for the project reach;

RSA = the runoff source area where excess polluted runoff is generated; and

CA = the areas of converted land enhancing stormwater infiltration

For the existing RRSI field value, where CA = 0 the equation becomes:

RRSI = [LDA – RSA] / LDA

For a restoration project proposing infiltration practices in the LDA, the proposed RRSI field value is computed by the above equation where all Converted Areas (CA) are summed up. RRSI = [LDA – RSA + ∑CA] / LDA

Project Site Example 1. Land-use Conversion of Runoff Source Area

The project LDA is 38 acres and the RSA is 23 acres of crop land (Figure 6.3). Disturbed areas upstream of the project site are not considered in the metric since those areas are outside the project reach, though it is understood there are possible cumulative effects from upstream activities. The stream restoration project proposes to add a 100-foot buffer on both sides of the stream reach, converting 7 acres (converted area, CA) of crop land to forested land use. Equations to compute the existing and proposed RRSI are shown above.

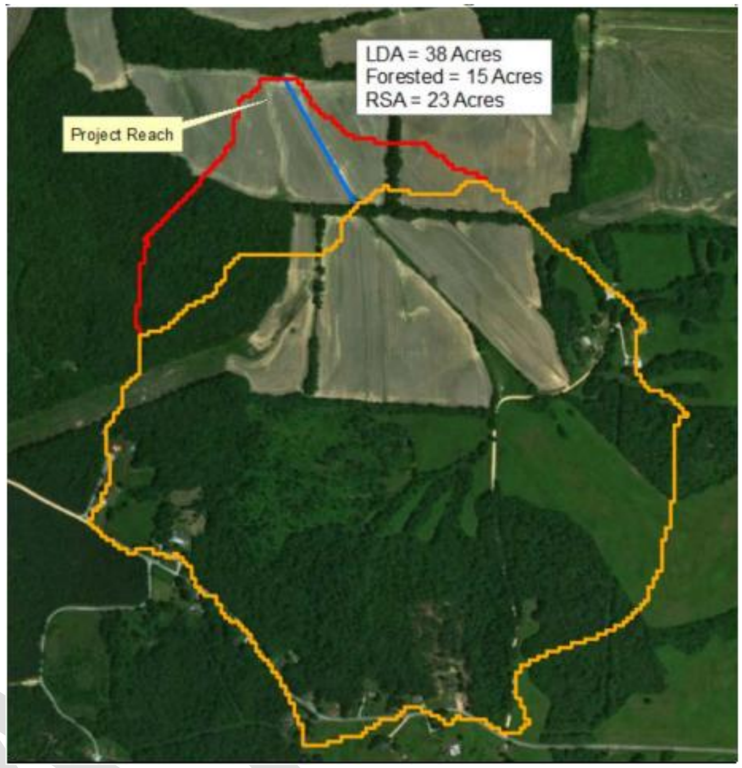


Figure 6.3. Land use conversion from agricultural land to riparian forest buffer within the LDA.

For this restoration project, the existing and proposed RRSI are computed as follow.

Existing RRSI = ECS = (38 acres − 23 acres)/38 acres = 0.39

Proposed RRSI = PCS = (38 acres − 23 acres + 7 acres)/38 acres = 0.58

Separately, the existing and proposed RRSI field values are incorporated into the TMAT worksheet in the Hydrology category section. As noted above, both RRSI field values are the same as the ECS and PCS in the TMAT worksheet, respectively. Note, if in this example 100% of the 23 acres of crop land was converted to forested land cover, the proposed RRSI would equal to one (PCS = 1). This watershed approach may be considered as a conservation approach to stream mitigation.

- The *second approach* accounts for the treatment of runoff from the RSA by SCMs. The Reach Runoff/Stormwater Infiltration (RRSI) metric incorporates the infiltration for individual SCMs in the project area that treats runoff from the RSA. This approach is most relevant for restoration projects in urban catchments with impervious surfaces generating runoff.

For mitigation projects proposing functional lift using SCMs and credits from the RRSI metric, SCM design and construction must meet TDEC NPDES permit requirement and local MS4 ordinance standards if applicable. Constructed SCMs require a long-term maintenance agreement and deed restriction as necessitated by the local MS4.

Each SCM receives runoff from a contributing drainage area, denoted as DA_{SCM}. The DA_{SCM} is multiplied by a Stormwater Infiltration Factor (SIF). The products of each DA_{SCM} by its SIF are summed as a runoff volume reduction within the RSA and expressed as $\sum(DA_{SCM} \times SIF)$. As noted above, SCMs include stormwater ponds, bioretention facilities, wetlands, and other floodplain infiltration enhancements. The RRSI field value is defined as follows, and used to compute both existing and proposed conditions:

RRSI = [LDA – RSA + $\sum$(DA$_{SCM}$ x SIF) + $\sum$CA] /LDA; where

DA$_{SCM}$ = the drainage area for each SCM infiltrating stormwater runoff from the contributing RSA within the LDA.

SIF = the ratio of the SCM infiltration volume designed to the runoff volume generated by the 1yr-24 hr. design storm from the drainage area.

RSA and CA are defined above in this section of the manual. However, the RSA in a developed LDA is the estimated impervious surface area. It is the area assumed to contribute to pollutants and excessive runoff volumes. To estimate the RSA based on impervious surface area, the LDA is multiped by a % impervious surface area factor based on different land use types. The USACE provides a table of these hydrologic factors in their HEC-HMS User's Manual (Table 6.3), which web link is: https://www.hec.usace.army.mil/confluence/hmsdocs/hmstrm/cn-tables.

Other resources for estimating % impervious surface, such as the USGS Multi-Resolution Land Characteristics Consortium (MRLC), a user-interface GIS tool (https://www.mrlc.gov/viewer/) can be used for more detailed values. Spatial data can be downloaded from this web site, and a % impervious surface area estimated using the tool's polygon measurement function. This tool provides multiple years with the most recent being 2021 though the data is continually updated. A user must compute a weighted average for the RSA from MRLC output.

Table 6.3. Default percent impervious surface areas based on land use type (USACE 2024).

Land Use Type	**Percent Impervious Surface**
Commercial and Business	85
Industrial	72
Residential (< 1/8 acre; Town Houses)	65
Residential (1/4 acre)	38
Residential (1/3 acre)	30
Residential (1/2 acre)	25
Residential (1 acre)	20
Residential (2 acre)	12

When computing an existing RRSI field value, existing SCMs within the RSA and their infiltration capacity are included in the above equation. When computing a proposed RRSI field value, the existing SCMs and proposed new SCMs, and any proposed SCM retrofits are included.

The SIF represents the proportion of the runoff volume that the SCM is designed to infiltrate to that of the total runoff generated by the design storm from the DA$_{SCM}$. The design storm for SCMs in Tennessee is the 1 yr-24-hr storm where storm and the data are obtained from NOAA Atlas 14. NOAA Atlas 14 data includes depths, intensities and updated storm distributions. The NOAA web link is: *https://hdsc.nws.noaa.gov/pfds/pfds_map_cont.html?bkmrk=tn*. The rainfall in terms of depth is obtained from a table provided using the above NOAA web link. The latitude and longitude of the project site are entered into the NOAA web site and the 1-yr-24-hr storm depth is obtained. The SIF is the ratio of the SCM infiltration volume to the runoff volume from the DA_{SCM}, and it can be expressed as the ratio of volume infiltrated (V_{Inf}) by the SCM to the volume of SCM's drainage area (DA_{SCM} based on the design storm depth (V_{DA}). It is expressed as follows:

$SIF = V_{Inf} / V_{DA}$

$V_{DA} = DA_{SCM}$ x Design Storm Depth

where V_{DA} is the design storm runoff from the contributing drainage area to the SCM.

V_{Inf} = volume held in the SCM that will infiltrate within 72 hours

To calculate if the SCM volume will infiltrate within 72 hours, additional information about the SCM and soil characteristics are needed. The SCM area is the footprint of the SCM used for infiltration. A soil infiltration rate (*Inf rate*) for the SCM is the rate of infiltration of runoff into the receiving soil layer. The *Inf rate* can be obtained by: 1) field tests measurements using an infiltrometer; 2) a SCM design tool/model, or 3) standard rates for Hydrological Soil Group (HSG classes = A, B, C, or D) in the SCM location where the *Inf rate* assumes the local soil equates to that in the SCM bottom. HSG classes for the local soil can be obtained from USDA Soil Web Survey Site.

The USDA Soil Web Soil Survey site, a desktop method for estimating HSG infiltration rate can be found at https://websoilsurvey.nrcs.usda.gov/app/. The procedure to obtain the HSG infiltration rate (*Inf rate*) is as follows:

1. Start WSS (click the green button), and US map appears (right) and function menu (left).
2. Click on the function menu 'Soil Survey Area' under 'Quick Navigation, and add state and county, click on available survey data and 'show soil survey areas layer in map'; and click 'Set AOI' where AOI is the defined 'area of interest'.
3. Zoom in on the project reach on the 'Area of Interest Interactive Map' and using the quick function button for creating an AOI, complete with the cursor (AOI can be created as a rectangle or a polygon).
4. Under the main menu, click on the 'Soil Map' tab. Soil types will appear with their Map Unit Symbol. Summarize each soil mapping unit type (symbol).
5. Under the 'Map Unit Legend' able, click on the soil name, in which a map unit description will appear in a table.
6. Under 'Properties and Qualities' go to 'Interpretive Groups' and find the Hydrologic Soil Group (HSG = A, B, C, or D). Use this HSG to obtain the soil infiltration rate (SIR) from published standards as follows (MSM 2023):
   <u>Group A</u>:
   Silty gravels, gravely sands, sand = 1.63 in/hr.
   Sand, sandy loam, loamy sand = 0.8 in/hr.
   Silty sand = 0.45 in/hr.
   <u>Group B</u>:
   loam, silt loam = 0.3 in/hr.

<u>Group C</u>:
sandy clay, loam, silts = 0.2 in/hr.
<u>Group D</u>:
clay loam, silty clay loam = 0.06 in/hr.
clay = 0.0 in.hr

These infiltration rates are used to confirm that the V_{inf}, the volume held in the SCM will infiltrate within 72 hours. Thus, confirm that V_{inf} /SCM area/HSG infiltration rate is less than 72 hours.

To compute the existing RRSI, the $\sum(DA_{SCM} \times SIF)$ is needed for all existing SCMs. If the SCM was not designed to infiltrate (historical detention basins), skip this step. For existing SCMs where the municipality requires infiltration, use the local historical design storm (typically 1 inch) per local municipality ordinance.

Computing proposed RRSI requires both the DA_{SCM} and SIFs for existing and proposed SCMs. Proposed SCMs require input for the runoff volume generated by the 1-yr 24-hr design storm from the DA_{SCM} and the runoff volume captured and infiltrated by proposed SCMs within 72 hours. The time for the SCM volume (V_{inf}) to infiltrate within the SCM is checked by using the HSG infiltration rate. In addition to hand calculations, various design tools can be used for sizing SCMs to meet state and local stormwater regulations, which includes various on-line tools and commercial software such as Pond Pack by Bentley™.

The equation for use, as defined above is shown here for convenience:

Reach Runoff/Stormwater Infiltration (RRSI) field value = $[LDA - RSA + \sum(DA_{SCM} \times SIF) + \sum CA] / LDA$

This second approach for computing the RRSI metric is illustrated by the following examples (Project Site Examples 2, 3, and 4). These examples provide calculations to obtain the RRSI field values for the most common site conditions. They are all based on a project site shown in Figure 6.4 in Knoxville where the 1-yr 24-hr storm depth from the NOAA database is 2.54 inches. The project LDA is 121 acres. The project reach site has three stormwater outfalls with their respective DA_{SCM} shown in red, yellow, and blue. The project area consists of predominately residential use. Examples 2 through 4 use all or some of the SCMs shown in Figure 6.4 based on different site SCM scenarios, thus a reference figure for all examples.

Looking up % impervious for residential use for 1/4 acre lots in Table 6.3, the % impervious surface area for this land use type is 38%. The RSA for *Runoff SCM Treatment* project examples is 46 acres (121 acres x 0.38 = 46 acres).

Figure 6.4. Project site for urban infiltration using SCMs showing the project lateral drainage area (LDA) and the drainage area for each SCM DA_{SCM} (blue, red, and yellow areas).

Project Site Example 2. The existing RRSI field value with an existing stormwater pond (red area in Figure 6.4).

As noted in Figure 6.4 the project area (LDA) encompasses 121 acres. The RSA is 46 acres (121 acres x 0.38 (% impervious) = 46 acres). The red DA_{SCM} has 6 acres of impervious surface treated in an existing 0.5-acre stormwater pond that captures runoff coming from the 6 acres of impervious drainage area to the receiving stream outfall. The design infiltration volume for this historic pond is assumed to be 1-inch over the 6-acre drainage area. The HSG in the area is classified as B. Web soil survey was used to confirm the distance to the confining layer was unlikely to inhibit the infiltration of the volume of water detained within the pond. The existing pond calculations are as follow.

SIF = V_{Inf}/ V_{DA}

V_{inf} = DA_{SCM} x infiltration volume = 6 acres x 1.0 inch = 6.0 ac-in

V_{DA} = DA_{SCM} x design storm = 6 acres x 2.54 inches = 15.24 ac-in

SIF = V_{Inf}/ V_{DA} = 6.0 acre-in/15.24 ac-in = 0.39

Existing Pond area = 0.5 acres

Confirming pond infiltration time < 72 hours:

Depth of V_{inf} in the 0.5-acre pond = 6.0 acre-in/0.5 acre = 12 inches

T = The time the stormwater volume depth is infiltrated through the pond bottom

T = SCM depth (in) / HSG soil infiltration rate (in/hr.)

T = 12 inch/ 0.30 in/hr. = 40 hours < 72 hours (*condition satisfied*)

DA_{SCM} x SIF = 6-acre x 0.39 = 2.34 acres

Reach Runoff/Stormwater Infiltration Value = [LDA – RSA + $\sum(DA_{SCM}\ x\ SIF)$ + $\sum$CA] / LDA

RRSI = ECS = [121- 46 + 2.34] / 121 = 0.64

Note: The RRSI field value is the ECS used in the TMAT worksheet.

Project Site Example 3. The proposed RRSI value for existing stormwater pond (red), 1-acre pervious pavement parking, proposed infiltration SCMs (yellow), 5-acre park.

Project Site Example 3 uses the existing conditions from Project Site 2 including the existing pond (red DA_{SCM}) and now adds a 5-acre park, 1-acre infiltration pavement, and proposed infiltration SCM for the yellow DA_{SCM} which has 7 acres of impervious surface (Figure 6.4). The proposed infiltration SCMs' footprint totals 1-acre that capture the 1-yr 24-hr runoff from all impervious surfaces in this area. This site is located in Knoxville with the design storm volume of 2.54 inch. The HSG is B with a soil infiltration rate of 0.3 in/hr.

From Project Site Example 2: Existing Pond SIF = 0.39 and Existing Pond Footprint = 0.5 acres

Proposed SCM SIF calculations follow:

SIF = V_{Inf} / V_{DA}

V_{inf} = DA_{SCM} x infiltration volume = 7 acres x 2.54 inch = 17.78 ac-in

V_{DA} = DA_{SCM} x design storm = 7 acres x 2.54 inches = 17.78 ac-in

SIF = V_{Inf} / V_{DA} = 17.78 acre-in/17.78 ac-in = 1.0

Confirming SCM infiltration time < 72 hours:

SCM footprint = 1 acre

Depth of V_{inf} in the 1-acre SCM = 17.78 acre-in/1.0 acre = 17.78 in

T = SCM depth (in) / HSG soil infiltration rate (in/hr.)

T = 17.78 in/ 0.30 in/hr. = 59.26 hrs. < 72 hours (*condition satisfied*)

DA_{SCM} x SIF = 7-acre x 1.0 = 7.0 acres

Park area (CA) = 5 acres

Pervious parking (CA) = 1 acre

RRSI field value = PCS = [121 – 46 + 2.34 + 7.0 + 5.0 +1.0] / 121 acres = 0.75

The RRSI value is the PCS used in the TMAT worksheet for this project example.

Project Site Example 4. The proposed RRSI value for existing stormwater pond, 5-acre proposed park, 1-acre pervious pavement parking lot, and enhanced riparian water quality buffer.

Project Site Example 4 uses the existing conditions from Project Site 2 including stormwater pond in the red area DA_{SCM}, the park and infiltration pavement, SCMs fully treating 7 acres of impervious surface and proposes a permanent riparian water quality buffer. The urban stream restoration project will provide an average 100-ft water quality riparian buffer on both sides of the stream reach totaling 9.5 acres. Converting the area from urban use to protected forested buffer. In this case example, the RRSI equation is applied where the 9.5 acres of enhanced infiltration is added for $\sum$CA. The calculation follows.

Reviewing the RRSI equation:

RRSI Value = [LDA – RSA + $\sum$(DA_{SCM} x SIF) + $\sum$CA]/LDA

Proposed RRSI field value = PCS = [121 – 46 + 2.34 + 7.0 + 5.0 +1.0 +9.5 acres] / 121 acres

PCS = 0.83

This RRSI field value is the PCS used in the TMAT worksheet for this project example.

6.1.3 Floodplain Storage – Infiltration Potential Metric

The Floodplain Storage – Infiltration Potential (FSIP) metric measures the floodplain area that has the potential for infiltrating flood waters. The FSIP metric represents areas within the floodplain adjacent to a stream project reach that includes uncompromised areas from development and areas compromised by some infrastructure preventing floodplain inundation and infiltration potential. Noting the difference with the Floodplain Inundation Frequency metric in the Hydraulics category, the Floodplain Inundation Frequency metric quantifies how often the floodplain is inundated as a function of the degree of channel incision or entrenchment. The two metrics differ where the FSIP field value represents the relative percentage of the floodplain area available for infiltration, not accounting for the range of flood flows that can inundate it. It promotes protection of floodplains from development, and restoration practices than can enhance infiltration and improve riparian quality.

The desktop method is straight forward using various on-line topographic and/or floodplain mapping data sources. On-line data sources include but are not limited to:

1) USGS topoView with support from Google Earth Pro and/or a field survey;
2) The topographic base layer with drawing tool in the TDEC Water Resources Map Viewer, obtained at https://tdeconline.tn.gov/dwr/;
3) GIS-based digital elevation model (DEM) data or Lidar data; and
4) FEMA Flood Map web site and the National Flood Hazard Layer (NFHL) Viewer.

Use of these sources visually estimates the floodplain area by topographic contours and any infrastructure identified within the floodplain. This visual delineation of the floodplain lateral to the project reach can use the USGS topoView with support from Google Earth or GIS-based DEM /Lidar data. Though computation of this metric is meant to be a desktop procedure, it can be ground-truthed during field assessments. If available, use the FEMA Flood Map web site and the National Flood Hazard Layer (NFHL) Viewer to show the 100-year floodplain area. Though this metric is meant to characterize the potential area for flood water infiltration it does not always coincide with the 100-year floodplain but rather the valley bottom based on topographic contours lateral to a project site reach. For mitigation, credit is given to enhancing floodplain area infiltration through restoration practices such as planting forests where it is currently lacking, adding stable multi-thread (side) channels, and/or constructing lateral/floodplain wetlands. Any areas receiving credit from proposed improvements to the FSIP metric must be under a site protection instrument. The basic equation for the FSIP metric is as follows.

FSIP field value = [TFSA – DFSA+ CA] / [TFSA] *100.

Where, TFSA, DFSA, and CA are defined as:

TFSA = total surface area of the floodplain lateral to the project reach

DFSA = developed area within the floodplain lateral to the project reach

CA = area of converted land enhancing flood water infiltration within project site

Note that for interpreting CAs which include floodplain wetlands (either existing or proposed), users should add 5% to the determined CA value from wetlands restoration for a proposed FSIP value and subtract 5% to the DFSA per debiting when development removes wetlands.

Topographic data for visually estimating the floodplain area as noted above can be obtained from the USGS topoView, available at the following web site:

https://ngmdb.usgs.gov/topoview/viewer/#4/40.01/-99.93aan

Delineating the floodplain boundaries and identifying areas of infrastructure development can be supported by the use of Google Earth Pro, and/or ground-truthed during field assessments. If GIS is available for use, a Digital Elevation Model (DEM) can be downloaded from the National Map data at: apps.nationalmap.gov/downloader/#/. Topographic data and DEMs provide the elevations for valley bottom floodplain surface and the stream location but generally do not provide details of the stream channel.

If FEMA maps are available, floodplain areas can be observed as the 100-year floodplain surface area. The 100-year floodway is the area shown for the 1% annual chance for a flood hazard. The NFHL web site can be obtained at:

https://hazards-fema.maps.arcgis.com/apps/webappviewer/index.html

The delineation of the FEMA 100-year floodplain area lateral to the project site can also be ground-truthed during field assessments. Estimating the areas for the floodplain lateral to a project site and any developed areas is best obtained using the polygon measuring tool in Google Earth Pro, and other GIS-based tools are also available for use. Illustrating the procedure for calculating this parameter is shown for a few example conditions, including the calculation of the existing and proposed FSIP field values.

Project Site Example 1. Small catchment with no floodplain delineated with USGS topoView.

This example demonstrates a scenario where the FSIP value will default to zero when no functional floodplain exists, as is common in colluvial or confined valleys (Figure 5.3). Restoration projects can occur within small catchments with no effective floodplains, but the existing and proposed FSIP field values will both be zero because there is no functional capacity for lift. Figure 6.5 demonstrates such a condition on a 2nd order tributary of Stamp Creek.

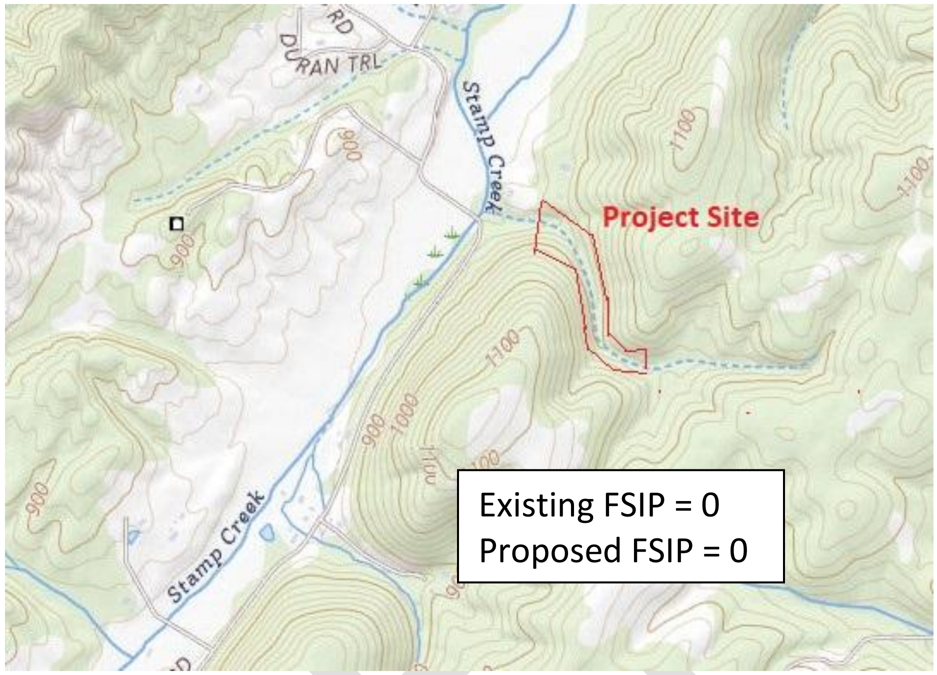


Figure 6.5. Floodplain Storage/Infiltration (FSIP) metrics for a proposed restoration project site on a 2nd order tributary of Stamp Creek, Roane County.

Project Site Example 2. Project reach with floodplain delineated with USGS topoView and where floodplain is fully available for infiltration.

This example demonstrates a restoration project site in a rural watershed where the floodplain remains natural with no development in the floodplain. The floodplain adjacent to the project site is fully available for infiltration of floodwaters. In this case, both the ECS and PSC will be equal to one, and computed scores are shown by the following equation. Figure 6.6 demonstrates this condition on Rock Creek in Morgan County near Pilot Mountain.

The FSIP metric equation is as follows:

FSIP field value = [TFSA – DFSA+ CA] / [TFSA] *100

TFSA = 10.8 acres; DFSA = 0 acres, and CA = 0 acres (*obtained from* Figure 6.6)

Existing and proposed FSIP field values = (10.8 – 0 + 0)/10.8 = 1.0

Project Site Example 3. Existing FSIP value for floodplain with floodplain structure impacting infiltration using USGS topoView with support from Google Earth Pro.

Example 3 demonstrates delineating a valley floodplain bottom area using topographic data from the USGS topoView web site and computing an existing FSIP value for a project site where an existing berm prevents flood inundation for a portion of the total floodplain area (TFSA) in the valley bottom. This area as shown in Figure 6.7 is the DFSA where the berm structure

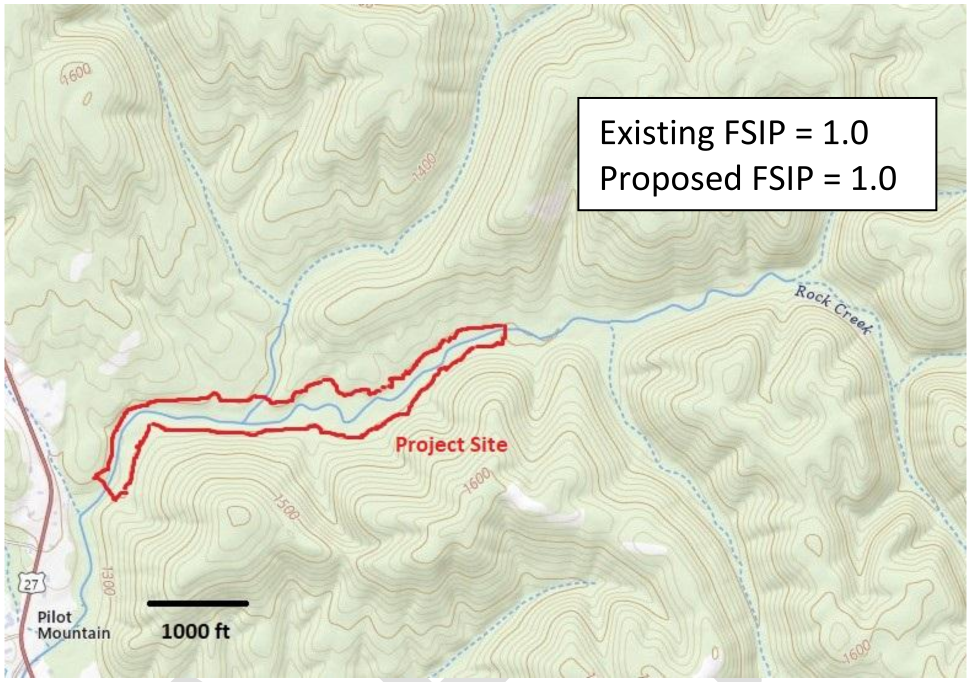


Figure 6.6. FSIP metrics for a proposed restoration project site along a 3rd order stream with the floodplain delineated by topoView topographic contours for Rock Creek, Morgan County near Pilot Mountain.

prevents the flood inundation. Any infrastructure development that prevents the natural function of a floodplain constitutes the DFSA, more typical in urban catchments.

The proposed project site is a stream reach along Bull Run Creek in Anderson County where historically the channel was moved to the southeast valley wall leaving a berm that prevents an area of the floodplain from being inundated (Figure 6.7). The berm is shown as a green line in Figure 6.7. The lateral floodplain area is delineated with a red boundary with the TFSA equal to 165.3 acres. The area lacking flood inundation and infiltration is delineated by a black boundary with the DFSA equal to 82.6 acres. For the existing FSIP field value there is no acreage for CA, the area of converted land enhancing flood water infiltration within project site. Computation of the existing FSIP field value is as follows.

FSIP field value = [TFSA – DFSA+ CA] / [TFSA] *100

TFSA = 165.3 acres; DFSA = 82.6 acres, and CA = 0 acres (*obtained from* Figure 6.7)

Existing FSIP field value = (165.3 – 82.6 + 0) / 165.3 = 0.50

Project Site Example 4. The proposed FSIP field value for restoring the floodplain for the project site described in Example 3 where a floodplain structure has impacted infiltration along a stream reach on Bull Run Creek, Anderson County.

In Example 3 the lateral floodplain area was delineated with a red boundary with the TFSA equal to 165.3 acres. The area lacking flood inundation and infiltration is delineated by a black boundary with the DSFA equal to 82.6 acres. The existing FSIP value for a delineated floodplain

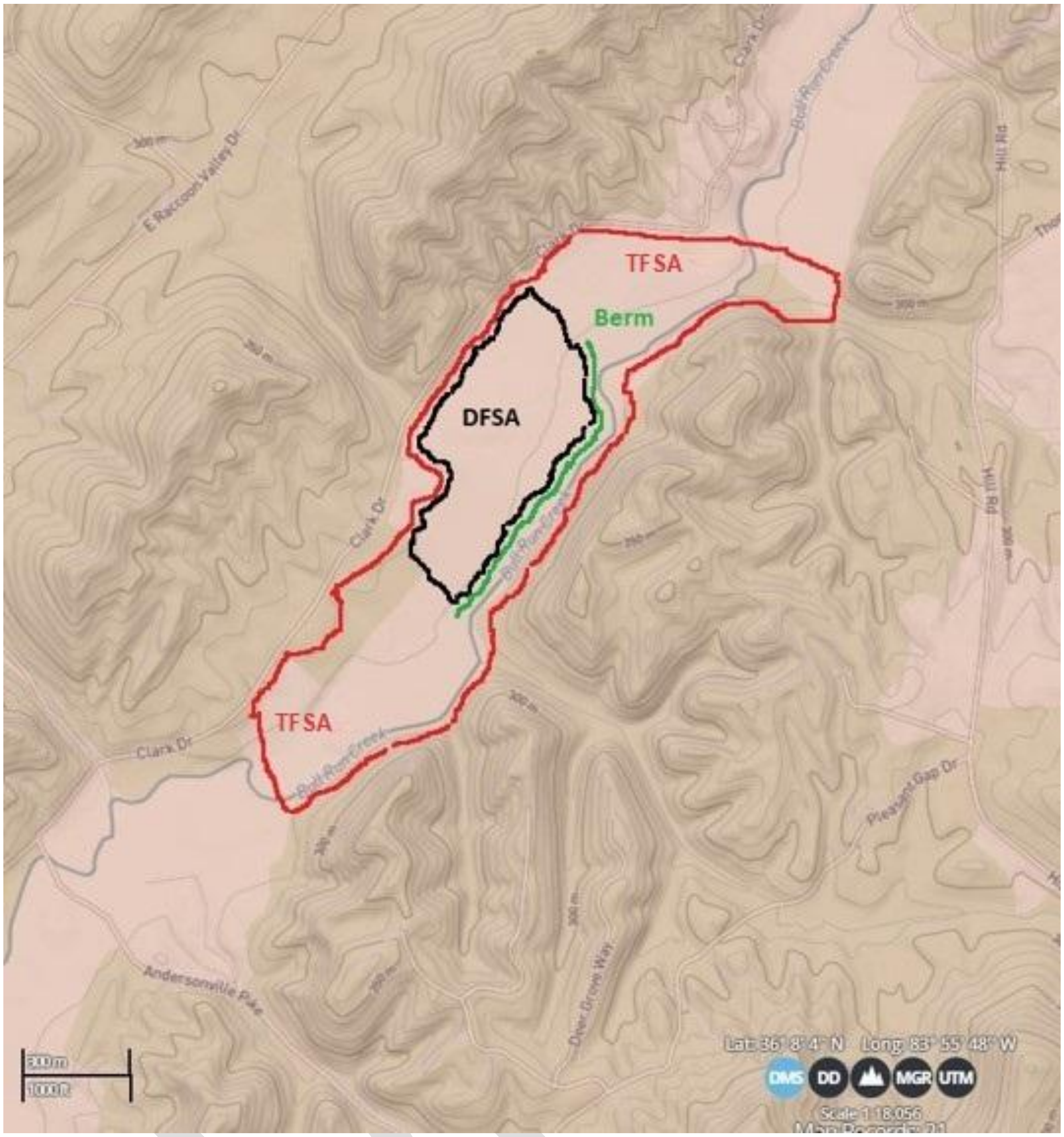


Figure 6.7. Existing FSIP metric for a stream reach along Bull Run Creek in Anderson County, where a berm is shown as a green line, the TFSA is within the red boundary and the DFSA is within the black boundary. Topographic DEM view from USGS topoView.

lateral to the proposed restoration project reach was computed as 0.50. The proposed restoration project consists of removing the berm preventing a large portion of the floodplain from inundation and infiltration. In addition, a side channel with a wetlands complex will be constructed as shown on Figure 6.8. The CA for the restoration is equal to 66.2 acres. Computation of the proposed FSIP field value is as follows.

FSIP field value = [TFSA – DFSA+ CA] / [TFSA] *100

TSFA = 165.3 acres; DFSA = 82.6 acres, and CA = 66.2 acres (*obtained from* Figure 6.8)

Proposed FSIP field value = (165.3 – 82.6 + 66.2) / 165.3 = 0.90

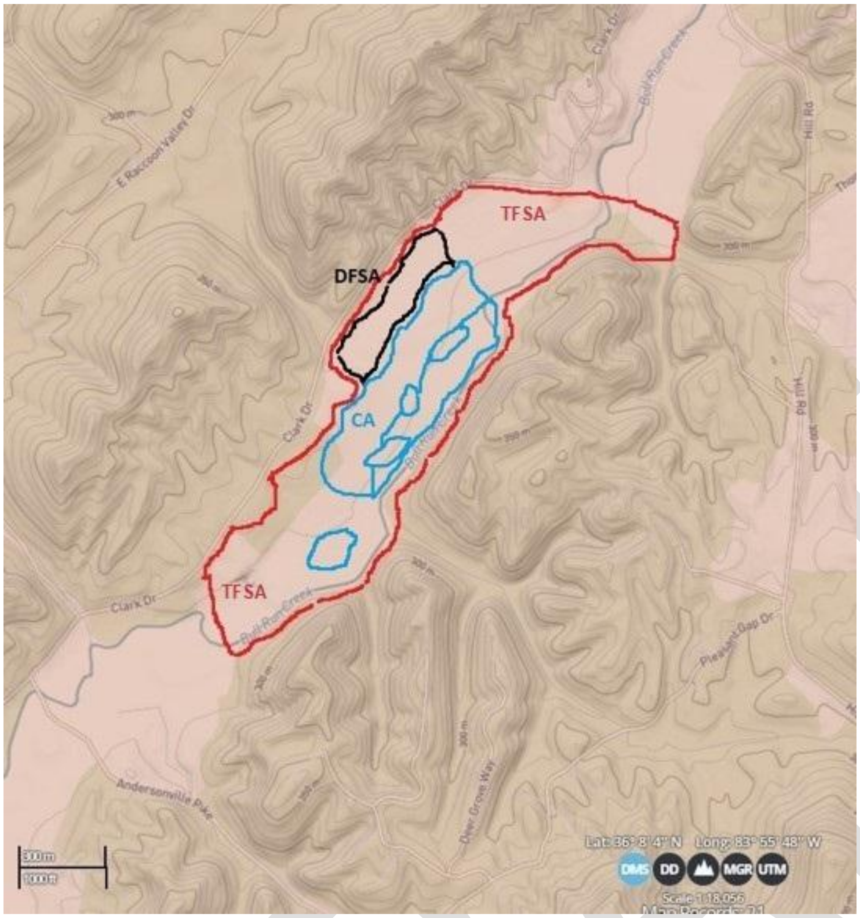


Figure 6.8. The proposed FSIP field value for a stream reach along Bull Run Creek in Anderson County consisting of floodplain restoration. The TFSA is within the red boundary, the DFSA is within the black boundary, and CA is shown as a side channel complex of wetlands as blue lines. DEM view from USGS topoView.

Project Site Example 5. Existing FSIP field value for a project reach with development encroachment on a floodplain in an urban watershed.

Project Site Example 5 demonstrates the use of a DEM obtained from Knox County KGIS along a section of Third Creek where a large apartment complex moved earth comprising the historic floodplain to delineate the TFSA and the DFSA. Since this example is to compute the existing FSIP value, CA is equal to zero. Because there were no historic records of the pre-construction floodplain, a qualitative geomorphic interpretation was completed to delineate boundaries. In Figure 6.9 the current floodplain boundary is shown with a red line, and the interpreted valley wall floodplain boundary is shown with a green line. The TFSA is the area bounded by the red and green lines, whereas the DFSA is the area between the green and red lines. The TFSA is equal to 6.81 acres, and the DFSA is equal to 3.12 acres. Computation of the ECS follows.

FSIP field value = [TFSA – DFSA+ CA] / [TFSA] *100

TFSA = 6.81 acres; DFSA = 3.12 acres, and CA = 0.0 acres (*obtained from* Figure 6.9)

Existing FSIP field value = (6.81 – 3.12 +0.0) / 6.81 = 0.54

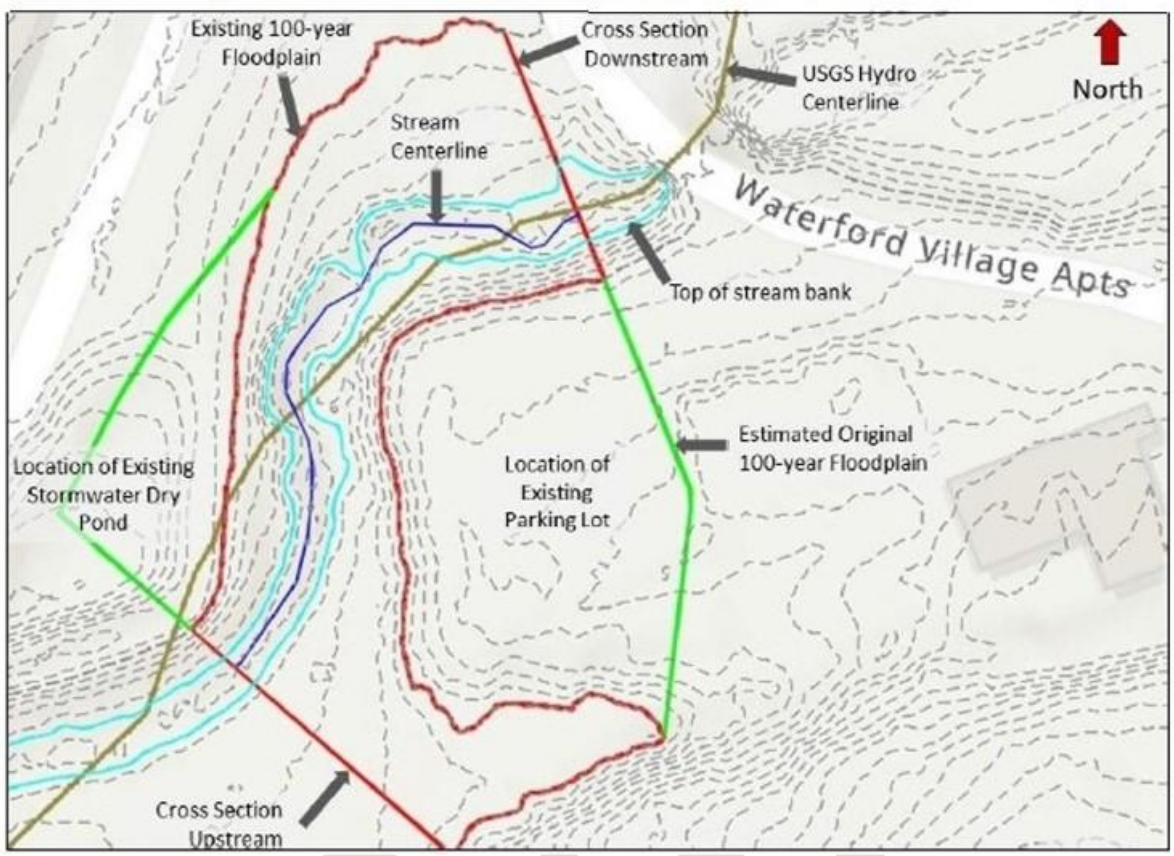


Figure 6.9. The existing FSIP field value for a stream reach along Third Creek in Knox County, where the TFSA is within the green-red boundaries and the DFSA is difference between the green and red boundaries. DEM view from Knox County GIS data.

Project Site Example 6. Existing and proposed FSIP field values for a project reach with development encroachment on a floodplain in an urban watershed and using the FEMA map for floodplain delineation.

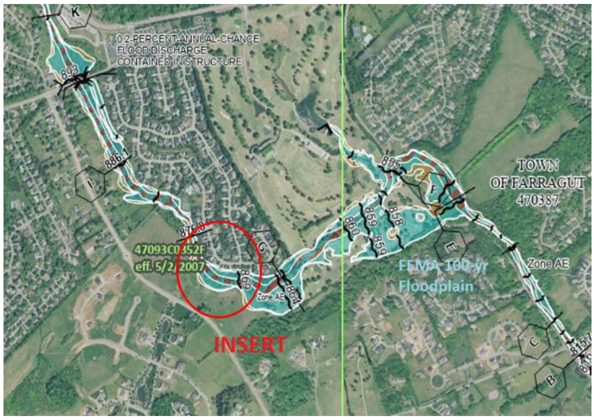
Project Site Example 6 demonstrates the use of a FEMA Flood Map from the NFHL Viewer to identify the 100-year floodplain area. The 100-year floodplain is shown in light blue in Figure 6.10. The project reach is on Turkey Creek in Farragut (Knox County) and a subdivision development encroaches on the 100-year floodplain. In order to compute the ECS, the TFSA for the project reach is delineated with a red line equal to 20.5 acres. The DFSA is delineated with a black line equal to 2.8 acres. The restoration project includes constructing three wetlands within the TFSA, where the CA is equal to 1.7 acres. The wetlands are shown in blue circles on Figure 6.10. Computations for the existing and proposed FSIP field values follow demonstrating the potential functional lift from enhancing infiltration on the floodplain.

FSIP field value = [TFSA – DFSA+ CA] / [TFSA] *100

TFSA = 20.5 acres; DFSA = 2.8 acres, and CA = 1.7 acres (*obtained from* Figure 6.10)

Existing FSIP field value = (20.5 – 2.8 +0.0) / 20.5 = 0. 86

Proposed FSIP field value = (20.5 – 2.8 +1.7) / 20.5 = 0.95



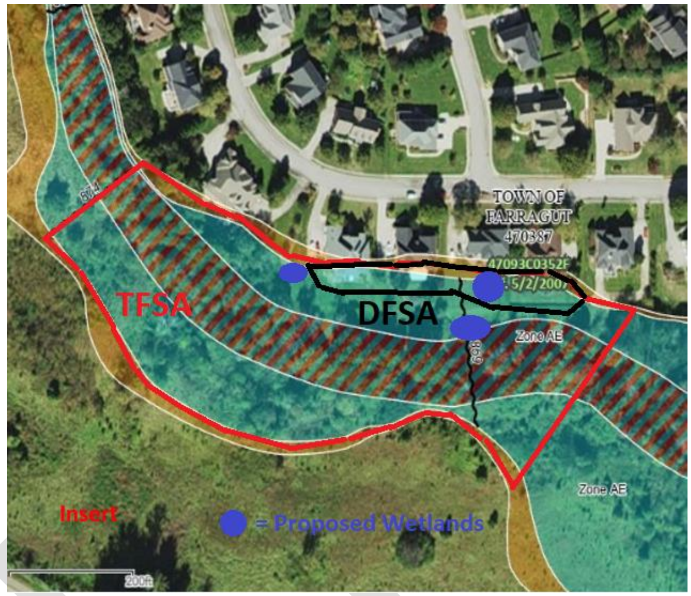


Figure 6.10. FSIP metric for a restoration project that includes constructing wetlands on a floodplain. FEMA NFHL for a Turkey Creek reach in Farragut to compute the existing and proposed FSIP field values. Left map shows insert for enlarged view.

Example output from FEMA NFHL for a section of Turkey Creek in Farragut to compute the existing and proposed FSIP field values. Light blue area is the FEMA 100-year floodway. In Figure 6.10, the insert figure to the right shows the TFSA delineated with red line and the DFSA per a residential development encroachment delineated with a black line. Proposed wetlands are shown as blue circles.

Project Site Example 7. The existing FSIP field value computed for a tributary reach within a larger river floodplain, and a proposed FSIP value for a proposed restoration that includes infiltration enhancement. The FEMA Flood Map for the 100-year floodplain is used for Drakes Creek in Hendersonville and the project tributary floodplain area.

Example 7 demonstrates the site condition where a tributary stream enters a larger stream (river). Near the tributary confluence with the larger river its floodplain merges with the floodplain of the larger stream. Under this site condition there is no valley wall associated with the tributary stream to delineate. This example uses the FEMA Flood Map for the 100-year floodplain for a tributary to Drakes Creek in Hendersonville (Figure 6.11). To delineate the TFSA for the FSIP metric, the lateral distance from the stream channel it is computed by multiplying the top of channel bank width by five and extending it left and right bank onto the floodplain area. These distance estimates determine the project area on the 100-year floodplain which can infiltrate flood waters, and are used to compute the existing and proposed FSIP field values. In this example top of channel bank width was measured as 20 feet thus the lateral distance left and right is 100 feet for the TFSA and shown on Figure 6.11. The TFSA includes an asphalt parking lot (upper left corner within the delineated TFSA). The TFSA is equal to 5.14 acres, and the DFSA is 0.13 acres per the impervious parking lot area. The proposed restoration project is to convert the impervious parking lot surface to a pervious pavement for enhanced infiltration, thus the CA is equal to 0.13 acres. Computations for existing and proposed FSIP field values follow demonstrating the potential functional lift from enhancing infiltration on the floodplain.

FSIP field value = [TFSA – DFSA+ CA] / [TFSA] *100

TFSA = 5.14 acres; DFSA = 0.13 acres, and CA = 0.13 acres (*obtained from* Figure 6.11)

Existing FSIP field value = (5.14 – 0.13 +0.0) / 5.14 = 0.97

Proposed FSIP field value = (5.14 – 0.13 +0.13) / 5.14 = 1.0

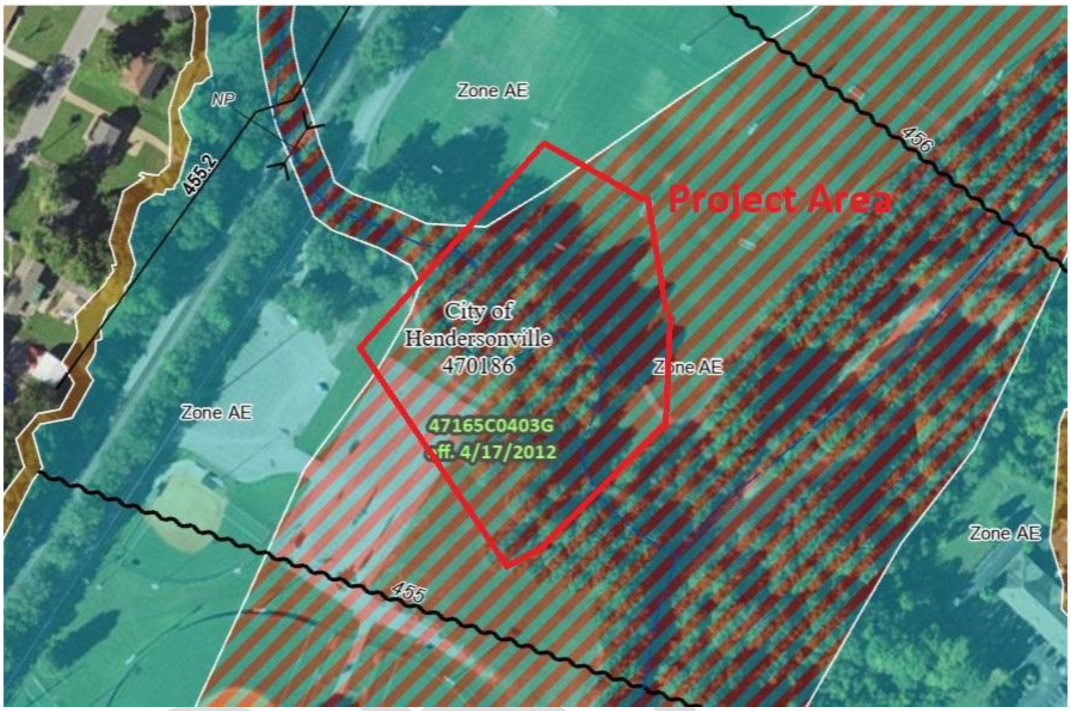


Figure 6.11. FSIP metric for a Drakes Creek tributary at the confluence of Drakes Creek in Hendersonville, Tennessee. TFSA is shown with red line boundary on a FEMA Flood Map with the 100-year floodway shown in light blue.

6.2 Hydraulic Functional Category Metrics

Within the Hydraulics functional category, the first task is to determine if adequate bankfull indicators are present within the assessment reach. Bankfull indicators are described in Section 5.4.3, and the geomorphic conditions limiting the use of metrics that require bankfull measurements are defined in Section 5.4.4. If bankfull indicators are present, the Entrenchment Ratio (ER) and the Bank Height Ratio (BHR) are computed and field methods are described in Section 6.2.1. If bankfull indicators are absent or there is not enough data to collect accurate bankfull data as described in Section 5.4.4, then the non-bankfull alternative measurement methods may be used with agency approval. The non-bankfull metrics are: Floodplain Inundation Frequency and Channel Incision. Methods to compute these metrics are described in Section 6.2.2, and they require coupling both desktop data accrual and field methods. Also included in the Hydraulics category is the Aggradation Ratio, which is an optional metric. It requires bankfull indicators and the field method is described in Section 6.2.3.

6.2.1 Hydraulics: Bankfull Metrics

When applying bankfull indicators, two measurement methods are used to quantify floodplain connectivity: Bank Height Ratio (BHR) and Entrenchment Ratio (ER). Both metrics are obtained for an assessment reach within the project site reach (Section 5.6.3, Table 5.6). The assessment reach is approximately 20 times the bankfull width or the entire reach if it is shorter in length.

6.2.1.1 Bank Height Ratio

The Bank Height Ratio (BHR) is a measure of channel incision and therefore the likelihood of floodplain inundation; the lower the ratio, the more frequently water from the stream accesses the floodplain. The most common calculation for the BHR, and the one used in the TMAT, is the low-bank height divided by the maximum bankfull riffle depth (Dmax). The low bank height is the lower of the left and right streambanks, indicating the minimum water depth necessary to inundate the floodplain (Figure 6.12).

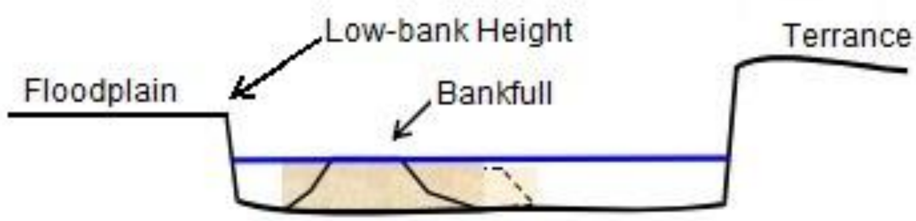


Figure 6.12. Channel cross-section schematic showing bankfull height based on a mid-channel bar, and low-bank height at the floodplain surface.

The BHR should be measured near the midpoint of the riffle, halfway between the head of the riffle and the head of the run or pool if there is not a run. First, measure the length of the riffle at the center of the riffle, and measure the vertical distance between the channel bottom at the thalweg and bankfull indicator height (Dmax, equation denominator). Then measure the vertical distance between the channel bed at the thalweg and the low-bank height (equation numerator). Divide the low bank height by the max bankfull depth. Measure the riffle length at this measurement location. The BHR equation is shown below.

$$BHR = \frac{Low\ Bank\ Height}{Dmax}$$

Repeat for every riffle in the stream reach. Using these data, a weighted BHR is calculated as follows:

a. Identify the bankfull line on both streambanks. Bankfull lines are distinguished by the top of point bars, slope breaks, the back of a sloping bench, and occasionally by observing scour lines (Section 5.5.3).
b. Measure the bankfull maximum depth at each riffle.
c. Identify the low-bank height of a given riffle as the lowest of the downstream right and left banks at the given point in the stream.

d. Measure the height of the low bank to the thalweg bed for each riffle.

e. Divide the low-bank height by the maximum bankfull depth to determine the bank height ratio for each riffle (BHR_i).

f. To compute a weighted average for BHR, measure the length of each riffle, where RL_i is the length of the riffle where BHR_i was measured.

g. Multiple each RL_i by its BHR_i, and sum the products (BHR_i *RL_i) for each riffle.

h. Divide the product sum by the sum of the riffle lengths, to calculate the weighted BHR with the following equation:

$$BHR_{weighted} = \frac{\sum_{i-1}^{n}(BHR_i * RL_i)}{\sum_{i=1}^{n} RL_i}$$

6.2.1.2 Entrenchment Ratio

Entrenchment ratio (ER) is a measure of floodplain connectivity and describes the ability of a stream to spread water across a floodplain to dissipate energy. ER is calculated as the flood prone width divided by the bankfull width of a channel. The ER does not have to be measured at every riffle, as long as the valley width is fairly consistent. For valleys that have a variable width or for channels that have bank height ratios above 2.0, it is recommended that the ER be measured at all riffles and to calculate the weighted ER.

ER is measured from surveyed riffle cross sections. Harrelson et al. (1994) describes basic field survey methods. ER is the flood prone width divided by the bankfull width of a channel, measured at a riffle cross section. The ER equation is shown below. The flood prone width is measured as the cross-section width at an elevation two times the bankfull max depth. Rosgen (2014) demonstrates the cross-sectional information needed for ER calculations (Figure 6.13).

$$ER = \frac{Flood\ Prone\ Width\ (FPW)}{Bankfull\ Width\ (BKF)}$$

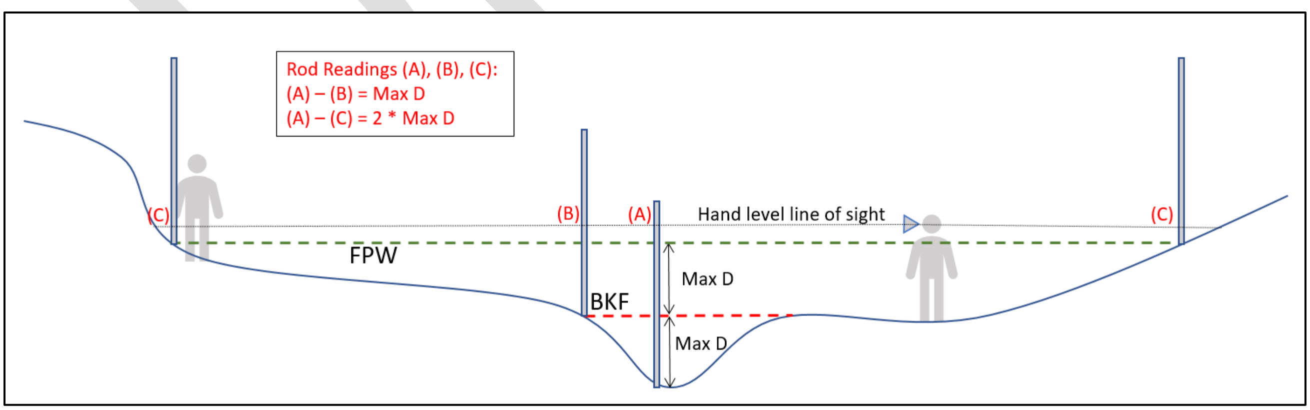


Figure 6.13. Cross-sectional illustration for field measurements to compute the Entrenchment Ratio (Rosgen 2014).

One measurement effort is sufficient for reaches with approximately uniform floodplains. If a target reach has a highly variable floodplain, ER measurements should be accomplished at each riffle, and a weighted average ER score is computed using the equation below:

$$ER_{weighted} = \frac{\sum_{i-1}^{n}(ER_i * RL_i)}{\sum_{i=1}^{n} RL_i}$$

Where, RL_i is the length of each riffle and where ER_i is the ER measured at each riffle.

Field and computational procedures for ER measurements at riffles are summarized below.

a. Identify the bankfull line on both streambanks at riffles. Bankfull indicators are described in Section 5.5.3.
b. Measure the bankfull max depth and width and measure the length at each riffle (RL_i).
c. Multiply bankfull max depth by two, and at that channel height keeping a tape level, measure the flood prone width FPW as illustrated in Figure 6.13 at each riffle.
d. Calculate the ER by dividing the flood prone width (FPW) by the bankfull width (BKF) for each riffle (equation on previous page).
e. More than one riffle is required to be measured, thus calculate a weighted ER for the project reach. An example table for computed a weighted average ER follows.

Riffle ID	Riffle Length (RL_i)	ER	ERi * RL_i
R1	27	1.3	35.1
R2	40	2.1	84.0
R3	12	1.8	21.6
R4	28	1.6	44.8
Total =	**107**	Total =	**185.5**
Weighted Average ER = 185.5 / 107 **= 1.7**			

6.2.2 Hydraulics: Non-Bankfull Metrics

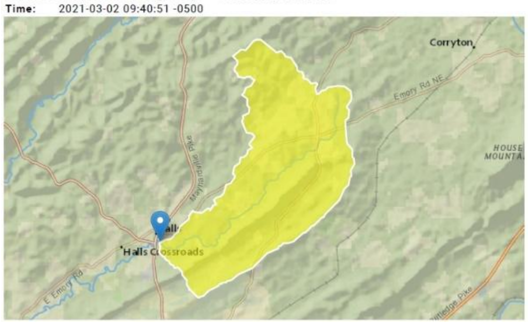
When bankfull indicators are not adequate, two measurement methods are used as an alternative to quantify floodplain connectivity: 1) Floodplain Inundation Frequency and 2) Channel Incision. Criteria for when to use these two metrics for conditions where bankfull indicators are inadequate is summarized in Section 5.4.4. Assessment reaches within the project site reach need to be delineated in the field and methodology for accomplishing this task is described in Section 5.6.3.

The first step needed for both the Floodplain Inundation Frequency and Channel Incision measurement methods is to obtain from the USGS StreamStats the discharge recurrence frequencies for Q_2, Q_5, Q_{10}, Q_{25}, Q_{50}, and Q_{100}, available at: https://streamstats.usgs.gov/ss/

The discharges are used to identify which recurrence frequency discharge overtops onto the floodplain. In USGS StreamStats, identify the state of Tennessee and zoom in onto the “study area” on the interactive map. Click on “Delineate” and place your cursor on the blue line at the point most downstream of your project reach, which will delineate the watershed boundary. Once the watershed has been successfully delineated, click on Peak-flow Statistics and "Continue" to obtain the recurrence frequencies. An example of a StreamStats output for the Beaver Creek watershed at Halls Crossing in Knox County is shown in Figure 6.14.

Beaver Creek at Halls Crossing

Region ID: TN
Workspace ID: TN20210302144033053000
Clicked Point (Latitude, Longitude): 36.08228, -83.92477
Time: 2021-03-02 09:40:51 -0500



Peak-Flow Statistics Flow Report[MultiVariable Area 1]

PII: Prediction Interval-Lower, Plu: Prediction Interval-Upper, SEp: Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	PII	Plu	SEp	Equiv. Yrs.
50_percent_AEP_flood	846	ft^3/s	455	1570	39.2	1.7
20_percent_AEP_flood	1320	ft^3/s	712	2450	38.2	2.6
10_percent_AEP_flood	1680	ft^3/s	890	3170	40.1	3.4
4_percent_AEP_flood	2160	ft^3/s	1100	4230	42.7	4.3
2_percent_AEP_flood	2540	ft^3/s	1250	5160	45.2	4.9
1_percent_AEP_flood	2960	ft^3/s	1400	6250	47.9	5.3
0_2_percent_AEP_flood	3980	ft^3/s	1700	9290	55.2	5.8

Figure 6.14. Example output from USGS StreamStats for upper Beaver Creek, Halls Crossing, Tennessee. Left figure is the delineated watershed and right is the peak-flow statistics (the 50% AEP is the 2-yr flood discharge, whereas the 1% AEP is the 100-yr flood discharge).

StreamStats has a minimum watershed size that the program can delineate and provide peak-flow statistics. If the watershed is too small to delineate no results will be computed and no message is provided. In this case for small watersheds, several hydrological equations/tools can be used to compute these discharge return frequencies (*Handbook of Hydrology*, Maidment 1993). They include: Rational Method, USDA TR-55 model, and USGS Regression equations. For the purpose of the TMAT, the USGS Regression Equations developed at the Tennessee Water Center (Table 6.4; Robbins 1984) are provided below for use to compute the Q_2, Q_5, Q_{10}, Q_{25}, Q_{50}, and Q_{100} values. On-line documents and/or tools for the Rational Method and USDA TR-55 model are as follows:

https://iowadot.gov/design/dmanual/04a-05.pdf

https://www.knoxcounty.org/stormwater/manual/Volume%202/knoxco_swmm_v2_chap3_jan2008.pdf

https://www.ars.usda.gov/research/software/download/?softwareid=527&modecode=30-70-10-10

The USGS regression equations are best summarized in Table 6.4 per the TDOT (2021) Drainage Manual, Chapter 4. For reference, TDOT (2021) Chapter 4 can be obtained at:

https://www.tn.gov/content/dam/tn/tdot/roadway-design/documents/drainage_manual/DM-Chapter-04.pdf.

The USGS regression equations for peak flow statistics in Table 6.4 are valid for impervious surface area less than 10% within a watershed. If the watershed area is urban (> 10%

Table 6.4. USGS Rural Equations for discharge recurrence frequencies (Robbins 1984; TDOT

2021). For use when impervious surface in a watershed is less than 10%. See Figure 6.15 for hydrologic area designations. DA is in square miles.

Discharge Recurrence Frequency	**Hydrologic Area 1**	**Hydrologic Area 2**
2-year, Q_2 =	$Q_2 = 119 \cdot (DA)^{0.755}$	$Q_2 = 204 \cdot (DA)^{0.727}$
5-year, Q_5 =	$Q_5 = 197 \cdot (DA)^{0.740}$	$Q_5 = 340 \cdot (DA)^{0.716}$
10-year, Q_{10} =	$Q_{10} = 258 \cdot (DA)^{0.731}$	$Q_{10} = 439 \cdot (DA)^{0.712}$
25-year, Q_{25} =	$Q_{25} = 342 \cdot (DA)^{0.722}$	$Q_{25} = 573 \cdot (DA)^{0.709}$
50-year, Q_{50} =	$Q_{50} = 411 \cdot (DA)^{0.716}$	$Q_{50} = 677 \cdot (DA)^{0.707}$
100-year, Q_{100} =	$Q_{100} = 672 \cdot (DA)^{0.699}$	$Q_{100} = 785 \cdot (DA)^{0.705}$

Discharge Recurrence Frequency	**Hydrologic Area 3**	**Hydrologic Area 4**
2-year, Q_2 =	$Q_2 = 280 \cdot (DA)^{0.789}$	$Q_2 = 436(DA)^{0.527}$
5-year, Q_5 =	$Q_5 = 452 \cdot (DA)^{0.769}$	$Q_5 = 618 \cdot (DA)^{0.545}$
10-year, Q_{10} =	$Q_{10} = 574 \cdot (DA)^{0.761}$	$Q_{10} = 735 \cdot (DA)^{0.554}$
25-year, Q_{25} =	$Q_{25} = 733 \cdot (DA)^{0.753}$	$Q_{25} = 878 \cdot (DA)^{0.564}$
50-year, Q_{50} =	$Q_{50} = 853 \cdot (DA)^{0.748}$	$Q_{50} = 981 \cdot (DA)^{0.570}$
100-year, Q_{100} =	$Q_{100} = 972 \cdot (DA)^{0.745}$	$Q_{100} = 1080 \cdot (DA)^{0.537}$

Figure 6.15. Hydrological unit areas for USGS regression equations for peak flow statistics.
impervious surface) then the recommended equations to be used are summarized as follows

from Robbins (1984) and TDOT (2021).

$$Q_2 = 1.76 \cdot A^{0.74}\ I_{IMP}^{0.48}\ P^{2.01}$$

$$Q_5 = 5.55 \cdot A^{0.75}\ I_{IMP}^{0.44}\ P^{2.53}$$

$$Q_{10} = 11.8 \cdot A^{0.75}\ I_{IMP}^{0.43}\ P^{2.12}$$

$$Q_{25} = 21.9 \cdot A^{0.75}\ I_{IMP}^{0.39}\ P^{1.89}$$

$$Q_{50} = 44.9 \cdot A^{0.75}\ I_{IMP}^{0.40}\ P^{1.42}$$

$$Q_{100} = 77.0 \cdot A^{0.75}\ I_{IMP}^{0.40}\ P^{1.01}$$

Where, Q_i is in cubic feet per second (cfs), drainage area (A) is in square miles (mi^2), I_{IMP} is % impervious area in the watershed; and precipitation (P) is the 2-year, 24-hour rainfall statistic.

The 2-year, 24-hour rainfall statistic (P) for any location in Tennessee can be obtained from NOAA's National Weather Service, Hydrometerorological Design Studies Center, Precipitation Frequency Data Server (PFDS). Output from this web page provides the NOAA Atlas 14 Intensity-Duration-Frequency (IDF) data. See the link below to this web page.

https://toolkit.climate.gov/dashboard-noaa-atlas-14-precipitation-frequency-data-server

The second step needed for both the Floodplain Inundation Frequency and Channel Incision measurement methods is to survey two channel cross-sections with adjacent floodplain surfaces that bound the assessment reach, and measuring the channel slope between the cross-sections. Selecting the upstream and downstream boundaries of the assessment reach is described in Sections 5.6.2 and 5.6.3. It is best to select these boundaries at riffles. The critical criteria are not to use pools as either of the survey boundaries, and should not include significant changes in channel slope between boundaries. Abrupt slope changes are to be an upstream or downstream boundary, i.e., a reach break. More than one assessment reach can be applied for these two metrics. Harrelson et al. (1994) describes the basic field procedures to surveying stream channel cross-sections and slope, in addition to other physical habitat metrics. Other references can be used that describe other means and methods acknowledging advances in survey gear over the years.

6.2.2.1 Floodplain Inundation Frequency Metric

Floodplain inundation frequency metric represents the discharge return frequency when floodwaters overtop the channel onto the floodplain. These discharges are defined as statistical return frequencies and denoted as 2-year, 5-year, etc. up to 100-year (Q_2, Q_5, Q_{10}, Q_{25}, Q_{50}, and Q_{100}). These discharge return frequencies are obtained from USGS StreamStats with an example output shown in Figure 6.14. After the field survey of channel cross-sectional data has been collected, the procedure for determining the Qi value where the floodplain is inundated is described below. The performance relations for calculating index values are based on geomorphic principles where a channel well connected to its floodplain would generally inundate its floodplain at a two-year return frequency (Q_2). A channel incised will contain floodwaters to a greater extent, thus the worst-case scenario is that even during a 100-year return flood all the floodwaters remain in the channel. The procedure described below applies the Manning's equation, though the USACE HEC-RAS (1D) can be easily used with an example output shown in Figure 6.16, and an example procedure described below.

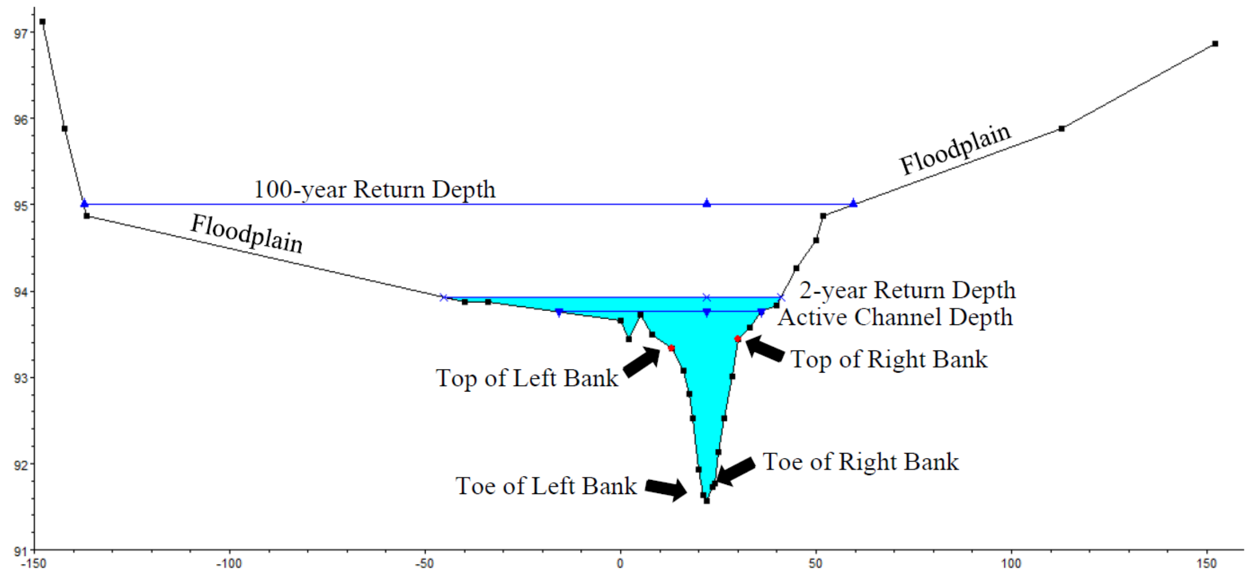


Figure 6.16. Example HEC-RAS model output at one cross-section for water surface depth in the channel and floodplain.

Manning's equation is used for open channel hydraulic problems, solving for a discharge given a defined channel morphology. Channel morphology includes surveyed cross-sections, and a channel distance and slope between cross-sections. Cross-sectional morphology includes the area (A) and the hydraulic radius (R_h). The cross-sectional R_h is the area (A) divided by the wetted perimeter (Pw). The cross-sectional flow area is A (an example shown as the light blue area in Figure 6.16). The P_w is estimated by the cross-sectional length in contact with stream flow. The Manning's equation is as follows (Chow 1959):

$$Q_i = \frac{1.49}{n} A \cdot R_h^{2/3} \cdot S^{1/2}$$

where, Qi = flow rate (ft^3/s); n = Manning roughness coefficient; A = average cross-sectional area (ft^2); P_w = cross-sectional wetted perimeter (ft); R_h = A/P_w; and S = channel slope.

For the purpose of computing the Floodplain Inundation Frequency metric, the Manning equation is rearranged as follow.

$$\frac{A^{5/3}}{P_w^{2/3}} = \frac{Q_i \cdot n}{1.49 \cdot S^{1/2}}$$

This equation rearrangement is applied where the left-hand side represents the cross-sectional A and P_w at low-bank height or other words when the channel is full and the flood flow overtops onto the floodplain. The right-hand of the equation includes a Manning n value and channel slope (S) that is obtained from a field survey. The discharge (Qi) varies using values obtained from USGS StreamStats with the goal to determine when the value for the right-hand side of the equation exceeds that computed for the left-hand side. A Manning n is determined from field observation for the reach matching standard table values published for different boundary properties. Table 6.5 is summary data with standard Manning n values with acceptable ranges, though there are other data sources for these values and those can be used with the reference for the data source cited pending approval by TDEC and the USACE. The NRCS (2007) provides a means to compute the Manning n from Rosgen (2014) and provided in Appendix 9.5.

Table 6.5. Manning n values summarized for different stream boundary conditions (Chow 1959).

Type of Stream Channel and Description	Manning n		
	Minimum	Normal	Maximum
Clean, straight channel, uniform bed, < 4% slope	0.025	0.030	0.033
Clean, meandering channel with pools, < 4% slope	0.030	0.035	0.045
Low-gradient channel with deep pools, < 1% slope	0.050	0.070	0.080
Low-gradient channel with sparse woody debris	0.060	0.080	0.095
Low-gradient channel with heavy woody debris	0.075	0.120	0.200
High-gradient channel, gravel/cobble bed, >5% slope	0.030	0.040	0.050
High-gradient channel, large boulders, > 5% slope	0.045	0.060	0.075
Channel bank, no vegetation	0.020	0.030	0.040
Channel bank, grassy bank cover	0.025	0.035	0.050
Channel bank, light tree/woody vegetation cover	0.035	0.050	0.065
Channel bank, medium tree/woody vegetation cover	0.070	0.100	0.016
Channel bank, heavy tree/woody vegetation cover	0.110	0.150	0.200
Concrete-lined channel	0.012	0.014	0.016
Trapezoidal soil channel with grass banks	0.028	0.035	0.045

To compute the Qi at which flood water overtops onto the floodplain, the following procedure is described below.

a. Obtain the discharge recurrence frequencies (Qi = Q_2, Q_5, Q_{10}, Q_{25}, Q_{50}, and Q_{100}) using the USGS StreamStats at the downstream end of each assessment reach if the watershed area is large enough to generate output; if not use the USGS regression equation as defined above in Table 6.4.
b. For each assessment reach, survey the upstream and downstream boundary cross-sections, and the slope (S) between the cross-sections. Survey boundaries are best at the riffle thalwegs although other channel bed surfaces are acceptable expect for pools.
c. Select a Manning n for the reach from Table 6.5, or other data source, that best matches the channel boundaries roughness characteristics. Describe and justify selection.
d. For both upstream and downstream surveyed cross-section compute the area (A) and wetted perimeter (P_w) for the flow condition when the channel flow is full and flood waters overtopping onto the floodplain, and then average the A and P_w for both cross-sections.
e. Using the average A and Pw, compute $A^{5/3}/P_w^{2/3}$ (left side of the equation).
f. Using the measured slope (S) and selected reach Manning n, for each of the discharge

recurrence frequencies (Qi) calculate $Qi{\cdot}n/1.49{\cdot}S^{1/2}$ (right side of the equation) for each Qi.

g. Determine the Qi in which the value for $Qi{\cdot}n\ /1.49{\cdot}S^{1/2}$ is greater than the value for $A^{5/3}/P_w^{2/3}$; this is the Qi in which the floodplain is inundated.

An example on how to compute the Floodplain Inundation Frequency metric will use a reach on Beaver Creek at Halls Crossing where the USGS StreamStats data was obtained and shown in Figure 6.14. The field survey data for the two cross-sections areas (A) and wetted perimeters (Pw), and channel slope (S) are shown in Figure 6.17. In this figure the upstream and downstream cross-sectional areas are 268.5 ft^2 and 272.7 ft^2, respectively, and the average A is 270.6 ft^2. The upstream and downstream wetted perimeters are 48.1 ft and 50.7 ft, respectively, and the average Pw is 49.4 feet. The averages are used to compute the $A^{5/3}/P_w^{2/3}$ value. It is $(270.6)^{5/3}/\ (49.4)^{2/3} = 840.9$ (left-side of equation). The slope was surveyed as 0.0017 and the reach Manning n is 0.15. For each Qi, the values for $Qi{\cdot}n/1.49{\cdot}S^{1/2}$ are computed (right-side of equation). Slope and Manning n do not change thus the equation can be simplified as:

$Qi \cdot n\ /1.49{\cdot}S^{1/2} = Qi \cdot 0.15\ /\ (1.49 \cdot 0.0017^{1/2}) =\ \ 0.77 \times{\cdot}\ Qi =$ _______;
and each Qi is used to compute < $Qi \cdot n\ /1.49{\cdot}S^{1/2}$ > left-hand side of equation as follows.

$Q_2 = 0.77 \cdot 846$ cfs = 653 $A^{5/3}/P_w^{2/3} = 840.9$

$Q_5 = 0.77 \cdot 1320$ cfs = 1019 Flood water overtops bank between Q_2 and Q_5

$Q_{10} = 0.77 \cdot 1680$ cfs = 1297

$Q_{25} = 0.77 \cdot 2160$ cfs = 1668

$Q_{50} = 0.77 \cdot 2540$ cfs = 1961

$Q_{100} = 0.77 \cdot 2960$ cfs = 2285

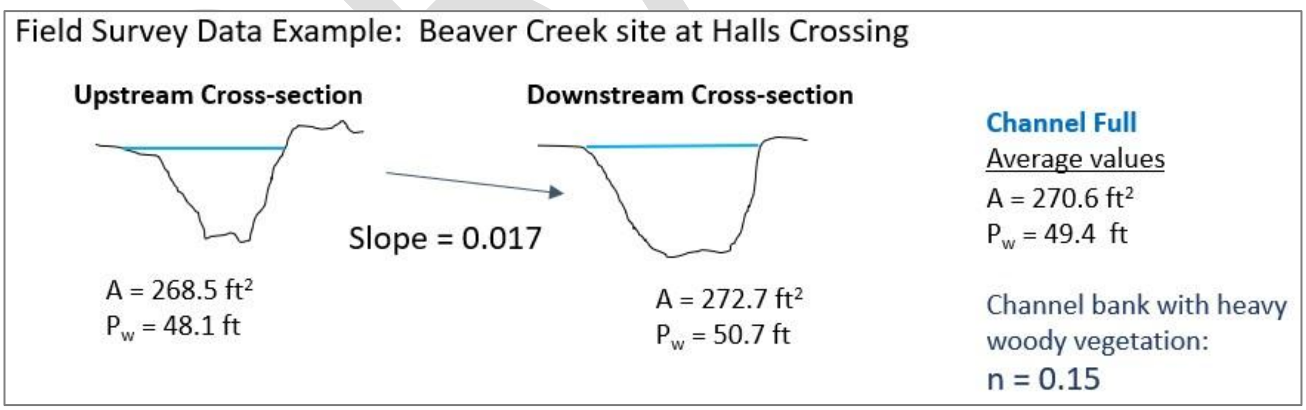


Figure 6.17. Channel survey data for cross-sectional areas and wetted perimeters, and channel slope for an assessment reach on Beaver Creek at Halls Crossing, Knox County.

An alternative method to determine the water surface elevation on the floodplain is to use the HEC-RAS 1D model, free-ware from the US Army Corps of Engineers (USACE). The HEC-RAS software can be downloaded from: https://www.hec.usace.army.mil/software/hec-ras/.

The HEC-RAS has a user's manual that provides helpful instructions for this modeling effort that is very straight forward for a single reach. Use of a HEC-RAS model allows for multiple reaches to be assessed, and provides accurate values for each cross-sectional A and P_w.

6.2.2.2 Channel Incision Metric

The Channel Incision metric is a measure of the potential excessive erosion over an assessment reach leading to vertical downcutting on the channel bed and lateral bank erosion. The measurement method is based on the "force vs resistance" concept, where the *force* is the hydraulic shear stress (τ) from moving water on the bed and bank. *Resistance* is a property of the boundary roughness to whether it can resist the hydraulic shear stress, and it is termed permissible shear stress (τ_p). This metric is based on the potential for vertical downcutting of the channel thus it is the measure of the resistance of the bed material and not the bank.

The Channel Incision metric is the ratio of τ/τ_p, where a ratio of 1.0 indicates that the channel is at the threshold of bed sediment erosion and less than 1.0 indicates no erosion potential. A ratio greater than 1.0 indicates the potential for erosion and a ratio greater than 1.3 is considered the value for excessive erosion potential (Langendoen 2000; Fischenich 2001). Note, the erosion potential scale for the ratio τ/τ_p follows the scale proposed in the Rosgen Near-Bank Stress (NBS) parameter, Level III, No. 6 assessment methodology. This Rosgen NBS ratio τ/τ_p is exactly the same metric as the Channel Incision metric.

Hydraulic shear stress (τ) for a reach is computed by the following equation.

$$\tau = \gamma R_h S$$

where, τ = Hydraulic shear stress for the reach at the channel bed (lb/ft^2)

γ = Specific weight of water = 62.4 lb/ft^3

R_h = Average hydraulic radius (R_h) of the channel with moving water (A/P_w) (ft)

A = Cross-sectional area of flow (ft^2)

P_w = Cross-sectional length of the wetted perimeter of flow (ft)

S = Slope of the channel bottom between the cross-sections (ft/ft)

The maximum τ is where the channel is full just at the stage floodwaters overtop the channel onto the floodplain which represents the greatest potential for erosion. The τ_{max} is computed for the flow stage overtopping the stream bank onto the floodplain requiring the average A and Pw for the upstream and downstream reach cross-sections. A reach hydraulic radius (R_h) is computed by from the average A and P_w as: $R_h = A/P_w$. The channel morphology data needed for τ_{max} is the same cross-sectional data surveyed for the Floodplain Inundation frequency metric and shown in Figure 6.17 example. The survey data includes channel slope (S).

A permissible shear stress (τ_p) is obtained from Table 6.6 based on the surface property of the bed material. Values for τ_p are summarized from Fischenich (2001), though other reference sources are available and can be used as approved by TDEC and USACE. Fischenich (2001) also provide τ_p values for the stream bank boundaries such as vegetation and soil bioengineering practices. For example, hardwood tree plantings range in τ_p between 0.4 and 2.5 lb/ft^2, long

Table 6.6. Permissible shear stress (τ_p) values in lb/ft^2 units for stream channel bed material

(summarized from Fischenich 2001).

Boundary Category	Stream Channel Bed Material Types	Permissible Shear Stress (lb/ft^2)
Soils	Alluvial silt, non-colloidal	0.05
	Alluvial sand, non-colloidal	0.04
	Stiff Clay, mobile	0.26
	Alluvial silt, colloidal	0.38
	Fine colloidal sand	0.03
	Mixed sediment, graded silts to cobble	0.43
	Shale	0.67
Non-cohesive Sediments	Fine gravel; dia. > 0.16 inch	0.08
	Course grave; dia. > 0.6 inch	0.25
	Very course gravel; dia. >1.3 inch	0.54
	Gravel; dia. > 2 inch	0.67
	Gravel/cobble; dia. > 6 inch	2.0
	Gravel/cobble; dia. > 12 inch	4.0
	Boulder; dia. > 20 inch	9.3
	Boulder; dia. > 40 inch	18.7
	Boulder; dia. > 80 inch	37.4
Artificial Rock / Quarried Rock / Rip-rap / Gabions / Hard Surfacing	Rock; dia. > 9 inch	3.8
	Rock; dia. > 12 inch	5.1
	Rock, dia. > 18-inch	7.6
	Rock; dia. > 24 inch	10.1
	Gabions	10.0
	Concrete	12.5
	Bedrock	20.0

native grasses between 1.2 and 1.7 lbs/ft^2; coir roll between 3.0 and 5.0 lbs/ft^2, and live willow stakes between 2.1 and 3.1 lbs/ft^2.

For mitigation projects proposing lift to this particular metric the primary goal is to reduce the reach boundary shear stress through better floodplain connectivity. By decreasing the water depth for flood waters to overtop onto a floodplain, the τ_{max} is reduced leading to lesser potential for channel incision. It is not necessarily to simply introduce larger, heavier bed material to increase the permissible shear stress. Any introduced bed material must comport with the natural bed material / particle size distribution found in similar ecoregion reference streams, in order to receive credit for functional lift in this metric.

The Channel Incision metric utilizes cross-sectional field data collected and calculations as conducted for the Floodplain Inundation Frequency measurement method (Section 6.2.2.1). The following procedure are applied to compute this metric.

a. Delineate the assessment reach per criteria described in Section 5.6, where the upstream and downstream boundaries for each reach are surveyed for cross-sectional area (A) and wetted perimeter (P_w), and the slope (S) between the cross-sections. See Figure 6.17 for a survey example (same data collected for the Floodplain Inundation Frequency metric).

b. Compute the hydraulic radius (R_h) for the upstream and downstream cross-section based on the surveyed A and P_w values for when the channel is full, and average the two values for R_h. Calculation procedures are demonstrated in Section 6.2.2.1.

c. Compute the reach hydraulic shear stress ($\tau = \gamma \cdot R_h \cdot S$).

d. While conducting field survey to obtain channel morphology data per step (a), estimate the length of dominant bed material "patches" along the longitudinal profile, and compute the % length of each along the channel centerline. Table 6.6 lists possible different types of bed sediment material types and surfaces.

e. Per the dominant bed material "patches" measured, obtain the permissible shear stress (τ_p) for the different identified bed material types from Table 6.7. The τ_p represents the value which most accurately matches the channel bed characteristics.

f. Calculate the ratio of the hydraulic shear stress to the permissible shear stress (τ/τ_p) for each characteristic length of channel bed material. If only one characteristic bed material is present then the computed ratio is used for the existing and proposed field values.

g. For multiple ratios due to more than one dominant bed material, calculate the weighted average ratio for the Channel Incision metric by multiplying each ratio of shear stresses by % length and sum all the weighted ratio-lengths. The reach weighted average ratio (τ/τ_p) is used for the existing and proposed field values. An example is described below.

Channel Incision metric example: If a 560-foot assessment reach consists of 240 feet of bedrock, 70 feet of alluvial silt (non-colloidal), and 250 feet of gravel between 2- and 6-inch diameter. The τ_p are 20.0 lb/ft^2, 0.38 lb/ft^2, and 0.67 lb/ft^2, respectively. The reach τ is equal to 0.58 lb/ft^2, computed per the hydraulic shear stress equation and surveyed field data. The following table computes the reach weighted average ratio (τ/τ_p) for the assessment reach.

Bed Material	**Ratio τ/τ_p**	**Channel Length**	**% Channel Length**	**Ratio * % length**
Bedrock	0.03	240 ft	42.9 %	0.013
alluvial silt (colloidal)	1.53	70 ft	12.5 %	0.191
Gravel (2-6 inch)	0.86	250 ft	44.6 %	0.384
	Total =	560 ft	Sum =	0.59
	Weighted Average τ/τ_p = 0.59 (< 1, stable, no channel incision)			

An alternative to using this hand calculation method is to use the USACE HEC-RAS model. The model directly computes τ at each cross-section and can be averaged between the two. This model is a simple tool and provides useful output for two additional parameters, floodplain storage and floodplain inundation. Guidance on use of the HEC-RAS software for simple channels is provided in the USACE User's Manual.

Within the HEC-RAS model, the surveyed cross-sectional data are entered into the Geometric

Data module, and Qi values obtained from the USGS StreamStats are entered into the Steady Flow Data module. Per the Warner Creek example, the water surface stages for the Qi values are shown in Figure 6.18. By inspection of the respective water surface stages for each Qi, it is observed that the 5-year recurrence frequency (Q_5) overtops onto the floodplain. This Q_5 is used for the Floodplain Inundation Frequency measurement method (Section 6.2.2.1). The output data table provides a τ value of 5.98 lb/ft^2 for the reach. The reach is mostly bedrock thus the τ_p is 20 lb/ft^2, and the τ/τ_p is 0.30 (5.98 lb.ft^2 /20.0 lb/ft^2), thus the channel is stable with limited potential for channel incision. Therefore, the index value is equal to 1.0.

Output from a HEC-RAS 1D model for Warner Creek, Bellevue, Tennessee with the location of the assessment reach within Edwin Warner Park, Davidson County. The use of a HEC-RAS model provides the data needed for both the Floodplain Inundation Frequency and Channel Incision metrics. Model output is shown in Figure 6.18.

6.2.3 Aggradation Ratio

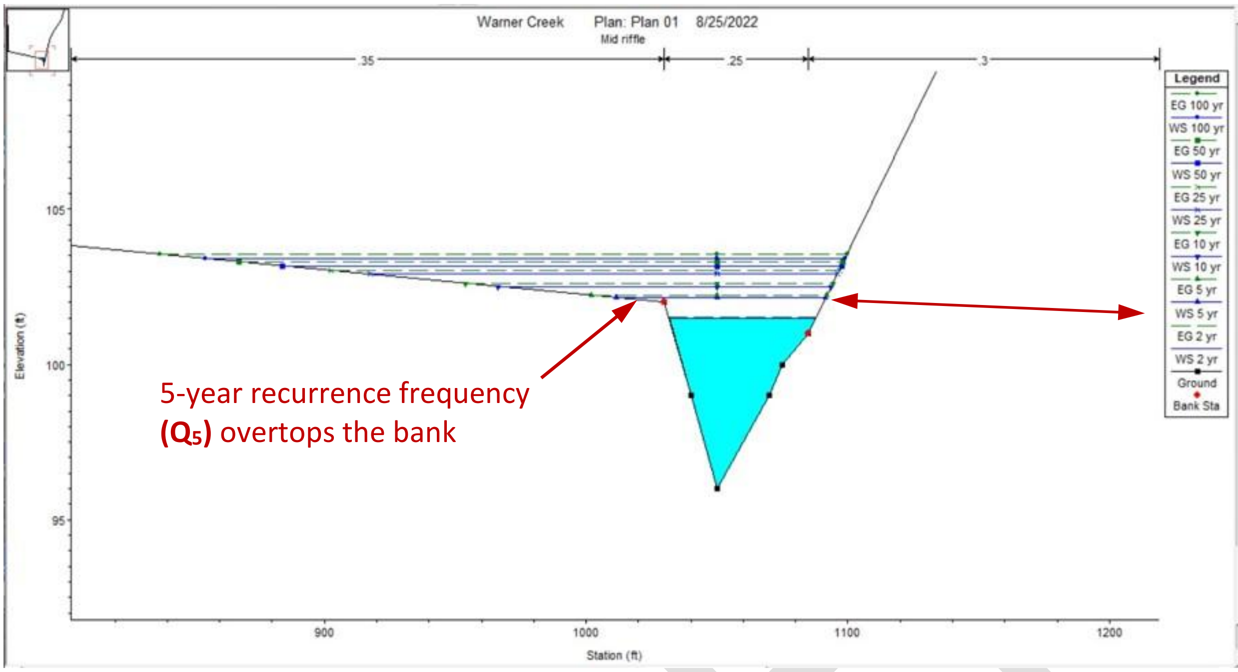
The aggradation ratio is an optional metric meant as an indicator of channel stability from excessive deposition observed by channel widening, lateral instability, and bed aggradation. This measurement method will be mainly used for C and E Rosgen stream types, but may apply to some B/Bc stream types if the channel is exhibiting aggradation. Visual indicators of aggradation may include mid-channel bars and bank erosion within riffle sections, though care must be applied because in some geomorphic settings a mid-channel bar is a stable feature (Knighton 1998). This metric can be applied when aggrading bed material causes alteration of the channel morphology to the extent that stable bedforms (e.g., pool/riffle sequences) are unstable or lacking. The aggradation ratio equation is as follows.

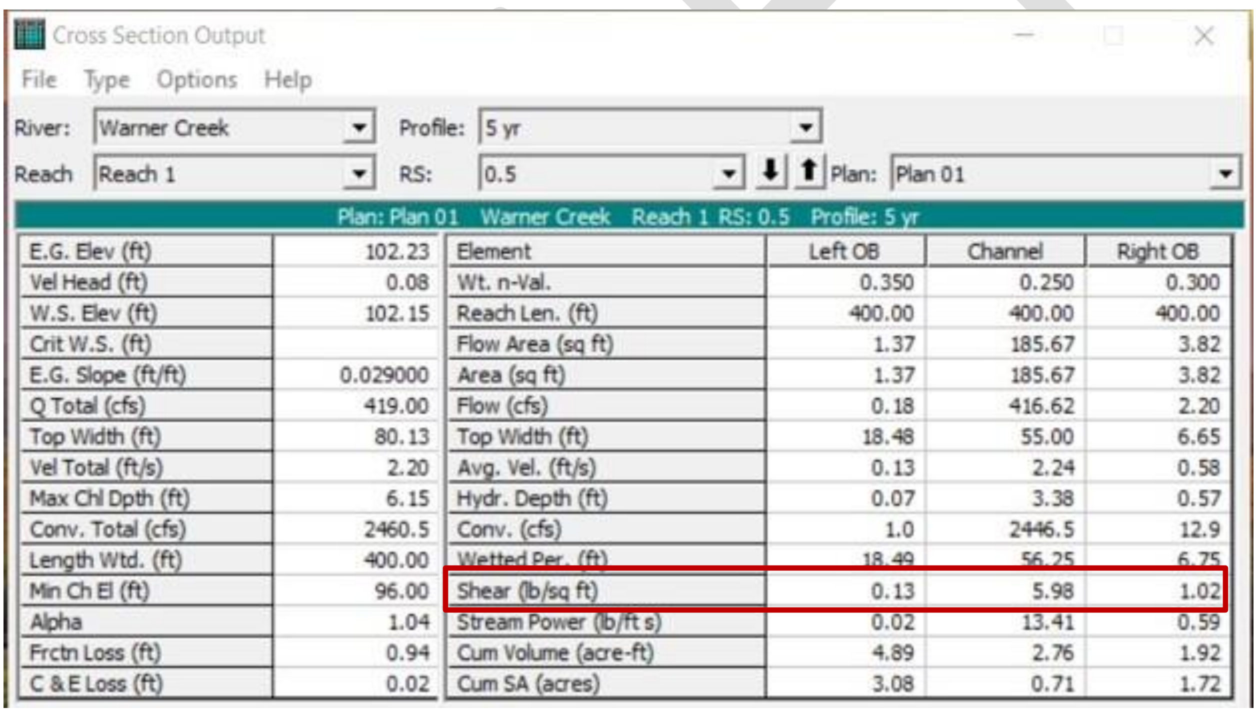
$$Aggradation\ Ratio = \frac{W_{max\ riffle}}{D_{mean\ riffle}} \Big/ Reference\ WDR$$

The aggradation ratio is calculated by dividing the bankfull width at the widest riffle by the mean bankfull riffle depth at that riffle, and dividing this ratio (he numerator) by a reference width to depth ratio (WDR) based on stream type (the denominator), and values per Rosgen stream type are listed in Table 6.7.

Table 6.7. Reference bankfull width to depth ratio (WDR) by Rosgen stream type.

Stream Type	B	C	E
Data Count	30	47	32
Minimum	10	12	6
25th Percentile	14	14	9
Median	19	16	10
75th Percentile	25	19	11
Maximum	40	33	12




Cross Section Output

File Type Options Help

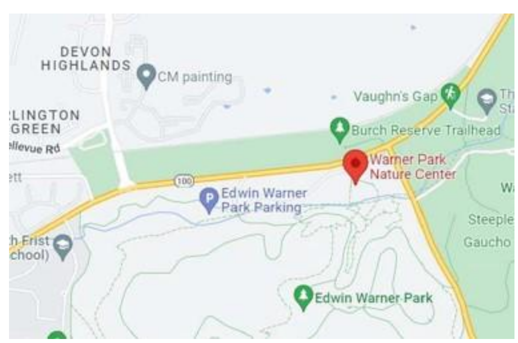
River: Warner Creek Profile: 5 yr

Reach: Reach 1 RS: 0.5 Plan: Plan 01

Plan: Plan 01 Warner Creek Reach 1 RS: 0.5 Profile: 5 yr

		Element	Left OB	Channel	Right OB
E.G. Elev (ft)	102.23	Wt. n-Val.	0.350	0.250	0.300
Vel Head (ft)	0.08	Reach Len. (ft)	400.00	400.00	400.00
W.S. Elev (ft)	102.15	Flow Area (sq ft)	1.37	185.67	3.82
Crit W.S. (ft)		Area (sq ft)	1.37	185.67	3.82
E.G. Slope (ft/ft)	0.029000	Flow (cfs)	0.18	416.62	2.20
Q Total (cfs)	419.00	Top Width (ft)	18.48	55.00	6.65
Top Width (ft)	80.13	Avg. Vel. (ft/s)	0.13	2.24	0.58
Vel Total (ft/s)	2.20	Hydr. Depth (ft)	0.07	3.38	0.57
Max Chl Dpth (ft)	6.15	Conv. (cfs)	1.0	2446.5	12.9
Conv. Total (cfs)	2460.5	Wetted Per. (ft)	18.49	56.25	6.75
Length Wtd. (ft)	400.00	Shear (lb/sq ft)	0.13	5.98	1.02
Min Ch El (ft)	96.00	Stream Power (lb/ft s)	0.02	13.41	0.59
Alpha	1.04	Cum Volume (acre-ft)	4.89	2.76	1.92
Frctn Loss (ft)	0.94	Cum SA (acres)	3.08	0.71	1.72
C & E Loss (ft)	0.02				

Figure 6.18. HEC-RAS 1D model output for an example assessment reach on Warner Creek, Davidson County, showing the downstream cross-section and water stages for the Qi values (above), and the data output table for the stage that overtops the channel bank onto the floodplain to obtain the hydraulic shear stress τ (below).



Perform cross-sectional surveys at all riffles within the assessment segment that are exhibiting signs of excessive aggradation. It is recommended to survey multiple riffle cross sections with aggradation features to ensure that the widest value for the reach is obtained and to document the extent of aggradation throughout the stream reach. Calculate the bankfull width, bankfull mean depth, and WDR for each of these surveyed riffles where the widest cross section is the reported WDR. The reference WDR is selected by the practitioner from Table 6.7 based on a geomorphic reference dataset collected throughout Tennessee. Use the median value for stream type unless another percentile can be justified geomorphologically. The reference WDR must remain consistent throughout all monitoring and condition assessments.

6.3 Geomorphology I Functional Category

Parameters and metrics for Geomorphology are organized into two categories as Geomorphology I and II. The Geomorphology I category consists of two parameters: 1) Large Woody Debris and Riparian Corridor (Table 2.1, Figures 2.2 and 2.3). Section 6.3 describes the measurement methods for the Geomorphology I functional category.

6.3.1 Large Woody Debris

Large Woody Debris (LWD) is defined as dead and fallen wood over 1m in length and at least 10 cm in diameter at the largest end. The measurement method consists of counting LWD pieces within cross-sectional Zones 1 and 2 of the assessment reach (Figure 6.19). Any LWD piece that is in Zones 1 and 2 are counted even those pieces that extend into Zones 3 and 4. Zone 1 is LWD that is below the base flow water surface or resting on the streambed, whereas Zone 2 is LWD below bankfull or low-height top of bank above baseflow so that during high flows it is within active channel supporting habitat maintenance processes. Figure 6.19 illustrates LWD in different channel zone positions. Zones 1-4 are shown only for general guidance related to LWD functional relationships for stream habitat and not used for the LWD Index measurement methods as described in Harman et al. (2017). The TMAT only uses number of LWD pieces as the field value to compute the metric's index score.

LWD pieces are counted within the assessment reach of the project site, determined as described in Section 5.6.3. Reach segmentation for each project site reach is described in Section 5.6.2. The length of the assessment reach will be approximately 15-20 channel unit widths. LWD field counts are recorded on field data sheets. Because the reference standards are based on pieces per 100 meters and ecoregion specific (Jennings Environmental 2017), the number of pieces counted must be normalized as pieces per 100 m.

The number of pieces counted must be divided by the ratio of total assessment reach length by 100 m, and that number is entered into the TMAT spreadsheet as the LWD field value. For example, if 35 LWD pieces were counted within a 120-m long assessment reach, the field value for the TMAT would be:

LWD field value = 35 pieces x (100 m/120 m) = 29

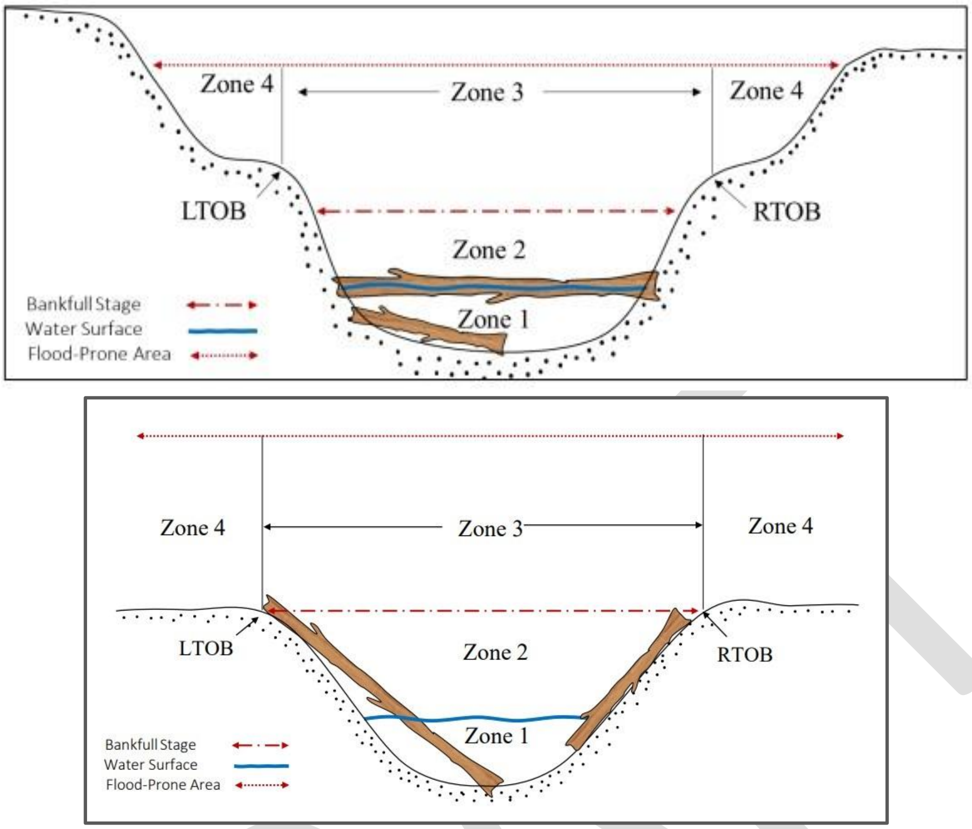


Figure 6.19. Large Woody Debris (LWD) cross-sectional positions to be measured. Figures from Harman et al. (2017).

The following steps are followed to obtain the LWD count:

a. Report the ecoregion the project site reach resides in.
b. Define the stream assessment reach between the upper and lower reach cross-sections and measure its longitudinal length down the channel centerline.
c. Count the number of LWD pieces at least partially within channel Zones 1 and 2 that are over 1 m in length and 10 cm in width at the widest end.

   Note: Within a debris dam or collective pile, each qualifying piece should be counted separately.

d. Record the LWD count, normalized counts on a per 100 m basis and enter that field value into TMAT spreadsheet.

6.3.2 Riparian Corridor

Riparian vegetation is a critical component of a healthy stream ecosystem. Riparian vegetation directly effects channel stability, provides for LWD recruitment maintaining instream habitat structure, supports water temperature attenuation, reduces instream nutrient concentrations and other water quality functions, provides organic matter inputs as leaf litter for ecosystem processes, and enhances species richness and biodiversity within this important habitat corridor. Within this parameter, four metrics are measured (Table 2.1). They are: 1) riparian width, 2) canopy cover, 3) average diameter at breast height (DBH), and 4) % invasive species. The canopy cover measure in conjunction with the average DBH represent the degree of forest structure, maturity, and density as an indicator to riparian ecosystem quality.

The riparian width metric is measured for the designated assessment reach. The canopy cover metric is measured at a minimum of three locations at riffle cross-sections if present within the assessment reach. If the reach has no riffles, this metric should be evaluated at the upper, middle, and lower reach locations. Sections 5.5.2 and 5.5.3 describe the procedures for project reach segmentation and delineating assessment reaches with a project site reach. The % Invasive Species metric, and the Average DBH metric are based on plots left and right of the streambank; therefore, if there are three cross-sections there will be six vegetation plots. As a check, the area of all the sample plots must be equal to or greater than 2% of the total riparian area with a minimum of four plots. Each 10 m by 10 m or 100 m^2 plot module represents 1/10 hectare of riparian area method (Lee et al. 2008). Where possible, the plots should be established at least 1 m from the top of bank into the riparian zone and within the first 30 m of the riparian zone.

6.3.2.1 Riparian Corridor Width

Riparian corridors contain riparian trees and shrub species that are generally unmanaged or in some cases managed for ecological purposes covering the corridor surface fully above top of bank. Large zones of solely herbaceous vegetation and grasses are not counted as functioning riparian areas unless these zones are limited and contribute to the species diversity and structure of that area. . The riparian corridor width is measured horizontally from the top of the stream bank to the edge of the unmanaged riparian community, or in the case of compensatory mitigation to the proposed site protection boundary. Minor disturbances or incursions do not sever the measured riparian corridor; for example, a greenway path or trail does not interrupt the corridor but a roadway would. If an assessment reach is immediately adjacent to a road or wide mowed area, then beyond that is forested, the riparian corridor width would be zero, since the road and managed grass zone abut the stream bank, and the forested zone is not adjacent to the stream.

The riparian corridor is measured perpendicular to the stream longitudinal profile on the left and right sides of the channel, and extends to the furthest extent of the drip line of the trees and shrubs. This measurement does not include the channel width. An average riparian width should be reported for both the right and left side of the channel separately. Riparian zones are defined by the presence of common riparian shrubs and trees; thus, grasses and herbaceous growth alone do not constitute a riparian zone. Measurements are required for the entire assessment reach, and the number of which are determined by major changes in riparian vegetation widths. A minimum of three measurements are required to obtain an average.

The following steps are followed to obtain the riparian width measurements:

a. Identify the riparian zone on both sides of the stream channel and examine any major differences in width of woody vegetation boundary to determine where width measurements are to be taken.

b. Measure the width of the riparian area within the riparian zone, perpendicular from the edge of the channel top of bank to the edge of the riparian zone. Record all measurements, left and right of the channel. At least three equally-spaced measurements are required.
c. Average the width measurements and record the average for both left and right sides of the channel.

Note, the functional limit of the riparian corridor width ends at a maximum of 200 ft. The distance maximizes both the metric's index score and the program considerations of riparian corridor function provided. Therefore, when collecting width measurements, a maximum of 200 ft. should be used for any single measurement to calculate the average riparian width even if undisturbed vegetation extends beyond this limit.

6.3.2.2 Riparian Canopy Cover

The Riparian Canopy Cover metric is measured in the field by use of a densiometer (Figure 6.20). The densiometer is a convex mirror etched into 24 ¼-inch boxes. Each box is subdivided into four smaller squares, via an imaginary cross in the center of each etched box, to create a total of 96 smaller squares that can be counted within the entire densiometer. Use of the device is described in the US Forest Service Research Notes by Strickler (1959). Densiometer protocols for measurement are also described in the TDEC's document DWR-WP-P-01-QSSOP-Macroinvert-122821 (2021), titled *Quality System Standard Operating Procedure for Macroinvertebrate Stream Surveys*.

The general field method is to hold the densiometer one foot above the water surface in the middle of a riffle area. Holding the instrument at this level eliminates errors due to differing heights of samplers and different water depths and includes low overhanging vegetation more consistently than holding the densiometer at waist level. Hold the instrument far enough away from the body so that the operator's head is just outside the grid, and use the bubble level to hold the instrument horizontal.

Three locations are to be surveyed using the densiometer at three riffles identified within the project reach. These three riffles should be as evenly dispersed as possible through the assessment reach. Measurements are to be taken at the position mid-riffle. At each riffle, take four measurements, facing upstream, downstream, the right descending bank, and the left descending bank. Count the number of small squares (out of a total of 96) that have tree canopy. Record this number (number of dots *with* canopy cover) on the field sheet. In order to get the overall percent canopy cover for that point, sum the four measurements, divide the total by 384 and multiply by 100%.

Figure 6.20. Photo of a US Forest Service densiometer, photo of grid cells with tree canopy on the mirror, and illustration of subdivided boxes for each data collection point (Cook et al. 1995).

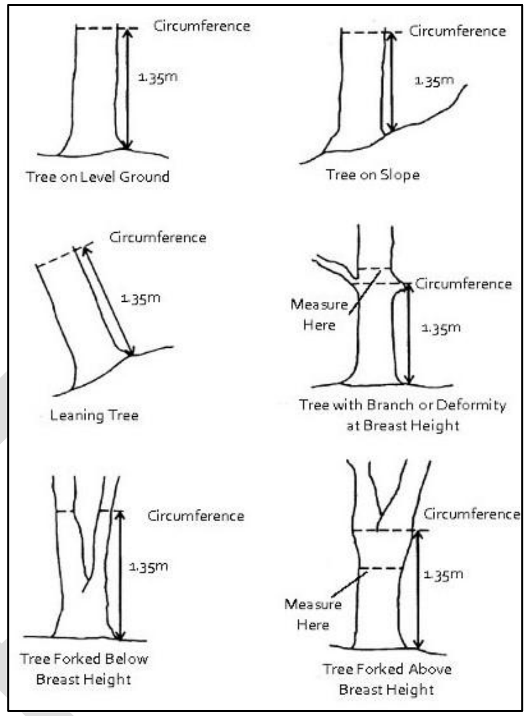
In heavy forested canopies, it may be easier to count open grid cells than covered cells. Within the densiometer sphere there are 24 whole grid cells, and 96 total quartered grid cells. Thus, if you count open quarter cells, subtract that count from 96, and enter that number for covered cell into the field datasheet. The performance curve is based on covered quarter grid cells.

The measurement method for the Riparian Canopy Cover metric using the densiometer is as follows.

a. Identify three riffles in the project reach and locate the riffle mid-point longitudinally along the stream centerline.
b. While standing in the center of each riffle, hold densiometer level following the procedure for its use described above, then turn in place for each of the four directional measurements.
c. Count the number of covered grid cells on the densiometer for four positions: parallel upstream and downstream with the channel longitudinally, and towards the left and right bank perpendicular to the channel longitudinally. Count the cells with canopy vegetation cover, and you can record the number of covered cells for each position.
d. Per each riffle measurement, sum the four covered grid cell counts, divide the total by 384 and multiply by 100% to obtain a percent cover average.
e. Average the three riffle densiometer measurements into a single value for entry into the TMAT spreadsheet.

If measurements are made in the winter, the canopy cover provided by deciduous tree leaves must be estimated from the observation of the branch and twig density patterns seen within the densiometer’s grid cells.

6.3.2.3 Average Diameter of Largest Trees at Breast Height (DBH)



Tree Diameter at Breast Height (DBH) is recorded within each vegetation plot, the same plot used to estimate % invasive species. Trees are defined as all single trunked woody stems. Both native and nonnative species are considered for this metric. Six plots are required and must align with the three riffles identified for use on geomorphic metrics and protocols described in the section on reach segmentation (Section 5.6.2). At a riffle cross-section field delineate plots above the left and right streambanks at each of the cross-sections. Each plot is 10 m by 10 m. Where possible, the plots should be established at least 1 m from the top of bank into the riparian zone and within the first 30 m of the riparian zone. If riffles are not present in the project site reach, use plots positioned at the upper, lower and mid longitudinal positions along the channel.

Measuring DBH using a Biltmore Stick. **Source:** *D. Mercker*

Vegetation plots with alternate dimensions are generally not appropriate, even if there is a narrow and long buffer along the stream. Data should still be collected in accordance with the standard 10 meter x 10 meter vegetation plots, set 1m from top of bank, as described above. Changes to plot dimensions will only be considered in areas where site constraints (property ownership, etc.) occur.

Within each plot, identify the three largest woody stems and measure their DBH values. DBH is measured at approximately 4.5 feet above ground using a DBH tape, calipers, or a Biltmore stick with measurements recorded in inches. If there are dead trees in a plot, these should not be used in DBH (or any other vegetation metric) - only living vegetation should be used in any evaluation of current stream function. The figures to the right and bottom illustrate example measurement positions (Waskiewicz et al. 2015; Mercher 2018). Record the DBH values for each plot on the field data sheet. The DBHs for the left and right bank plots are averaged, thus each bank side will have nine tree DBHs measured and reported on the TMAT datasheet. If more than one and less than three woody stems are present within a plot, record a zero for the missing stem(s) and include the zeroes in the calculation of average DBH. Also, a total average DBH for the project reach is computed by taking the average of all 18 possible largest diameter tree measurements and reported on the TMAT datasheet.

6.3.2.4 Percent Invasive Species

An invasive species is a plant or animal that is foreign to an ecosystem, and its introduction causes or is likely to cause economic or environmental harm. This invasive species metric measures invasive plant species in the riparian corridor of the project site reach. Some common species are listed in Table 6.8 and photos shown in Figure 6.21.

Table 6.8. Invasive plants selected from a list of common species by the Tennessee Invasive Plant Council (https://www.tnipc.org/invasive-plants/).

Plant Class	**Plant Name**	**Species Scientific Name**
Tree	Tree of Heaven Mimosa Empress tree Bradford pear	*Ailanthus altissima* (Mill.) Swingle *Albizia julibrissin* (Durazz) *Paulownia tomentosa* (Thunb.) *Pyrus calleryana* Dcne
Shrub	Chinese privet Amur bush honeysuckle Autumn Olive Burning bush Bicolor Lespedeza Golden Bamboo Japanese meadowsweet	*Ligustrum sinense* Lour. *Lonicera maackii* (Rupr.) Herder *Elaeagnus umbellate* var. *parviflora* *Euonymus alatus* (Thunb.) *Lespedeza bicolor* Turcz. *Phyllostachys aurea Carr.* *Spiraea japonica* L.f.
Vine	Kudzu Winter creeper Japanese honeysuckle English ivy Asian bittersweet Common periwinkle Chinese wisteria Japanese wisteria Sweet Autumn Clematis Chinese Yam Amur Peppervine (Creeper)	*Pueraria montana* var. *lobate* (Willd.) *Euonymus hederaceus Champ. & Benth* *Lonicera japonica* Thunb *Hedera helix* L. *Celastrus orbiculatus* Thunb. *Vinca minor* L. *Wisteria sinensis* (Sims) DC *Wisteria floribunda* (Willd.) DC *Clematis terniflora* DC *Dioscorea polystachya Turez* *Ampelopsis glandulosa* var. *brevipedunculata*

Tree of Heaven

Mimosa

Amur Peppervine (Creeper)

Chinese Privet

Japanese Honeysuckle

Kudzu

Chinese Yam

Winter Creeper

Amur Bush Honeysuckle

English Ivy

Golden Bamboo

Empress Tree

Figure 6.21. Photos of selected common invasive plant species (TN Invasive Plant Council).

This metric is measured at all vegetation plots, the same plots used for measuring the DBH values. Review the measurement methodology for locating plots within the project reach in Section 6.3.2.3. Per plot the % area covered by invasive vegetation is visually estimated and reported on the field datasheet. Average the % areas per each plot for this metric to compute a single field value for TMAT worksheet.

Identification of invasive vegetation consists of the most commonly found species as determined by the Tennessee Invasive Plant Council (https://www.tnipc.org/invasive-plants/), and those species that can dominate a riparian corridor that has be disturbed by removal of native species. Guidance for identifying common invasive plants is provided for restoration practitioners, acknowledging one does not need to be an expert. Also, Table 6.8 is not a comprehensive list of possible invasive species, those other species may be enumerated with documentation provided to the IRT. Site photos of the invasive species are to be taken for report documentation.

6.4 Geomorphology II Functional Category

Parameters and metrics for Geomorphology are organized into two categories as Geomorphology I and II. The Geomorphology II category consists of two parameters: Channel Stability and Physical Habitat (Table 2.1, Figure 2.3). Section 6.4 describes the measurement methods for the metrics within these two functional parameters.

6.4.1 Channel Stability

Geomorphic processes of a stable channel are essential to maintain physical habitat quality and support heathy ecosystems. Channel stability reflects the degree of existing bank erosion and channel incision, and the potential for excessive channel erosion based on geomorphic processes. Bank erosion consists of two different processes: 1) fluvial erosion based on moving water over a soil surface and detaching the bank soil into the flow, and 2) bank mass failure or mass-wasting which is a geotechnical failure where soil mass falls into the channel. Slumped soil material is then transported downstream during floods. Mass-wasting may also include soil blocks with trees falling into the stream. Lateral fluvial erosion leading to bank mass failure and vertical downcutting results in channel incision (Simon 1989). Streambank erosion increases fine sediment loads into the stream causing water quality degradation, embeddedness, and habitat siltation leading to impairment of aquatic biota. Riffle habitat quality is commonly degraded from channel incision. Impacts to stream physical habitat can be caused by other human disturbances such as streambank armoring.

The Channel Stability parameter consists of three metrics: 1) percent streambank erosion, 2) percent streambank armoring, and 3) the Rapid Geomorphic Assessment (RGA). The RGA is an index developed by the USDA National Sedimentation Laboratory (NSL) with field protocols described by Simon (2004).

6.4.1.1 Percent Streambank Erosion

Actively eroding streambanks are areas of bank retreat caused by fluvial erosion and mass wasting. Fluvial erosion is the removal of bank soil from high-velocity stream flows moving over the bank surface. Fluvial erosion is observed as banks with recently exposed soils and commonly found at locations with exposed roots of large riparian trees (Figure 6.22). These areas are often located on the outside bend of meanders. -- Sections 3.2.4 and 3.7.1 provides additional information on the physical processes of streambank erosion. Mass wasting is the geotechnical failure of a bank with soil en-mass collapsing into the channel causing bank retreat. The failure is primarily due to the weight force from a block of soil with water forming a surface crack followed by a slumping of bank soil down into the channel.

Percent streambank erosion is assessed on both the left and right banks. As a matter of consistency, left and right banks are based on looking downstream. Bank erosion is visually assessed along the longitudinal profile and measured with a fiberglass tape running down the channel centerline. The following steps are taken to obtain this measurement.

a. Measure the channel length from the upstream to downstream terminal points of the survey reach.
b. Distinguish and record any fluvial erosion or mass-wasting for both the downstream left and downstream right banks.
c. Calculate and record the streambank erosion parameter per the following equation:

$$Streambank\ erosion\ \left(\frac{ft}{ft}\right) = \frac{eroding\ left\ bank\ (ft) + eroding\ right\ bank(ft)}{2 * total\ channel\ length\ (ft)}$$

Figure 6.22. Photos showing fluvial erosion on streambanks.

6.4.1.2 Percent Streambank Armoring

Channel armoring is the alteration of stream banks by concrete-lining or rip-rapping. Armoring is the result of a human intervention to arrest excessive channel erosion. While armoring may resolve this problem, it often can provoke negative effects downstream. In addition, physical habitat quality can be impaired depending on the degree and type of armoring. Examples of armoring include rip rap, gabion baskets, concrete, and other engineered materials that prevent streams from meandering. Stone toe protection is not counted if the remainder of the bank height is natural vegetation, e.g., bioengineering methods. If stone-toe protection exceeds more than a quarter of the low-bank height, it is classified as armoring. Rock bluffs, bedrock outcrops and other natural rock features are not to be counted.

The Percent Streambank Armoring metric is measured for the entire project reach. To calculate the armoring field value, measure the total length of armoring along both the left and right banks, and divide by the total length of streambanks (left and right banks). Multiply by 100 to compute as a percentage of bank armoring. Enter this field value into the field datasheet.

$$Percent\ Armoring = \frac{Length\ of\ Armored\ Bank}{Total\ length\ of\ Streambank\ in\ Reach} * 100$$

6.4.1.3 Rapid Geomorphic Assessment

Rapid adjustments to channel morphology are a result of some disturbance to the stream system. Disturbance can be from reach-scale impacts caused by channelization (channel straightening) and riparian vegetation removal, and watershed-scale impacts from land use conversion causing hydromodification, the increase in storm runoff and stream peak flows from urbanization. The systematic geomorphic response to a disturbance, the processes of channel incision and recovery is known as the channel evolution model and described by Simon (1989, 1995). Six different stages are described by the channel evolution model and described in Section 3.2.4, and the science justification for this metric is described in Section 3.7.1. Detailed illustrations of the six stages are in Figure 3.7 and 3.18. A quick guide illustrating the six stages for convenient use of the User's Manual is in Figure 6.23. The sequence of stages follows a stream from one in dynamic equilibrium through systemic morphological changes to a recovery stage and then returning back to a state of dynamic equilibrium (FISRWG 1998; VDEC 2009). Additional scientific background on this geomorphic process is described in Section 3.7.1, in addition to an expanded version of the model by Cluer and Throne (2014) offering a stream evolution model consisting of eight stages (Figure 3.9).

The RGA was developed at the USDA NSL based on the concepts of the channel evolution model (Simon 1989, 1992, 1995, 2004; Simon et al. 2000). The RGA captures the response to a channel disturbance and the quantifies the level of channel stability. As shown in Figure 6.23, the channel evolution model consists of six classes (stages), and the classes are described in Table 6.9. A modified version of the RGA is used for the TMAT, applying eight of the nine original sub-metrics. The modified RGA consists of the following eight sub-metrics: 1) primary bed material, 2) bed/bank protection, 3) degree of incision, 4) degree of constriction, 5) stream bank erosion, 6) stream bank instability, 7) established riparian

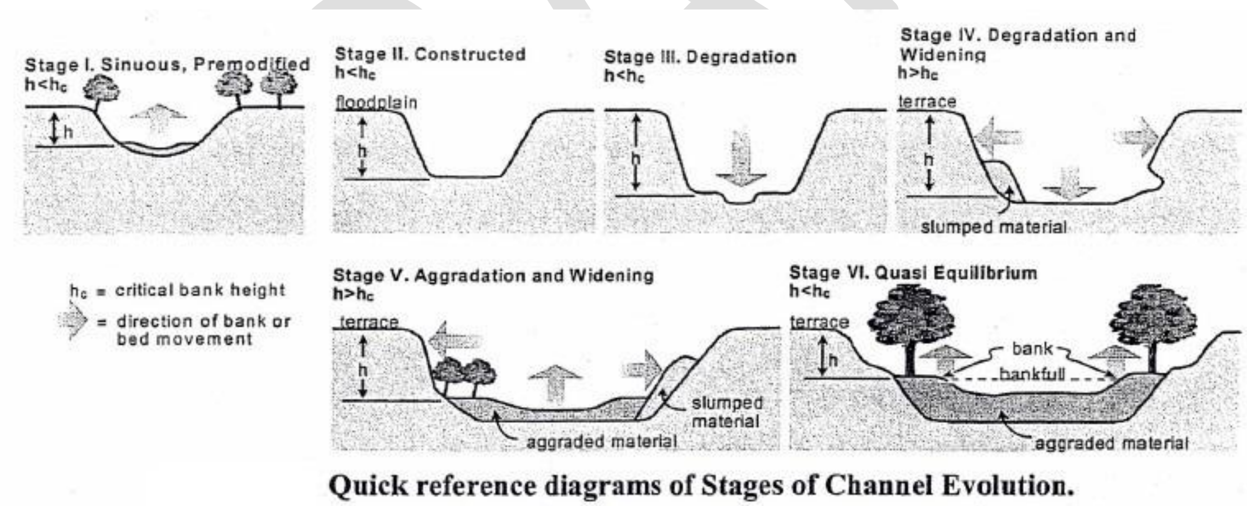


Figure 6.23. Stages of the channel evolution model based on Simon and Darby (1999), a quick guide for using the RGA. See Figures 3.7 and 3.8 for details. (*from* Simon 2014).

Table 6.9. Descriptions of the six stages of the channel evolution model (Simon 1992, 1995; Simon et al. 2000).

Stage	Channel Evolution Stage Descriptions
I	**Pre-modified** - Stable bank conditions, no mass wasting, small, low angle bank slopes. Established woody vegetation, convex upper bank, concave lower bank.

II	**Constructed or Disturbed** - Disturbance from artificial reshaping of existing banks, watershed impacts from hydromodification, or other human activities impacting geomorphic processes. Riparian and/or bank vegetation are often removed. Banks that have been steepened, heightened and made linear, and roughness characteristics changed by rip-rap cover or other harden artificial materials.
III	**Degradation** - Lowering of channel bed and consequent increase of bank heights (vertical downcutting). Channel incision without widening. Bank toe material removed causing an increase in bank angle. As observed in Figure 6.22, the bed will be devoid of sediment substrate.
IV	**Threshold** - Degradation and basal erosion. Channel incision and active channel widening from fluvial erosion and mass wasting. Vertical face on the bank may be present. Excessive undercutting may lead to mass wasting. Mass wasting may be observed by leaning and fallen vegetation on the bank. As observed in Figure 6.22, the bed will be devoid of sediment substrate.
V	**Aggradation** - Deposition of sediment material on bed, often a sand and gravel mix but depends on the sediment source and ecoregion. Bed material reworked and deposited. Figures 6.22 illustrates aggraded bed substrate which can be riffles and bars. Widening of channel continues through bank retreat but no incision. Banks with a concave profile. Channel thalweg follows a meandering course. A quasi-equilibrium single-thread channel connected to stable floodplain formed within abandoned floodplain, and floodplain terraces may be observed.
VI	**Restabilization** - Reduction in bank heights, sediment aggradation of the channel bed. The bed will have riffles and bar features. Channel geomorphic processes returned to a state of dynamic equilibrium Deposition on upper bank therefore visibly buried vegetation. Channel may be observed with inner berms and/or floodplain terraces.

woody-vegetation cover, and 8) occurrence of bed/bank accretion (Table 6.10). The ninth original RGA sub-metric not applied for the field value is the stage of channel evolution. However, this is still observed and recorded on the field sheet as it helps inform the scoring of the sub-metrics. It is reported to document the stage of channel adjustment and its potential for recovery. Each RGA sub-metric is evaluated along a scale of 0 to 4. A lower value indicates channel stability and a higher score indicates channel instability. The reference standard for computing the RGA index score sets channel stability ranges as: stable (0-10), conditional stable (>10-17), and unstable (> 17-32).

The basic field procedure is to identify the assessment reach within the project site reach as described in Sections 5.6.2 and 5.6.3. Understanding the sequence of channel adjustment and

Table 6.10. Summary of Rapid Geomorphic Assessment (RGA) eight sub-metrics and scoring ranges for each, and the stage of channel evolution.

CHANNEL STABILITY – RGA RANKING SCHEME						
Sub-Metric						**Score**
1. Primary Bed Material						
Bedrock	Boulder/Cobble	Gravel	Sand	Silt/Clay		
0	1	2	3	4		
2. Bed/Bank Protection						
Bed = Yes	Bed = No	with	Yes =1 bank	Yes – 2 banks		
0	1		2	3		
3. Degree of Channel Incision						
0-10%	11-25%	26-50%	51-75%	76-100%		
4	3	2	1	0		
4. Degree of Channel Constriction						
0-10%	11-25%	26-50%	51-75%	76-100%		
0	1	2	3	4		
5. Stream Bank Erosion						
	None	Fluvial	Mass Failure			
Left Bank	0	1	2			
Right Bank	0	1	2			
6. Stream Bank Instability from Mass Failures (Wasting)						
	0-10%	11-25%	26-50%	51-75%	76-100%	
Left Bank	0	0.5	1	1.5	2	
Right Bank	0	0.5	1	1.5	2	
7. Established Streambank Woody-Vegetation Cover						
	0-10%	11-25%	26-50%	51-75%	76-100%	
Left Bank	2	1.5	1	0.5	0	
Right Bank	2	1.5	1	0.5	0	
8. Occurrence of Bank Accretion						
	0-10%	11-25%	26-50%	51-75%	76-100%	
Left Bank	2	1.5	1	0.5	0	
Right Bank	2	1.5	1	0.5	0	
9. Stage of Channel Evolution (*not used for index score but recorded*)						
I	II	III	IV	V	VI	
( )	( )	( )	( )	( )	( )	

geomorphic processes is necessary to accurately score the eight sub-metrics used for the modified RGA. Walk the assessment reach to identify the geomorphic features relevant to the modified RGA sub-metrics. For the sub-metrics that require a reach-scale estimate from visual inspection, the key to scoring those sub-metrics is to view the dominant geomorphic processes within the entire reach. Do not focus on “hot spots” of a sub-metric condition within a reach. Sub-metrics #1, #2, and #5 require visual estimates.

Several sub-metrics require measurement. Sub-metric #3, the Degree of Channel Incision requires a stadia rod and fiberglass tape. Sub-metric #4, the Degree of Channel Constriction requires a fiberglass tape. Sub-metrics #6, #7, and #8 use a fiberglass tape laid out along the channel longitudinal profile, and distances of the feature are measured when present, in addition a total distance of the assessment in order to compute percentages. Sub-metrics #5 through #8 require measurements on *Left* and *Right* banks relative to looking in the downstream direction. If the reach is a meandering reach, the banks are viewed in terms of *Inside* and *Outside* as opposed to *Left* and *Right*. The *Inside* bank is the inner bank of the meander, if the stream bends to the left as you face downstream, this would be the left bank. *Outside* bank is the outer bank, on your right as you face downstream in a stream meandering left. Each of the sub-metrics are described below with procedures for how to estimate or measure their quality.

<u>1. Primary Bed Material</u>

Bedrock	The parent material that underlies all other material. In some cases, this bedform becomes exposed at the surface. Bedrock can be recognized by appearing as large slabs of rock, parts of which may be covered by other surficial material.
Boulder/Cobble	All rocks greater than 64 mm (2.5 inch) median diameter.
Gravel	All particles with a median diameter between 64.0-2.00 mm.
Sand	All Particles with a median diameter between 2.00-0.63 mm.
Silt/Clay	All fine particles with a median diameter of less than 0.63 mm.

It is most common that the bed material will exhibit characteristics of mixed bedload. The value reported is based on the dominant material transported during high flows. It is allowed to enter a value between sediment categories, for example if the dominant material transported is gravel-sand, a value of 2.5 may be entered for this sub-metric score.

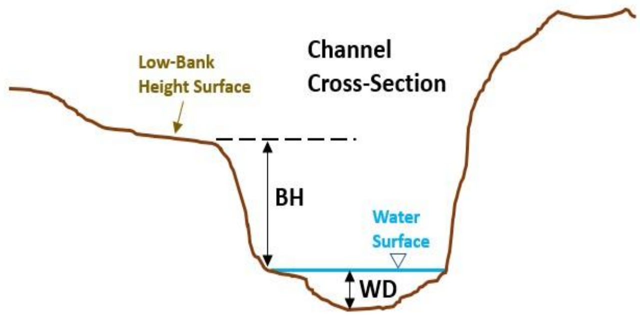
<u>2. Bed/Bank Protection</u>

Bed: Yes	Mark if the channel bed is artificially protected, such as with rip rap or concrete.
Bed: No	Mark if the channel bed is not artificially protected and is composed of natural material.
1 Bank Protected	Mark if one bank is artificially protected, such as with rip rap or concrete.
2 Banks Protected	Mark if two banks are artificially protected.

Scoring this sub-metric is a two-part process. First, examine the channel bed and determine if it is artificially protected along any area within the assessment reach and mark the score for it. Second, inspect the banks (left and right) to whether they are artificially protected. Artificially protection should constitute at least a quarter of the channel length in the assessment reach.

3. Degree of Channel Incision

The degree of channel incision is the relative elevation of “normal” low water to floodplain/terrace as a percentage.



During a flow stage as baseflow or “normal” low flow, locate the deepest water depth across-a cross-section and measure the water depth (WD); the cross-section should be located at the deepest pool location in the reach. At this same cross-sectional location measure the bank height as the distance from the bank base (where the bank slope breaks at the toe to become the channel bed) to the top of the bank (BH, low-bank height onto a floodplain). If the channel is dry, find the lowest depression in the bed (deepest), and estimate a vertical “depth” by using a level tape measure or projecting a line of sight to upstream bed elevation. The upstream bed likely will be a dry riffle or glide features.

The sub-metric is calculated by dividing deepest water depth measurement (WD) by the bank height (BH) measurement as illustrated above. Multiply this ratio by 100 to obtain the percentage. The percentage is score for this sub-metric as:

Degree of Channel Incision = WD/BH *100

4. Degree of Channel Constriction

The degree of channel constriction sub-metric is the relative decrease in top-bank width longitudinally from upstream to downstream.

This channel condition is often where flow obstructions or artificial protections occur along the channel, such as a bridge or rip-rapped banks. Such artificial protections are one criterion for designating the downstream boundary of an assessment reach (Sections 5.5.2 and 5.5.3). Within the assessment reach, measure the top of bank channel widths at the reach upstream and downstream boundaries (USW, DSW, respectively). The sub-metric is the relative difference of widths computed as a percentage as:

Degree of Channel Constriction = (USW – DSW)/DSW *100

5. Stream Bank Erosion (Each Bank)

The dominant form of bank erosion is marked separately for each bank, left and right, facing in a downstream direction.

• None	No erosion
• Fluvial Erosion	Fluvial processes eroding bank soil by flow over that surface detaching soil particles.
• Mass Wasting	Mass movement of large amounts of material from the bank is the method of bank erosion for over 50% of the reach. Mass wasting includes rotational slip failures and block failures.

This sub-metric requires a visual integration of the entire assessment reach determining the dominant bank erosion process. If no erosion is present then the score is ‘0’ per each bank. Fluvial erosion is observed by bare soil on the bank with evidence of recent erosion during high flow events (Figure 6.22). In older channelized streams, tree roots may be exposed from fluvial erosion but the tree has not fallen into the channel. Fluvial erosion also includes undercutting of the bank toe causing erosion which will likely lead to bank failure by mass wasting geotechnical processes. Mass wasting is often characterized by high, steep banks with shear bank faces (≥90-degree bank slopes). Conditions may include where trees have fallen into the channel and/or other soil-vegetation blocks at the bank toe appears to have fallen from higher up in the bank face. Evidence of older events of mass wasting includes where tree root wads had fallen with a soil block, and roots continued to grow horizontally into the bank and are exposed. In the channel evolution model, Classes IV and V consist of slumped soil-vegetation blocks (Figure 6.22). As guidance, Figure 6.24 shows some photos of fluvial erosion and mass wasting. For mass wasting to be dominant, it must be observed for over 50% of the assessment reach.

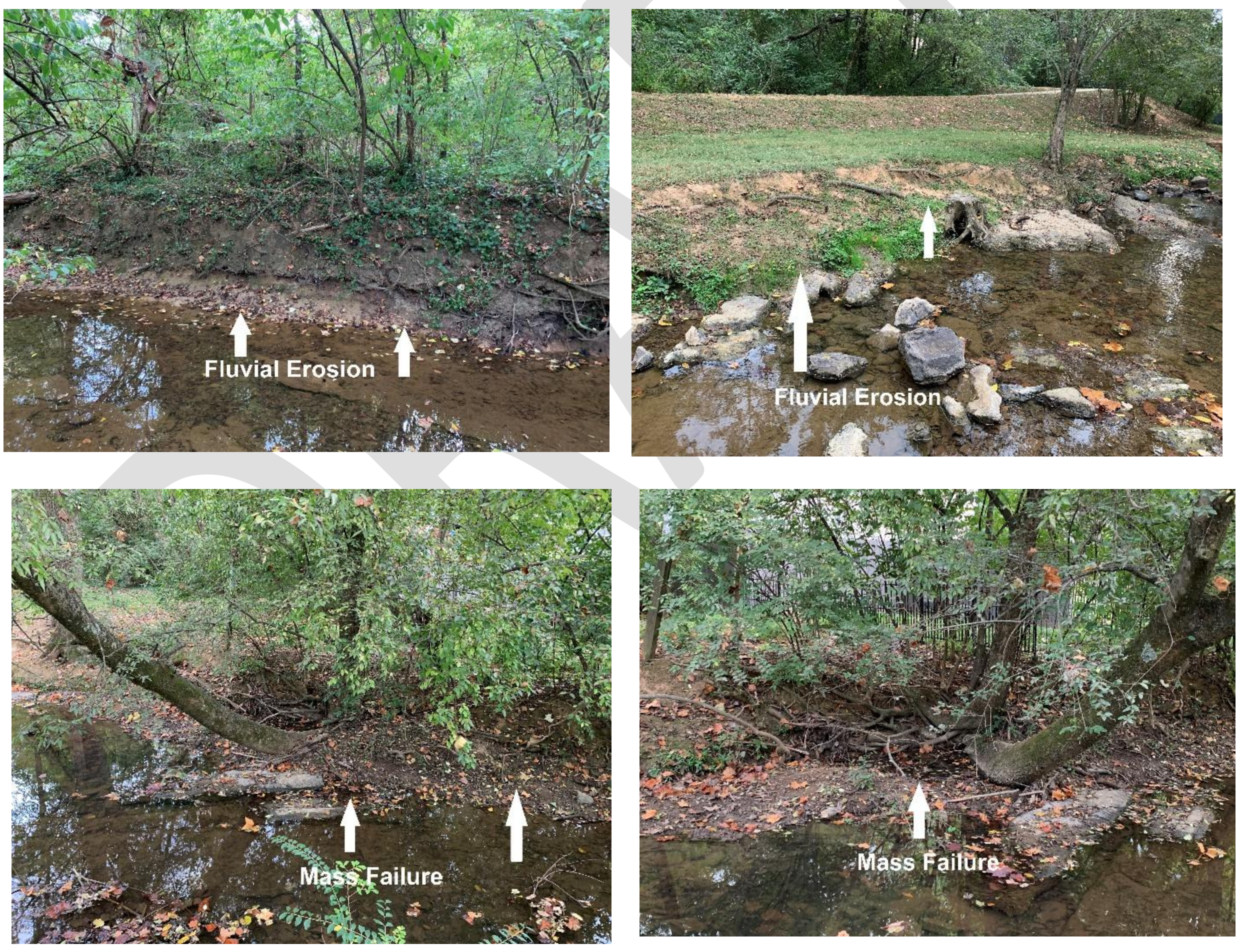


Figure 6.24. Example photos of fluvial erosion and mass wasting on stream banks (Turkey Creek, Knox County). Mass failure typically observed with fallen trees and regrowth upwards.

6. Stream Bank Instability

Percent of each bank failing. If the bank exhibits mass wasting, mark percentage of bank with failures over the length of the reach.

Using a fiberglass tape laid out longitudinally along the channel centerline, measure the lengths where mass wasting is observed along the left and right banks. The sub-metric is the percentage of the total length of the assessment reach that is exhibiting bank failure mass wasting. Sub-metric #5 provides a description of mass wasting and Figure 6.24 shows photos of this bank erosion condition. If more than 50% of reach is marked along the assessment reach (left and right banks), the dominant process for Sub-metric #5 is marked as mass wasting.

In CEM Stage 5 if mass wasting has been arrested for some time, historically small trees on the failure block continue to grow but will be observed with a horizonal root mass into the bank (Figure 6.24). The original failure block over time is eroded and sediment transported downstream leaving the horizontally exposed root mass. Eventually, the trees will fall into the channel leading to channel instability. However, the channel bed substrate is aggrading representing recovery.

7. Established Streambank Vegetation

Percent of streambank woody-vegetative cover as permanent vegetation that grows on the left and right riparian stream banks.

Using a fiberglass tape laid out longitudinally along the channel centerline, measure the lengths where woody-vegetative cover is observed along the left and right riparian streambanks. Woody vegetation is distinguished by its woody stem, which includes trees and shrubs but does not include grasses. Grasses grow and die annually with the summer and thus do not provide permanent bank protection over all seasons. A bank surface is considered covered if woody stems and/or root masses are within one to three feet of each other. Roots not protecting the bank such as hanging roots are not counted as vegetative protection area. Woody bank vegetation is assessed and counted as “protected’ when it covers the entire surface from bank toe to top of bank. Sum the channel length of woody vegetated banks for both left and right banks respectively and divide by the total longitudinal length of the assessment reach. Per left and right banks, the ratio of the stream lengths of woody vegetated areas to total stream length is multiplied by 100 to compute the sub-metric score as a percentage.

8. Occurrence of Bank Accretion

Percent of each bank and channel near-bank with some evidence of sediment deposition.

Using a fiberglass tape laid out longitudinally along the channel centerline, measure the lengths where bank sediment deposition is observed along the left and right banks. Deposited sediment material on banks is often silt and sand. This sub-metric also includes near-bank deposition on the channel bed such as deposited sediment forming a point bar or other depositional bed feature. Deposited sediment on near-bank areas often consists of mixed loads of gravel and sand. Sum the channel length with accretion for both left and right banks and divide by the total longitudinal length of the assessment reach. Per left and right banks, the ratio of the stream lengths with sediment accretion to total stream length is multiplied by 100 to compute the sub-metric score as a percentage.

9. Stage of Channel Evolution

Stage of channel evolution is reported but not used. Stage and class are the same (I – VI).

Stage descriptions for the channel evolution model are in Table 6.10 and shown in Figure 6.23. Carefully examine the vertical and horizontal arrows in Figure 6.23 showing vertical downcutting (downward pointing) or channel sediment aggradation (upward pointing), and bank retreat from lateral erosion (horizontal outward pointing). Note in Figure 6.23, aggraded sediment on the channel bed for Classes I, V, and VI.

6.4.2 Physical Habitat

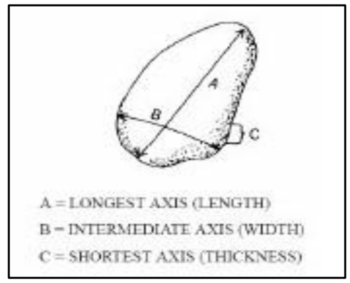
Stream physical habitat is where aquatic biota live, providing food, shelter, and recruitment. Each species has adapted to unique habitat structures to survive; thus, habitat stability, variability, and heterogeneity are key elements to maintaining biodiversity and a healthy ecosystem. Many aquatic species have evolved and specialized to survive in either pools or riffles. Mesohabitat types commonly consist of pools, glides, riffles, and runs. Some species are generalists and occupy different mesohabitat types. Other species are keyed into microhabitat structures, such as bed substrate, LWD, root wads, undercut banks, aquatic vegetation, etc. Parameters in the sub-category reflect habitat quality, and the geomorphic processes that either maintain or degrade habitat quality.

For this parameter, three metrics are always measured: 1) Wolman Pebble Count, 2) Percent Riffle, and 3) Pool-Pool Spacing Ratio (Table 2.1). A fourth metric, the Pool Depth Ratio requires bankfull width thus is only applied if bankfull indicators are applicable. If bankfull indicators are unavailable, an alternative measurement method can be applied to compute the Pool-Pool Spacing Ratio metric, and the Pool Depth Ratio metric is not used.

6.4.2.1 Wolman Pebble Count

Bed substrate provides the essential riffle habitat for many aquatic macroinvertebrates and the substrate for spawning by many aquatic species. Riffle habitat is key to a biologically diverse stream ecosystem. Geomorphologically, bed substrate represents the bedload sediment transported during high-flow events for a stream that is in dynamic equilibrium; this bedload transport maintains riffle structures within a channel reach. Alluvial channels typically transport mixed bedload sediment consisting of gravel and sand, and may include cobble. Sediment size characteristics for mixed load is governed largely by the watershed sediment source and the reach channel slope. Streams in the Southwestern and Central Appalachians (Cumberland Plateau) and Interior Plateau ecoregions may naturally consist of bedrock beds. In West Tennessee, many streams may consist mostly of sand bed channels.

Bed substrate material is characterized using a Wolman Pebble Count procedure. The original procedure was to use a 1-m square grid with crossing strings equally spaced 0.1 m apart to where a sediment particle was selected for measurement (Wolman 1954). The grid is randomly based on a riffle and 100 particle sizes counted. Modified field collection procedures have been used such as zig-zagging across a riffle and measuring particle at a constant interval (e.g., 0.1 ft.), and a random walk procedure where a sediment particle is picked up at the boot toe, and measured. The key to all procedures is to collect 100 particles in an unbiased field method and measure each particle along its b-axis. Several documents can provide general guidance for this procedure including Bevenger and King (1995), and Bunte and Abt (2001). For the TMAT, the field procedure to be used is that described by TDEC's SOP for macroinvertebrate and habitat surveys (TDEC 2017).



The field collection of 100 sediment particles following the TDEC (2017) protocols is as follows.

a. Establish one or more transects perpendicularly across a representative riffle exhibiting the dominant substrate of the assessment reach. The number of transects needed to obtain 100 particle measurements will be dependent on the riffle width. In very small streams, more than one riffle may be needed to obtain the requisite number of measurements.
b. Start the particle count at the edge of the left descending bank, approximately at the bankfull or active channel margin (which will often be above the water level).
c. Averting your gaze, pick up the first particle touched by the tip of your index finger at the toe of your wader boot. It is important to not look down when choosing a particle because it can introduce bias. Even when choosing by first touched, be mindful that very small particles are not "overlooked".
d. Using a clear ruler or other measurement device, measure in millimeters the intermediate axis, neither the longest nor shortest of the three mutually perpendicular sides of the particle. Measure embedded particles or those too large to be moved in place. For embedded particles, measure the smaller of the two exposed areas. Record data.
e. Take one small step across the channel transect in the direction of the opposite bank, and repeat the process. Large boulders or bedrock may be counted more than once if they fall more than once in subsequent step increments.
f. Repeat until you have reached the right channel bankfull or active channel margin. If 100 particle measurements have not been reached, move to a new transect and repeat the process until a minimum count of 100 particles have been measured. Do not stop in the middle of a transect – once started you must keep measuring until the full width of the channel has been characterized. It is fine if over 100 measurements are recorded, which will almost always be the case.

Once the 100 sediment particles have been collected that data is used to compute a statistical index (p-value) based on a particle side distribution (PSD) of bed sediment from a reference reach. The index p-value is a significance level comparing the project site PSD to that of a reference PSD. It is computed with an Excel spreadsheet tool developed by the US Forest Service (USFS), the Size-Class Pebble Count Analyzer (v.1). The Analyzer can be obtained from the following link:

https://www.fs.usda.gov/biology/nsaec/assets/size-classpebblecountanalyzer2007.xls

In addition to conducting a pebble count on a dominant riffle within the project site reach, use of the Pebble Count Analyzer (v.1) also requires pebble count within a reference reach and its enumerated PSD. A standard PSD dataset for a reference reach for streams in East, Middle, and West Tennessee follows in Table 6.11. East Tennessee includes ecoregions (ERs) 66 and 67; Middle Tennessee includes ERs 68, 69, and 71, and West Tennessee includes ERs 65, 73, and 74 (Figure 5.1). In lieu of using this standard dataset, a reference reach identified by the practitioner can be used to quantify a PSD from a Wolman pebble count, and this reference data summarized into the Analyzer's bin requirements. A reference reach for this measurement method is defined in Bevenger and King (1995). Note, reference reach stratification may include Rosgen stream classification, catchment area, gradient, and lithology. When possible, pick a reference reach that is upstream of the stream reach. For example, a stable C stream type with a forested watershed upstream of an unstable C4 or Gc/F4 stream type is ideal for this analysis. The mapped location of the reference reach and the rationale for its suitability are to be documented, and use is contingent on agency approval.

In channels without mixed-load gravel substrate, such as bedrock and sand-bed channels the index score for this metric may need to be consulted with agency staff.

The practitioner should only characterize the channel as "Bedrock" if the bed material is dominated by exposed, solid bedrock in the bed of the stream. Bedrock may be located underneath other substrate (such as having some areas of solid bedrock bed material, but also with some riffles and pools, where the bed material is composed of cobble or other materials underlain by bedrock). In such cases, the practitioner should categorize the existing bed material based upon the bed material that is exposed in the bed of the stream; the underlying geologic layers below the stream bed are not categorized within the assessment. "Bedrock" should only be a classification when it dominates the channel to such as extent that it precludes the development and ability to characterize bed load substrate.

A unique reference dataset for the Analyzer may be used for sand bed streams if that bed material is deemed the natural and stable bed sediment. However, if the bed material consists of a sand plug caused by human disturbance then the Analyzer should be used to obtain a p-value for the field value. In the case of bedrock channels it must be evaluated whether it is a natural geomorphic condition, or a disturbed condition whereby the bed sediment has been removed and sediment supply limited from a disturbance.

Table 6.11. Particle size distribution for an alluvial channel with gravel beds creating riffle habitat based on a Wolman pebble count of 100 sediment particles based on field data collected in East, Middle, and West Tennessee.

Sediment Size Class Name	**Sediment Particle Size Class (mm)**	**Number of Particles**		
		East TN	**Mid TN**	**West TN**
Sand	< 2	8	12	65
VF Gravel	2.0 - 2.8	2	4	14
VF Gravel	2.8 - 4.0	3	4	10
Fine Gravel	4.0 - 5.6	4	5	6
Fine Gravel	5.6 - 8.0	5	5	5
Medium Gravel	8.0 - 11.3	9	7	0
Medium Gravel	11.3 - 16.0	11	9	0
Course Gravel	16.0 - 22.6	12	11	0
Course Gravel	22.6 - 32.0	11	12	0
VC Gravel	32.0 - 45.3	9	10	0
VC Gravel	45.3 - 64.0	7	9	0
Small Cobble	64.0 - 90.5	7	5	0
Small Cobble	90.5 - 128.0	6	4	0
Large Cobble	128.0 -181.0	4	2	0
Large Cobble	181.0 – 256.0	2	1	0
Small Boulder	256.0 – 362.0	0	0	0
Small Boulder	362.0 – 512.0	0	0	0
Medium Boulder	512.0 – 1024.0	0	0	0
Large Boulder	1024.0 – 2048.0	0	0	0
Very Large Boulder	2048.0 – 4096.0	0	0	0
Bedrock	➢ 4096.0	0	0	0
Total Sample Size		**100**	**100**	**100**

The TMAT performance relationship to obtain an index score is based on a p-value generated by the Analyzer. The p-value is a quantitative measure of the likelihood that the collected particle distribution is similar to the particle distribution of reference streams within the region. Steps for obtaining a p-value using the USFS Pebble Count Analyzer (v.1) is as follows:

a. Download the Size-Class Pebble Count Analyzer from the US Forest Service web page and read the Introduction tab, with internet link provided above.
b. Read the Sample Size tab within the Analyzer spreadsheet. Keep the default values for Type I and Type II errors, which are 0.05 and 0.2, respectively. Set the Factor relating the project reach to the reference reach sample size to '1'. Set the reference proportion to 0.1 and the study proportion to 0.25. Samples should consist of 100 particles to be collected for both site and reference reaches, however it is acceptable for the Analyzer

data entry to only have 95 particles, where the reduced number includes a few bedrock locations.

c. In the field at the project site reach, identify the dominant riffle that best represents the bedload transported during high-flow events.

Conduct a pebble count following the TDEC protocols described above on the identified dominant riffle in the project reach measuring a minimum of 100 particles along the b-axis in millimeter (mm) units. Per the TDEC protocols more than 100 particle measurements will likely be collected in order to complete the transect.

e. The pebble count data is summarized into size class bins as shown in Figure 6.25 and data entered into the Data Input tab within the Analyzer spreadsheet (Column D). You will overwrite the data that is displayed as shown in Figure 6.25.

f. Within the same Data Input tab, totals of sediment size class for a reference reach must be entered in the third column. For East, Middle, and West Tennessee ecoregions, the reference reach values for particle size numbers are in Table 6.11. If reference reach data is collected or obtained other than Table 6.11, provide the location, Rosgen stream types, and justification for its use. As noted above, streams in West Tennessee may need to adjust the reference data provided in Table 6.11 due to morphological differences in that part of the state.

g. After data for the study (project reach) and the reference have been entered into the Data Input sheet, go to the Analysis tab. As shown as Contingency Tables, the Analyzer sheet will display the p-values for particle size differences as a function of a particle size. Three Contingency Tables options are shown; they are: a user select size, 4 mm, and 8 mm particle sizes (Figure 6.26).

h. Obtain the p-value from the Contingency Tables for the selected particle size as a function of the ecoregion of the project site reach. Use the particle size of 4 mm to obtain the p-value (Figure 6.26). Note, if justified, the user can select the 8 mm or user defined option from the dropdown menu. The use of the 8 mm size would be preferred in cobble bed channels in East Tennessee.

i. Record the p-value from the contingency table and enter it as the field value in the TMAT spreadsheet.

Class Name	Particle Size Class (mm)	Reference Total	Study Total	Reference Cumulative %	Study Cumulative %
Sand	<2	8	12	8.0	12.0
VF Gravel	2 - 2.8	2	6	10.0	18.0
VF Gravel	2.8 - 4	3	6	13.0	24.0
Fine Gravel	4 - 5.6	4	6	17.0	30.0
Fine Gravel	5.6 - 8	5	8	22.0	38.0
Med. Gravel	8 - 11.3	9	14	31.0	52.0
Med. Gravel	11.3 - 16	11	10	42.0	62.0
Coarse Gravel	16 - 22.6	11	11	53.0	73.0
Coarse Gravel	22.6 - 32	12	12	65.0	85.0
VC Gravel	32 - 45.3	9	8	74.0	93.0
VC Gravel	45.3 - 64	8	5	82.0	98.0
Sm. Cobble	64 - 90.5	6	2	88.0	100.0
Sm. Cobble	90.5 - 128	6	0	94.0	100.0
Lg. Cobble	128 - 181	3	0	97.0	100.0
Lg. Cobble	181 - 256	2	0	99.0	100.0
Sm. Boulder	256 - 362	1	0	100.0	100.0
Sm. Boulder	362 - 512	0	0	100.0	100.0
Med. Boulder	512 - 1024	0	0	100.0	100.0
Lg. Boulder	1024 - 2048	0	0	100.0	100.0
VL Boulder	2048 - 4096	0	0	100.0	100.0
Bedrock	>4096	0	0	100.0	100.0
	Totals	100	100		

Figure 6.25. Particle size class bins used for the Size-Class Pebble Count Analyzer (v.1). Per the Data Input sheet, an example input page is shown for the particle size class bins.

Follow instructions in pink for other sizes.

User-selected size criterion: Press <Ctrl-U>

16mm

	<	> or =	Total
Reference	40	60	100
Study	75	25	100
Total	115	85	200

Reference <	Study <	Average <	Average >=
40.0%	75.0%	57.5%	42.5%

p-value	<.0001

4 mm

	<	> or =	Total
Reference	13	87	100
Study	24	76	100
Total	37	163	200

Reference <	Study <	Average <	Average >=
13.0%	24.0%	18.5%	81.5%

p-value	0.0343

8 mm

	<	> or =	Total
Reference	22	78	100
Study	38	62	100
Total	60	140	200

Reference <	Study <	Average <	Average >=
22.0%	38.0%	30.0%	70.0%

p-value	0.0103

Figure 6.26. Example display of the Analyzer tab and three Contingency Tables in the Size-Class Pebble Count Analyzer (v.1) showing p-value outputs for each table.

6.4.2.2 Percent Riffle

The percent riffle is the proportion of the assessment segment containing riffle bed form. Pool-riffle sequences in streams are fundamental to maintaining a healthy ecosystem, where riffles provide shelter for benthic macroinvertebrates and food for fish sustaining healthy aquatic ecosystems. This metric, and the Pool-Pool Spacing Ratio and Pool Depth Ratio metrics (Sections 6.4.2.3 and 6.4.2.4) quantify the functional attributes of channel-scale physical habitat. Longitudinally, riffles are elevated bed areas typically composed of gravel/cobble/boulder substrate, whereas pools are depressions in the channel bed. Run features are included within the riffle length. Glide features are not included in the riffle length. A pool must be a geomorphic pool as described in Section 6.4.2.3. Depending on the ER, riffle bed structure will vary based on the sediment supply for example in the Interior Plateau (ER 71) bedrock may dominate as run substrate, whereas in the Mississippi Valley Loss Plains (ER 74) depositional sand may be dominant as the riffle substrate. For overall guidance on channel-scale types of physical habitat, see Section 3.7.2. Figure 3.24 provides detailed descriptions with figures of different types, i.e., pools, riffles, glides, runs, and cascades.

Riffle length is measured along the longitudinal profile for the project's assessment reach. It is measured from the head (beginning) of the riffle downstream to the head of the pool. The following field-survey and computation steps are followed:

a. Beginning at the most upstream point of the proposed survey reach, use the fiberglass tape measurement stretched along the center line of the channel as per the longitudinal profile survey.
b. Record the upstream and downstream boundaries of all riffles, the transition locations along the reach's longitudinal profile, and the total reach length. It is suggested to provide a sketch with the datasheet documenting distances along the reach's longitudinal profile of the pool-riffle and riffle-pool transitions, or other mesohabitat transitions with riffles.
c. Percent riffle is calculated by dividing the total length of riffles within the assessment segment by the total assessment segment length.

6.4.2.3 Pool-Pool Spacing Ratio

Pool-to-pool spacing is a measure of the frequency of geomorphic pools within the assessment reach. Pool-riffle sequences along a channel are an indicator of a stream in geomorphic dynamic equilibrium, thus indicative of channel stability. As noted for the Percent Riffle metric, the pool-riffle sequences are also fundamental to maintaining healthy ecosystems. For this metric, geomorphic pools are channel bed depressions forming a concave bed surface, and they will be deeper than an adjacent riffle. The water surface slope is flatter than that in a riffle. They should only be included in this metric if they are geomorphic pools where the pool length is equal or greater than the active channel width. Small scour pools in the channel bed are not included.

> Pool Spacing Ratio is equal to the average distance between the deepest point of sequential geomorphic pools divided by the stable riffle bankfull width (or active channel width).

Geomorphic pools are commonly associated with the outside of a meander bend, or downstream of a cascade/step. However, geomorphic pools can also occur in straight channels generally caused by a narrowing of the channel cross-section. Pool types can be classified by formative geomorphic features, thus noted above as meandering, channel narrowing, cascade flow drops, and large flow obstructions. Small scour pools can be found next to woody debris or other in-channel physical structures, and they can occur within a riffle thalweg and are not used in the calculation of this metric.

For pools in meanders and cascade morphology, Figures 6.27 and 6.28 provide illustrations where pools are marked with an 'X'. Figure 6.27 illustrates a meandering stream, where the pools located in the outside of the meander bend are counted for the Pool-Pool spacing metric, and the 'X' marks the approximate location of the deepest part of the pool. Alluvial compound pools that are not separated by a riffle within the same bend are treated as one pool. However, compound bends with two pools separated by a riffle are treated as two pools. Pools within step-pool sequences commonly observed in colluvial or V-shaped valleys should only be counted if they are downstream of a step longitudinally along run or cascade bedforms (Figure 6.28). Micro-pools in a run or cascade are not counted, just like micro-pools within a riffle within an alluvial valley stream are not counted. Figure 6.28 illustrates geomorphic pools marked with an 'X', and a micro-pool is shown in blue within a cascade.

Pool spacing is measured along the longitudinal profile as the distance between each pair of sequential geomorphic pools within the assessment reach. A distance is measured between each pool pair and averaged. If bankfull indicators are absent or not adequate to reflect stable geomorphic processes, then an "active" channel width can be used. The active channel width is measured from the bank location where annual vegetation is not present or permanent or measured from an identified top of low bank perpendicular across the channel to the opposite bank. Use of the active channel width will provide similar values for this metric as with using bankfull width within natural variance of stream geomorphic properties.

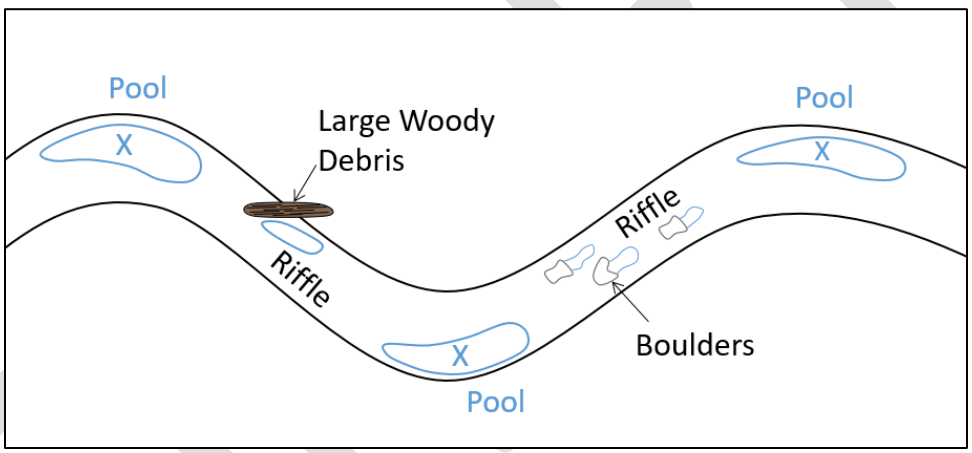


Figure 6.27. Identifying geomorphic pools in alluvial-valley streams with channel slopes < 2%. Central location in a geomorphic pool is shown by an 'X' (TDEC 2018).

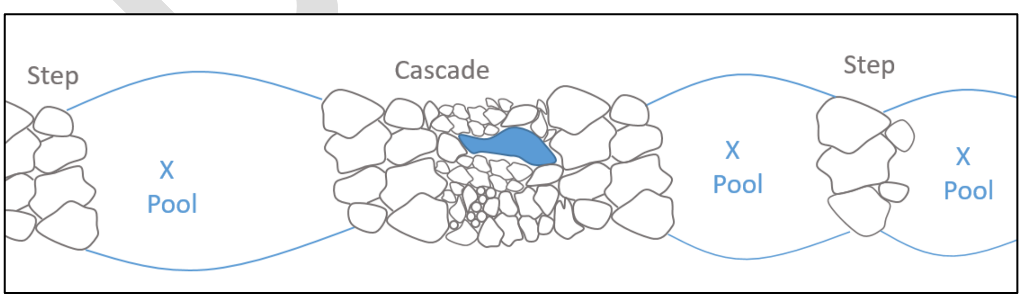


Figure 6.28. Identifying geomorphic pools in colluvial and V-shaped valleys with channel slopes > 5% and termed step-pool morphology. Pools shown with an 'X' (TDEC 2018).

The metric is an average value if two or more pools are present. If there is only one pool or none, users are to designate 'none' in the workbook for this metric resulting in the ESC to equal zero. The following equation is used for the Pool-Pool Spacing Ratio metric.

$$Pool - Pool\ Spacing\ Ratio = \frac{Average\ Distance\ between\ Sequential\ Geomorphic\ Pools}{Mean\ Bankfull\ or\ Active\ Channel\ Width}$$

The following field procedures are used to compute the Pool-Pool Spacing Ratio metric within the assessment reach.

a. With a fiberglass tape stretched along the channel centerline, measure and record the longitudinal distance (station) for each geomorphic pool at its deepest bed location.
b. Measure and record the bankfull width across the riffles, or the active channel width.
c. From the measured longitudinal distances for each geomorphic pool, calculate the pool spacing stream length between each pool, and average those stream lengths.
d. Calculate the mean bankfull or active channel width within the assessment reach.
e. Calculate the Pool-Pool Spacing Ratio metric with the equation shown above.

6.4.2.4 Pool Depth Ratio

The Pool Depth Ratio metric is a measure of bed diversity quantifying pool quality within riffle-pool sequences whereas the Pool-Pool Spacing Ratio metric reflects bed diversity as the frequency of pools between riffles. The combination of these metrics recognizes pools as essential mesohabitat features. Deeper pools within riffle-pool sequences support greater ecosystem functions and aquatic biodiversity.

The Pool Depth Ratio metric is only used for project site reaches that have bankfull indicators (Table 2.1). If adequate bankfull indicators are not present per criteria defined in Section 5.4.4, then this metric is not used and practitioners will follow the non-bankfull metric option computing the ESC (Table 2.1) In addition, this metric is not used if there is dry or exhibits no flow.

Pools to be used for this metric include geomorphic pools, backwater pools, and scour pools associated with large wood, and/or boulders. Descriptive criteria for geomorphic pools are summarized above in Section 6.4.2.3 for the Pool-Pool Spacing Ratio metric. In addition, mesohabitat descriptions and figures are in Section 3.7.2, which included pool types and their formative processes. Because this metric includes scour pools, criteria for a pool designation is that the pool width should be greater than one-third the active channel width.

The Pool Depth Ratio metric is calculated by dividing the maximum bankfull pool depth by the mean bankfull riffle depth per the equation below.

$$Pool\ Depth\ Ratio = \frac{D_{max\ pool}}{D_{mean\ riffle}}$$

The pool depth is measured from the longitudinal bed profile assessing each pool within the assessment reach. Maximum bankfull depth is the water depth plus the distance from the water depth to the projected vertical distance to bankfull. The mean bankfull riffle depth is from a stable riffle cross section surveyed within the assessment reach. Criteria for identifying a stable riffle versus a non-stable riffle are defined in Section 5.4.3). In addition, the geomorphic processes of riffle development and maintenance are described in Section 3.2.2.

The following steps are used to compute the Pool Depth Ratio metric:

a. Within the assessment reach, record the longitudinal station distance of all pools along a fiberglass positioned on the channel centerline.
b. Measure the pool depth as the vertical distance from the estimated bankfull elevation to at the deepest point in each pool;
c. At each stable riffle, record the longitudinal station distance, measure the bankfull depth, and record that depth.
d. Review the recorded bankfull pool depth data and identify the maximum value.
e. Compute the mean bankfull depth of the riffles.
f. Calculate the Pool Depth Ratio with the equation show above.

Note : It is still possible to calculate a pool depth ratio in a stream that is not flowing. When the stream is not flowing, one can utilize the bankfull indicators to determine the bankfull stage at the pool. Alternatively, since the mean depth can be estimated as the difference between the edge of channel and the bankfull stage, the practitioner can use the previously calculated value of mean bankfull depth and measure vertically up and level from the toe of slope at the pool to help determine where bankfull would be in the pool. This will provide an approximate measure of the bankfull stage in a dry pool.

Once the bankfull stage is determined at a pool, the user simply measures the vertical distance between the deepest part of the pool and the bankfull stage to find the maximum pool depth. If site conditions are so adverse due to dryness during the field survey that these measurements cannot be accurately obtained, the practitioner may choose to either complete the measurements during more favorable field conditions, or, in the case of establishing an ECS for debit purposes, may utilize the default value for these parameters. (See Section 4.2.3 *Existing Condition Score Options*)

6.5 Water Quality / Biology Functional Category

Water quality and biology are a single functional category for the TMAT as a measure of the biological integrity and aquatic biodiversity of a stream reach. Multiple stressors can impair the biological integrity including siltation, physical habitat loss, and degraded water quality (Sections 1.3 and 5.3.1). Measures of physical habitat quality are included among the metrics in the Geomorphology I and II Functional Categories. For the Water Quality / Biology Category, function-based metrics are primarily based on the macroinvertebrate community structure. Macroinvertebrates are an integral part of the food chain that supports healthy aquatic ecosystems. The Tennessee Macroinvertebrate Index (TMI) is used to assess biological integrity as part of the state's Water Quality Standards and implemented through their biomonitoring program. Within this category for the TMAT, the TMI is the only metric that is required within the Biology parameter. Assessment of the metrics in the Water Quality parameter is optional.

Existing TDEC macroinvertebrate or water quality data may be used for TMAT calculations in some cases, depending on the proximity of existing data to the site in question, and how old the data is. These and other factors will determine if the existing data can be considered representative enough to evaluate the current condition of the stream reach(es) being evaluated with the TMAT. As for the suitability of existing data in watersheds that have had relatively stable land uses (e.g. always been heavy agriculture, still is), a general rule of thumb would be around a maximum of 10 years old, less old in areas with more rapidly changing land uses. Determining suitable distance from site is more variable and would be based on factors such as confluences of larger tributaries, point source discharges, significant land use changes, etc., between the site and the existing data point. *In all cases, use of existing TDEC data for TMAT is contingent on agency approval and should be discussed with TDEC prior to use*.

Existing TDEC macroinvertebrate or water quality data may be found by utilizing TDEC's Division of Water Resources public-facing Data & Map Viewers. TDEC monitoring station locations can most easily be found using the Water Quality Map GIS application at:

https://tdeconline.tn.gov/dwr/.

Once entered into TDEC's website, zoom to the area of interest, or enter latitude and longitude into the search bar. Monitoring stations are represented by blue water drop icons. Clicking on a station gives you the Station ID code (e.g. MURFR003.9WI), which can then be entered into the TDEC Data Viewer's Chemical Data or SQSH Data tabs at:

https://dataviewers.tdec.tn.gov/dataviewers/f?p=2005:34618:3370729099105

6.5.1 Biology

6.5.1.1 Biotic Integrity Indices

In the Biology parameter, the Tennessee Macroinvertebrate Index (TMI) score is the primary metric used. The Semi-Quantitative Single Habitat (SQSH) protocol used to calculate a TMI and its associated submatrices is described below. For determination of an ECS on a channel proposed to be impacted (debit calculation) the overall TMI score should be used.

An alternative is to use only a subset of biometrics, which are: percent Clingers, percent EPT-Cheumatopsyche (% EPT-Cheum), and percent Oligochaeta and Chironomidae (% OC). These biometrics have been determined to be slightly quicker to respond and reestablish after temporal disturbances associated with restoration, and are provided as an option for channels proposed for mitigation. Mitigation providers should coordinate with the IRT to determine whether the overall TMI score or the optional suite of TMI sub-metrics should be used as evidence of biological lift.

6.5.1.2 Macroinvertebrate Collection Methods

There are four potential measurement methods for macroinvertebrates included in the TMAT. All four measurement methods are components of the SQSH survey methodology found within the *Quality System Standard Operating Procedure (QSSOP) for Macroinvertebrate Stream Surveys* (2017) from TDEC. TDEC TMI standard operating procedure available at:

https://www.tn.gov/content/dam/tn/environment/water/policy-and-guidance/DWR-PAS-P-01-Quality_System_SOP_for_Macroinvertebrate_Stream_Surveys-122821.pdf

This protocol is semi-qualitative and uses kick nets or dip nets, and the target habitat type is dependent on the stream type and ecoregion in which the project is located. Specimens are collected, preserved in the field, and identified in the laboratory. The collection, sorting, taxonomy and data reduction protocols must be performed by a qualified biologist and follow the protocols outlined in TDEC's QSSOP. Care must be taken to note the ecoregion, drainage area and data collection season when collecting benthic insect data. Record both the selected approach and the collection procedure as either SQBANK or SQKICK.

The TMI data used in the TMAT can be used as either the total index score or an alternative approach for mitigation reaches as noted above that includes only the percent clingers, % EPT-Cheum, and % OC. The reference standards for this measurement method are based on the individual metric ranges established by TDEC (2017).

It is not always necessary to collect TMI data on every stream segment on a site. As noted above, representative scores can often be applied to more than one reach. When in doubt about how to measure or apply the Biology parameter, please consult with TDEC staff prior to submittal. If data from sites outside of the stream reach are used, information should be presented with discussion and justification of the assumptions made in interpreting the available data to score the stream reach. Use of data from sites outside of the stream reach are contingent upon regulatory agency approval.

6.5.2 Water Quality

Degraded water quality can be a stressor on stream ecosystems reducing biological integrity and potentially impacting human health. A common stressor on stream ecosystems includes excessive nutrients that can reduce dissolved oxygen and/or promote harmful algae growth. Excessive nutrients can be measured indirectly through the assessment of macroinvertebrate community structure (biological integrity), and directly through chemical analysis of nitrate-nitrite, and total phosphorus. Sources of excessive nutrients can come from overuse of fertilizers on agricultural lands and runoff to streams, stormwater runoff in urban areas, rural residential areas with failing septic tanks, and cattle manure instream and in runoff. Sources of nutrient pollution typically co-occur with excessive *Escherichia coli* (*E. coli*) from contaminated runoff from cattle manure and failing septic tanks leaking to streams.

Assessment of the Water Quality parameter is optional, however if used all metrics within this categorical parameter must be measured. Macroinvertebrates data are obtained by a TMI Semi-Quantitative Single Habitat (SQSH) sample. The four metrics are: % Nutrient Tolerant Macroinvertebrates, mean Nitrate-Nitrite, mean Total Phosphorus, and geomean *E. coli*. The Water Quality parameter may be chosen to be assessed for mitigation projects where overall nutrient loadings, organic enrichment, or *E. coli* levels are expected to be improved by restoration activities including mitigation of non-point source loadings, or for impact-related ECS calculations if desired.

6.5.2.1 TMI Index: % Nutrient Tolerant Macroinvertebrates

This measurement method is a component of the SQSH survey methodology found within the Quality System Standard Operating Procedure (QSSOP*) for Macroinvertebrate Stream Surveys* (TDEC 2017). The collection, sorting, taxonomy and data reduction must be completed by a qualified biologist and follow the protocols outlined in the QSSOP as described above in Section 6.5.1.2. The reference standards for this metric are based on TMI individual sub-metric ranges as established by TDEC (2017).

6.5.2.2 Mean Nitrate-Nitrite and Total Phosphorous

Nitrate-Nitrite and Total Phosphorous metrics require taking a grab sample following protocols described in TDEC's *QSSOP for Chemical and Bacteriological Sampling of Surface Water* (TDEC 2011). Laboratory analysis must be conducted by EPA approved methods and analyses must have sufficiently low minimum detection and measurement limits, as outlined in the QSSOP referenced above.

Preferably, monthly grab samples for these two nutrients are collected over the course of a year, to capture the annual range of loadings. At a minimum, at least four representative grab samples, spaced at least two weeks apart, must be collected to produce a valid mean field value. Representative samples should reflect baseflow conditions and not capture stormwater events. Methods are outlined in the Chemical QSSOP by TDEC (2011).

Reference standards for this measurement method were developed using data collected throughout the state on reference and non-reference streams, and based on regional interpretations and goals of the narrative nutrient criteria (Denton et al. 2001).

6.5.2.3 Geomean Escherichia coli

E. coli is an indicator of the presence of mammalian fecal matter, and potential pathogens that can be a serious risk to human and animal health. When livestock have free access to streams or pastureland with limited riparian corridor, manure can be deposited in the channel or washed in during a runoff event. Water collection is by a grab sample with a sterilized bottle and stored in ice during transportation to the laboratory for analysis. Samples must be analyzed within 6 hours of collection. Samples should not be collected during or immediately after a rain event. Practitioners are required to follow the TDEC *QSSOP for Chemical and Bacteriological Sampling of Surface Water* (TDEC 2011).

The field value entered in the TMAT will be the geometric mean of five consecutive samples collected during any 30-day period. The reference standards for this metric are based on Tennessee Water Quality Standards for recreational use (TDEC 2016).

7. TMAT Workbook/Datasheet Completion Procedures

Section 7 of the TMAT User's Manual provides the guidance on data entry for two Microsoft Excel workbooks; they are the 1) TN Debit Tool, and 2) TMAT for compensatory mitigation. Each workbook contains several worksheets to accomplish either debit or credit calculations. Section 7.1 provides an overview of the worksheets (tabs) in both workbooks. Detailed guidance on the use of the TN Debit Tool and the TMAT workbooks are described in Sections 7.3 and 7.4, respectively. The workbook files can be downloaded from TDEC's web page for *Compensatory Mitigation for Stream and Wetlands*:

https://www.tn.gov/environment/permit-permits/water-permits1/aquatic-resource-alteration-permit--arap-/permit-water-arap-compensatory-mitigation.html.

- TN Debit Tool workbook: wr_nru-tmat-debit-tool-workbook
- TMAT workbook: wr_nru-tmat-workbook

Within both the TN Debit Tool and TMAT workbooks, a worksheet is provided as the *Project Datasheet* for reporting basic stream site information, desktop metric data, and field-collected metric data. The *Project Datasheet* compiles all the necessary data required for the *TMAT worksheet*. Section 7.2 summarizes data entry in the *Project Datasheet*.

Both workbooks also include the *TMAT worksheet* used to compute functional condition scores (ESC, PCS) for assessed project reaches. The structure of the *TMAT worksheet* follows the functional categories and metrics as listed in Table 2.1. As described in Section 2, the *TMAT worksheet* is used to calculate the ECS for pre-disturbance or pre-restoration conditions. It is then used to calculate PCS at a stream reach for anticipated impacts causing functional loss (debits) or benefits from restoration resulting in functional lift (credits). The TMAT workbook includes a worksheet containing the reference standards for all the TMAT metrics. The reference standards, or performance relationships are used to convert metric desktop/field values into an index score (metric index scores range from 0.0 to 1.0).

7.1 Overview of TN Debit Tool and TMAT Workbooks

7.1.1 TN Debit Tool Workbook

Open the TN Debit Tool workbook in an Excel file, and you will observe six worksheets (tabs). The six worksheet tabs are organized as follow.

- The first tab (most left) is the *Project Datasheet*;
- The second tab (right of Tab 1) is the *Debit Project Assessment* worksheet;
- The third tab is the *Debit Calculator* worksheet;
- The fourth tab is TMAT *Existing Conditions* worksheet, with site tables for nine reaches;
- The fifth tab is *Photos by Reach* worksheet; and
- The sixth tab is the *Reference Standards* worksheet.

As noted above, detailed guidance on the use of the TN Debit Tool is described in Section 7.3.

7.1.2 TMAT Workbook

Open the TMAT workbook in an Excel file, and you will observe eighteen worksheets (tabs) providing data entry up to five project reaches. The worksheet tabs are organized as follow.

- The first tab (most left) is the *Project Datasheet*;
- The second tab (right of Tab 1) is the *Project Assessment* worksheet;
- The third tab is the *Quantification Tool R1* worksheet (TMAT mitigation worksheet for Reach 1);
- The fourth tab is the *Monitoring Data R1* worksheet (TMAT scores per monitoring year for Reach 1);
- The fifth tab is the *Data Summary R1* worksheet (summary tables and graphs of TMAT scores for the monitoring period for Reach 1);
- The 6th, 9th, 12th, and 15th tabs are the *Quantification Tool* worksheets for Reaches 2 through 5 (R2, R3, R4, and R5);
- The 7th, 10th, 13th, and 16th tabs are the *Monitoring Data* worksheets for Reaches 2 through 5 (R2, R3, R4, and R5);
- The 8th, 11th, 14th, and 17th tabs are the *Data Summary* worksheets for Reaches 2 through 5 (R2, R3, R4, and R5); and
- The eighteen tab is the *Reference Standards* worksheet.

As noted above, detailed guidance on the use of the TMAT is described in Section 7.4.

7.2 TMAT Datasheet

Within the TN Debit Tool and TMAT workbooks, the first worksheet, left-most tab is the *Project Datasheet*. As noted above, this worksheet is where for each delineated stream reach, basic stream site information, desktop metric data, and field-collected metric data are entered. The *Project Datasheet* is in Appendix 9.6 consisting of 13 pages.

The *Project Datasheet* pages consist of the following.

- Page 1: basic project and assessment site information including name and location;
- Pages 2-3: desktop data for Hydrology category metrics for Watershed Land Use, Floodplain Storage Infiltration Potential and Reach Runoff Stormwater Infiltration;
- Page 4: field survey data for water surface slope, bankfull indicators and indicator elevation slope;
- Pages 5 and 6: location of assessment reach, and desktop and field data for Hydraulic category metrics when no bankfull indicators are present or not adequate. These pages are skipped (left blank) if bankfull indicators are present.

  Page 5 – consists of field survey data channel cross-sections at assessment reach boundaries; survey channel slope and pool and riffle measurements.

  Page 6 – consists of both desktop and field data for the Floodplain Connectivity and Floodplain Inundation Frequency metrics. Field data relies on cross-sectional data from

Page 5, and requires field estimates of Manning n and channel bed permissible shear stress.

- Pages 7 and 8: location of assessment reach, and field data for Hydraulic and Geomorphology category metrics when bankfull indicators are present. If Pages 5 and 6 are used because of bankfull indicators are absent or not adequate, then Page 7 and top part of Page 8for these metrics are skipped (left blank)

  Page 7 – consists of field measurements of bankfull cross-section and riffle dimensions.

  Page 8 – consists of the field measurements for geomorphic pool dimensions; also included data entry for the optional Aggradation Ratio metric (*upper part of Page 8*).

- Page 8: (bottom part of Page 8) stream walk data Geomorphic category metrics for both bankfull and non-bankfull conditions, consisting of LWD, % streambank erosion, and % streambank armoring .
- Page 9: data collection for the Geomorphology category metric – the Rapid Geomorphic Assessment and designation of Channel Evolution Stage;
- Page 10: field data collected for Geomorphology category metrics per the Physical Habitat and Riparian Corridor parameters; note, the Riparian Corridor width metric can be measured by desktop tools and/or field surveys.
- Page 11: field data collected for Geomorphology category metrics per the Riparian Corridor parameter consisting of the Canopy Cover, plot DBH, and plot invasive species metrics.
- Page 12: data for the Biology/Water Quality category metrics, includes the required data entry for the Biology category, TMI metric.
- Page 13: field sheet for notes.

The *Project Datasheet* provides data entry for both project-scale and assessment-scale data. A project may consist of multiple reaches with a delineated assessment reach (Figure 5.4). Reach segmentation requires determining upstream and downstream boundaries based on various site geomorphic and riparian conditions. Guidance for reach segmentation is provided in Section 5.5. For a project with a single assessment reach, only one *Project Datasheet* needs to be completed. If there are multiple reaches, then a user is required to copy and paste a new *Project Datasheet* into the Excel workbook with a unique reach ID name and number. Project data will remain the same, but field data for each assessment reach will differ.

7.2.1 Project Datasheet: General Procedures for Data Entry

The general procedure starts with a general stream walk of the potential impact or restoration project site delineating the project boundaries and assessment reach boundaries within the project (Section 5.2). During the stream walk, assess site geomorphic and riparian vegetation characteristics to determine the assessment reach upstream and downstream boundaries. The stream walk also includes a visual assessment of whether bankfull indicators are present at stable riffles. If bankfull indicators are present, select the assessment reach boundaries to maximize the number of riffle locations with indicators. Guidance on reach segmentation is provided in Section 5.5.2. The assessment reach will typically be shorter than the project reach, approximately 20 channel unit widths in length representing the overall character of project reach. Flag the upstream and downstream boundaries of the assessment reach within the project reach.

Once the project and assessment reaches have been delineated attain the latitude and longitude of the delineated reach boundaries and record. The *Project Datasheet* can now be completed. It can be found in Appendix 9.6 in addition to the tabs in the TN Debit Tool and TMAT workbooks.

Before going out into the field to collect TMAT data, complete whatever information is available for *Pages 1 through 3*, which consists of data entry for project site basic information, and the desktop data for the Hydrology category metrics. Some input such as the Rosgen stream type will have to be entered after field data are collected. Procedures are described in detail below in Section 7.2.2.1 and 7.2.2.2. SCMs for the Stormwater Infiltration metric can be ground-truthed for locations and dimensions.

The next steps are to collect the field data to complete the Hydraulic and Geomorphology category metrics. Field data is entered into *Pages 4 through 11*. This User's Manual assumes the practitioner has basic stream survey skills. A general reference for stream surveying is Harrelson et al. (1994) though other references are also available on-line such as by Varricchione and Crowley (2009). Individuals will have different equipment and collection strategies based on field experience and methodological preferences.

Field work starts with an investigation of bankfull indicators and if present flagging their stage elevation. Once completed and starting at the upstream boundary, stretching out a fiberglass tape downstream along channel centerline and taking slope measurements. Depending on the project reach, a 300-ft tape is appropriate though for smaller reaches a 100-ft tape may be easier to use. For reaches longer than 300 feet, multiple tapes need to be used moving in the downstream direction until the downstream boundary is reached. Stationing is additive for the entire assessment reach.

Complete *Page 4* for slope measurements (Section 7.2.2.3). Page 4 also is where bankfull indicator locations, elevations, and descriptions are recorded if present, and a check on whether bankfull indicators are adequate is assessed by comparing slopes for the water surface (or channel bed slope if dry) and bankfull stage elevations (difference with water surface). In addition, at bankfull indicator locations, vertical elevation measurements are taken between the water surface and the bankfull indicator stage, and these measurements are checked for consistency. A check on bankfull dimensions can also be completed by comparing the regional curve data.

Within the assessment reach with no bankfull indicators, *Pages 5 and 6* are completed. If bankfull indicators are present skip *Pages 5 and 6* and go to *Pages 7 and 8*. When bankfull indictors are absent or not adequate, cross-sections are surveyed at the upstream and downstream boundaries. Major channel slope inflections should be a reach boundary. A project reach could have more than one assessment reach, but not typically. A channel slope for the assessment reach is needed. These survey measurements are illustrated in Figure 6.17. Two Hydraulic category metrics, the Floodplain Frequency Inundation metric and the Channel Incision metric require estimation of the reach Manning n value and the Bed Permissible Shear

Stress value (Tables 6.5 and 6.6).

When bankfull indicators are present with the tape stretched per segment, metrics for the Hydraulic and Geomorphology categories are measured. Field data will be collected at riffles and pools and recorded on *Pages 7 and 8*. Note on these pages, inputs that are greyed are calculation entries, whereas the non-greyed input blocks are the actual field measured values. For each stable riffle, the beginning and end station distances along the tape are recorded. These station measurements allow for the calculation of riffle lengths. At each riffle, bankfull width, bankfull depth, flood prone width, and low bank height are measured and recorded. Each pool is identified as a geomorphic pool with criteria defined in Section 6.4.2.3. At each pool's maximum depth location, a station distance is recorded on *Page 8* of the *Project Datasheet*. This distance is used to compute the Pool to Pool Spacing metric. The Pool Spacing Ratio metric requires the bankfull width: however, if no bankfull indicators are present then an active channel width can be substituted for this width. Description for measuring an active channel width is in Section 6.4.2.3. If no bankfull indicators are present then the Pool Depth Ratio metric is not used in the TMAT.

If the assessment reach currently has no flowing water (such as a seasonally intermittent stream) the practitioner must still collect the necessary riffle and pool measurements needed for the various attendant metrics. These measurements are of the geomorphic characteristics of the stream channel, and may be recorded during a variety of flow conditions. The riffle and pool data are not dependent on the elevation of the water surface at the time of the survey. While it is advisable for practitioners to complete the assessment while the assessment reach is flowing, the process of locating geomorphic channel features during dry conditions can be completed. If site conditions are so adverse during the field survey that these measurements cannot be obtained, the practitioner may choose to either complete the measurements during more favorable field conditions, or, in the case of establishing an ECS for debit purposes, may utilize the default value for these parameters.

The remaining field survey data on the bottom part of *Page 8, and Pages 9 through 11* are collected for the entire assessment reach. *Page 8* includes data collected for three Geomorphology category metrics; they are LWD pieces, % Streambank Armoring, and % Streambank Erosion. As noted above, a measurement tape is stretched down the centerline of the channel, and data collected and recorded with stationing data. If the reach is longer the one tape length, then another section of tape is stretched down the channel centerline. The station distancing for entry into the *Project Datasheet* will be cumulative, adding distances of each extended tape with the project boundary start as zero at the upstream end. Continue with the longitudinal profile survey to the project downstream boundary and record its location. Cross sectional data that apply to bankfull indicators is to be recorded at every stable riffle location in the reach.

Within the assessment reach, an RGA is conducted and stage of channel evolution identified, and sub-metric data recorded on Page 9. Other data for Geomorphology category metrics are collected including the Wolman Pebble Count, Riparian Corridor Width, and Riparian Corridor Canopy Cover (*Pages 10 and 11*). The Riparian Corridor Canopy Cover metric is conducted at three stable riffles, or if not available then upper, mid, and lower areas of the assessment reach. At these same locations where the Riparian Corridor Canopy Cover metric is collected, vegetation plots are set up on both side of the channel onto the riparian corridor. Each plot is 10 m by 10 m (33 ft by 33 ft). Where possible, the plots should be established at least 1 m from the top of bank into the riparian zone. Within each plot, the DBH of the three largest trees are recorded, and the % area of Invasive Species. Macroinvertebrates are sampled and a TMI score computed following TDEC (2017) protocols and recoded on *Page 12*. *Page 12* of the *Project Datasheet* is where data is entered for optional biology/water quality data. A page for taking notes is provided on *Page 13*, this can include cross-section sketches and other survey notes.

7.2.2 Project Datasheet: Description of Data Inputs

7.2.2.1 Datasheet Basic Information

The basin information that is completed on Page 1 of the datasheet includes: project site name and location, project length, watershed drainage area for the project site (above downstream project boundary), ecoregion, ETW/ONRW listing, flow type (perennial or intermittent), valley type (unconfined/confined alluvial, or colluvial), whether bankfull indicators are present or not, regional curve data, Rosgen stream type, dominant bed substrate, channel slope, channel elevation model stage, and TN Macroinvertebrate Index and season collected. Google Earth™, GPS, or other software/devices can be used to project location latitudes and longitudes for site upstream and downstream boundaries. Descriptions and methods for valley types and Rosgen stream types, and protocols for identifying bankfull indicators are explained in Section 5.4.

7.2.2.2 Hydrology Category Desktop Data

Desktop data needed for the Hydrology category metrics are: 1) Catchment Hydrology – Watershed Land Use, 2) Floodplain Storage/Infiltration Potential, and 3)Reach Runoff – Stormwater Infiltration. Desktop data are entered on Pages 2 and 3 of the *Project Datashee*t. Detailed instructions on computing the field values for these metrics are in Sections 6.2.1 – 6.2.3. These sections provide example project cases and illustrate computational procedures.

7.2.2.3 Bankfull Indicators and Water Surface and Bankfull Stage Slopes: Data Collection

A survey of the longitudinal profile slope is completed starting at the upstream boundary of the project reach working downstream. Stationing of bankfull indicators at stable riffles are recorded on Page 4 of the Datasheet, and includes a description and a measure of the vertical distance between the water surface and the bankfull elevation stage. This vertical distance can be conducted with a stadia rod. Water surface or channel bed and bankfull stage slopes are surveyed are recorded using standard survey methods, and the method choice is determined by the practitioner. Page 4 of the Datasheet provides for the data entry using an auto level/hand level and stadia rod or a rangefinder with a slope indicator. For sections of the assessment reach with longitudinal stationing recorded, an elevation drop is measured (starting at the uppermost boundary of the assessment reach moving downstream). If using an auto level, for the water surface slope, the stadia rod is positioned at the water surface edge, and vertical distance differences are recorded. For the bankfull stage slope, the stadia rod is positioned at top of the bankfull depth elevation, and vertical distance differences are recorded. For both the water surface or dry channel bed slopes and bankfull stage slopes, the total vertical elevation drop is summed from the individual section drops measured, and divided by the total length of the assessment reach. This ratio is multiplied by 100 to report them as percentages.

Water surface or channel bed slope of the assessment reach is solely used to determine the Rosgen stream type for the metrics that apply bankfull indicators, however it is also used for the Channel Incision non-bankfull metric. Bankfull stage slope is compared to the water surface slope to assess channel stability, and whether bankfull indicators should be used. According to Rosgen (2014), these two slopes should be within 10% of each other for the channel to be considered stable and bankfull indicators can be appropriately used. A minimum of three bankfull indicators are required, and field data collected is described in Section 6.2.1. If no bankfull indicators are present then only compute the project channel slope, and then follow the data collection procedures needed to compute the Hydraulic category non-bankfull metrics (Section 7.2.2.4).

7.2.2.4 Hydraulics Category: Non-Bankfull Metrics Data Collection

The Hydraulic category metrics Floodplain Frequency Inundation and Channel Incision are used when bankfull indicators are absent or not adequate, and require field measurements within the assessment reach. The assessment reach is delineated and flagged during the initial stream walk. Pages 5 and 6 of the *Project Datashee*t is where data is entered for these two metrics. For the upstream and downstream reach boundaries, record the latitude and longitude, and the project reach station distance along the longitudinal profile survey. Channel cross-sections are surveyed at the upstream and downstream boundaries, and the channel slope (S) is measured between the boundaries. Survey of the cross-sections must include the floodplain surface area about three feet beyond the top of bank. A separate field sheet for cross-sectional surveys may be needed and example shown in Harrelson et al. (1994). The water surface slope as the channel slope is obtained on Page 4.

Floodplain Inundation Frequency metric: The Floodplain Frequency Inundation metric requires the practitioner to obtain flow frequency data from USGS StreamStats for the Q_2, Q_5, Q_{10}, Q_{25}, Q_{50}, and Q_{100} flow return frequencies. With StreamStats delineate the watershed from the downstream boundary of the assessment reach (Section 6.2.2). If the watershed drainage area is too small StreamStats cannot delineate the watershed area, in which case USGS regression equations are to be used (Table 6.4). Another tool has to be used to obtain drainage area, such as using the polygon tool in GoogleEarth. Also, a Manning n value must be estimated from a visual inspection of channel bed roughness characteristics and the value obtained from Table 6.5. Manning n can also be computed based on an equation using the cross-sectional data and the Wolman Pebble Count, which methodology is described in Appendix 9.5. This equation for Manning n should only be used with a W/D ratio greater than 12 and where banks are not heavily vegetated.

The cross-sectional survey data is plotted and a water surface line is drawn at the stage when flood waters overtops the channel onto the floodplain. The flow area is computed for both cross-sections ($A_{u/s}$, $A_{d/s}$) and averaged (Avg. A). For the flow area, the wetted perimeter is computed for both cross-sections ($Pw_{u/s}$, $Pw_{d/s}$) and averaged (Avg. Pw). The hydraulic radius (R_h) is computed with the average area and wetted perimeter as: R_h = Avg. (A/Pw). With this data, compute the following geometric relationship:

_____ = (Avg A)$^{5/3}$ / (Avg. Pw)$^{2/3}$

Next, for each flow return frequency (Q_i,) compute the following:

(Q_i x n) / (1.49 x $S^{1/2}$) = ______

Six values will be obtained from the above equation, in which the practitioner compares each with the one value computed for the above geometric relationship. Enter these six values into the *Project Datashee*t, in addition to the one value for the geometric relationship. The field value for this metric is the Qi which exceeds the geometric relationship value.

<u>*Channel Incision metric*</u>: The Channel Incision metric uses the same surveyed cross-sections and slope as for the Floodplain Frequency Inundation metric. As described above, the average A and Pw is used to calculate the hydraulic radius (R_h) as: R_h = Avg. (A/Pw). The R_h is used to compute the hydraulic shear stress ($\tau = g \cdot Rh \cdot S$). To compute the hydraulic shear stress, the specific weight of water (g = 62.4 lb/ft^3) is multiplied by the Rh and channel slope (S). A channel bed permissible shear stress (τ_p) must be estimated from a visual inspection of channel bed characteristics and the value obtained from Table 6.6. The field value for this metric is the ratio of hydraulic shear stress by channel bed permissible shear stress (τ / τ_p).

7.2.2.5 Hydraulics Category: Bankfull Metrics Data Collection

With bankfull indicators field identified at stable riffles, two metrics for the Hydraulics Categories are computed, which are: Entrenchment Ratio (ER) and Bank Height Ratio (BHR). The upstream and downstream boundary locations (latitude and longitude), their station distance within the project reach if shorter, and assessment reach total length are recorded. Station distances are obtained from the longitudinal profile survey with the fiberglass tape stretched down the channel centerline. For each riffle in the downstream direction, the beginning and end station distances are recorded on Page 7 of the *Project Datashee*t. These distances are used to compute the riffle length. The bankfull measurements taken at the riffle cross-sections include: maximum depth, mean depth, and width. In addition, flood prone width and low bank height is measured. These measurements for each riffle are recorded on Page 7 of the *Project Datashee*t, and used to compute the ER and BHR. With multiple riffle measurements, a weighted average based on riffle lengths are computed for the ER and BHR.

Field data for geomorphic pools are recorded on the upper part of Page 8. The station distance of the deepest location in each pool along the longitudinal profile are recorded. Criteria for whether a pool is considered a geomorphic pool is described in Section 6.4.2.3.

The optional Aggradation Ratio metric applies the bankfull width to depth ratio (WDR) and measurement data recorded on Page 8 of the *Project Datashee*t. The maximum WDR is obtained from Page 6 for the WDRs computed for each riffle. The Rosgen stream type determines the expected WDR, in which a table of values are shown for B, C, and E stream types. The field value for the Aggradation Ratio is the maximum WRD divided by the expected WDR.

7.2.2.6 Geomorphic Category: Physical Habitat Metric Data Collections

Physical Habitat metrics include field measurements from the longitudinal profile survey associated with pools. Depressions in the channel bed constituting a pool structure are determined to be a geomorphic pool or not based on criteria defined in Section 6.4.2.3. The station distance for the maximum pool depth is recoded and then used to compute the distance between pools as 'pool to pool' spacing. The Pool Spacing Ratio is computed for the second pool and following pools downstream along the longitudinal profile as the 'pool to pool' spacing divided by the channel width. If bankfull indicators are present, the channel width is the mean bankfull width averaged from the values entered on Page 6 of the *Project Datashee*t. If bankfull indicators are absent, an estimate for the active channel width is used. Field criteria for identifying active channel width is in Section 6.4.2.3. Either mean bankfull width or the active channel width is entered on Page 7 of the *Project Datashee*t. The field value for the Pool Spacing Ratio is the mean of the individual pool measurements.

The Pool Depth Ratio (PDR) is computed only if bankfull indicators are present. This metric requires the mean bankfull riffle depth, which is obtained by averaging the values reported on Page 8 of the *Project Datashee*t. For each pool, the maximum pool depth is measured from bankfull height and divided by the mean bankfull riffle depth to obtain the PDR. The field value for the PDR is the average of all pool measurements.

7.2.2.7 Geomorphic Category: Stream Walk Data Collection

A stream walk of the project reach is conducted to collect field data for the LWD, % Streambank Erosion and % Streambank Armoring metrics. Field data collected for these three metrics from the stream walk are entered on Page 8 of the *Project Datashee*t. The number of LWD pieces that met the size criteria as defined in Section 6.3.1 are counted, and data recorded. The field value is the number of pieces counted normalized by a 300-ft channel length.

The % Streambank Erosion and % Streambank Armoring and metrics are visual estimates of the left and right banks with artificially-constructed bank materials, i.e., rip-rap, and evidence of fluvial erosion. The % Streambank Armoring metric is measured for the entire project reach, whereas the % Streambank Erosion metric is surveyed only in the assessment reach. Criteria for visual estimates are described in Sections 6.4.1.1 and 6.4.1.2, respectively. For both metrics, left and right bank measurement lengths meeting the metric's core criteria are summed. The field value is the sum of the left and right bank estimates divided by twice the total project reach length.

7.2.2.8 Geomorphic Category: Rapid Geomorphic Assessment

The RGA is a metric for the Channel Stability parameter, and field-based measures are reported on Page 9 of the *Project Datashee*t. The RGA is conducted on the assessment reach, approximately 20 channel unit widths. Eight sub-metrics are assessed and data collection fully described in Section 6.4.1.3. When conducting this assessment, the practitioner needs to integrate the sub-metric's attribute over the entire reach and not to locally fixate on it. The stage of channel evolution is also recorded on Page 9, in addition to Page 1 where general stream reach information is summarized.

7.2.2.9 Geomorphic Category: Bed Sediment Field Measurements

The Wolman pebble count is a metric for the Physical Habitat parameter, and field-based measures are reported on Page 10 of the *Project Datashee*t. Methodology for the Wolman pebble count measuring 100 sediment particles is conducted within the assessment reach and fully described in Section 6.4.2.1. A field sheet to record 100 particles is needed, and various field sheets are available on-line.

7.2.2.10 Geomorphic Category: Riparian Corridor Data Collection

The Riparian Corridor parameter consists of four metrics. They are: 1) Riparian Corridor Width, 2) Canopy Cover; 3) % Invasive Species, and 4) Average DBH. Data for these metrics are collected in the assessment reach. Measurements for the Riparian Corridor Width are taken above the left and right banks from multiple longitudinal positions as described in Section 6.3.2.1. Data for Riparian Corridor Width are entered in the *Project Datashee*t on Page 10, and an overall average width is computed and recorded for the field value.

The Riparian Canopy Cover metric is measured at three locations within the channel either at stable riffle locations, or positioned equally-spaced in the assessment reach as upper, middle, and lower positions. Using the densiometer, the measurement method for this metric is fully described in Section 6.3.2.2. Data for the Riparian Canopy Cover metric are entered in the *Project Datashee*t on Page 11. An overall average is computed and recorded for the field value.

At the same longitudinal positions for the Riparian Canopy Cover metric, 10-m x 10-m vegetative plots on the left and right banks are demarcated along the bank, and 1-m back from top of bank extending 10 m into the riparian corridor. Within these vegetative plots, Average DBH and % Invasive Species are measured and recorded on Page 11 of the *Project Datashee*t. Measurement methodology for collecting data for these two metrics are in Sections 6.3.2.3 and 6.3.2.4. Overall averages are computed and recorded for field values.

7.2.2.11 Biology/Water Quality Category: Data Collection

The TMI score is entered on Page 12 of the *Project Datashee*t. The metric is the required measure for the Biology/Water Quality Category. An alternative option to the TMI is the use of three TMI sub-metrics: percent clingers, % EPT-Cheum, and % OC. Page 11 also provides a table to report these three sub-metrics. Measurement methodology for collecting these biological data are in Section 6.5.1.2. Water Quality metrics are optional, and if used data is entered in the provided table on Page 12 of the *Project Datashee*t. Measurement methodology for collecting water quality data is in Section 6.5.2.

7.3 TN Debit Tool Workbook

The *Project Datasheet* is used to enter basic site information, desktop metric data, and field-collected metric data for each project reach (Section 7.2). This sheet is used for a single project reach assessment thus if more than one reach is assessed for a project it needs to be copied in the Debit Tool workbook, and completed for each reach. Data summarized are entered into the TMAT *Existing Conditions* worksheet, with each reach data entered into separate tables provided. Multiple tables are provided where an existing condition score (ECS) for each project reach is computed within each table.

The *Debit Project Assessment* worksheet is a summary sheet that names the project, applicant, and permit number; and provides a cell to describe the project (Table 7.1). It provides spreadsheet rows used to define project reaches, reach location information, and each reach impact description (Section 2.3.3, Table 2.3). The worksheet displays the total number of debits as computed in the *Debit Calculator* worksheet.

Table 7.1. *Debit Project Assessment* worksheet within TN Debit Tool workbook.

Project Name				Total Debits (FF)
Applicant				0
Project ID/Permit Number(s)		Date	[illegible]01	
Project Description				

Stream ID By Reach	Impact Description	Latitude	Longitude

7.4 TMAT Workbook

The *TMAT workbook* spreadsheet is the keystone data submission document.

7.4.1 Project Assessment

The project assessment tab contains the project description and goals, which are each entered by the user as appropriate (Table 7.2).

Table 7.2. Project assessment tab - Project description.

Project Name:	
Stream Name:	
Programmatic Goals:	
Explain the goals and objectives for this stream project:	
Goals: are goals to get credits	
Objectives:	
Explain the restoration potential of this stream based on the programmatic goals:	Describe this stream AND reach break criteria:

The stream summary information section is automatically populated from information entered in the quantification tool tabs (Section 7.4.2). This summary information is placed in Table 7.3. CEM descriptions are also manually populated and accompanied by project reach photos (Table 7.4).

Table 7.3. Project assessment tab – Stream summary information.

Stream Summary Information					
Reach ID	**Existing Stream Length (feet)**	**Proposed Stream Length (feet)**	**Change in Functional Condition (PCS - ECS)**		**Functional Lift (Credits)**
0	0.00	0.00	0.00		0.00
0	0.00	0.00	0.00		0.00
0	0.00	0.00	0.00		0.00
0	0.00	0.00	0.00		0.00
0	0.00	0.00	0.00		0.00
Totals	0.00	0.00	0.00		0.00

Table 7.4: Project assessment tab – CEM description.

Stream Evolution Description		
Describe the stage of channel evolution for each reach using either the Stream Evolution Model (Cleur and Thorne, 2013) and/or the Rosgen Channel Succession Scenario (Rosgen, 2006).		
Describe the stage of channel evolution for: REACH 1	Describe the stage of channel evolution for: REACH 2	Describe the stage of channel evolution for: REACH 5
Describe the stage of channel evolution for: REACH 3	Describe the stage of channel evolution for: REACH 4	

7.4.2 Quantification Tool

The quantification tool tab consists of five subsections and the overall mitigation summary, which states the overall functional lift as mitigation credits that are calculated through data entered in the other subsections of this tab.

7.4.2.1 Functional Lift Summary

This subsection presents the overall change in functional category as the existing condition score minus the proposed condition score, which are automatically populated through the calculations in the ECS and PCS subsections (Sections 7.4.2.5 and 7.4.2.6), and shown in Table 7.4. *The additional stream length is calculated from the manually entered existing and proposed stream length.*

Table 7.5. Quantification tab – Functional lift summary.

FUNCTIONAL LIFT SUMMARY	
Exisiting Condition Score (ECS)	0.00
Proposed Condition Score (PCS)	0.00
Change in Functional Condition (PCS - ECS)	0.00
Existing Stream Length (feet)	
Proposed Stream Length (feet)	
Additional Stream Length (feet)	0
Existing Stream Functional Feet (FF)	0
Proposed Stream Functional Feet (FF)	0
Functional Lift (Proposed FF - Existing FF)	0

7.4.2.2 Function Based Parameters Summary

All results for the TMAT functional categories are summarized and presented for the existing and proposed condition scores. Each is calculated via the data entered in the ECS and PCS subsections of this tab (Table 7.6).

Table 7.6. Quantification tab – Function-based parameters summary.

FUNCTION BASED PARAMETERS SUMMARY			
Functional Category	**Function-Based Parameters**	**Existing Parameter**	**Proposed Parameter**
Hydrology	Catchment Hydrology	0.00	0.00
	Reach Runoff	0.00	0.00
	Floodplain Storage	0.00	0.00
Hydraulics	Floodplain Connectivity	0.00	0.00
Geomorphology I	Large Woody Debris	0.00	0.00
	Riparian Corridor	0.00	0.00
Geomorphology II	Channel Stability	0.00	0.00
	Physical Habitat	0.00	0.00
Biology / Water Quality	Biology	0.00	0.00
	Water Quality	0.00	0.00

7.4.2.3 Functional Category Report Card

The ECS and PCS scores are calculated through the data entered in the ECS and PCS subsections (Sections 7.4.2.4 and 7.4.2.5) of this tab and displayed here, broken down by functional category and the corresponding functional lift (Table 7.7). All fields in the functional category report card are automatically generated from data entered elsewhere in the quantification tool subsections.

Table 7.7. Quantification tab – Function category report card.

FUNCTIONAL CATEGORY REPORT CARD			
Functional Category	**ECS**	**PCS**	**Functional Lift**
Hydrology	0.00	0.00	0.00
Hydraulics	0.00	0.00	0.00
Geomorphology I	0.00	0.00	0.00
Geomorphology II	0.00	0.00	0.00
Biology / Water Quality	0.00	0.00	0.00

7.4.2.4 Existing Condition Score (ECS)

The existing condition score subsection includes two notable components, the site information and condition assessment (Tables 8, 9, 10, 11, and 12).

The site information consists of the site metadata, stream data, and macroinvertebrate data. Within the metadata, the reach ID is manually entered while the ecoregion is selected from a dropdown menu, as is the selection of bankfull or non-bankfull approaches. Please note that

Table 7.8. Quantification tab – Existing condition score (ECS) site information.

Site Information							
Metadata		Stream Data				Macroinvertebrate Data	
Reach ID:		Upstream Latitude:		Stream Type:	Click Here	Macro Collection Season:	Click Here
		Upstream Longitude:		Flow Type:	Click Here	Macro Collection Method:	Click Here
		Downstream Latitude:		Stream Slope (%):			
Ecoregion:	Click Here	Downstream Longitude:		Drainage Area (sq mi):			
Bankfull/Non-bankfull:	Click Here	Valley Type:	Click Here	Bed Material:	Click Here		

Table 7.9. Quantification tab – Existing condition score (ECS) site information with metadata cells highlighted.

Site Information							
Metadata		Stream Data				Macroinvertebrate Data	
Reach ID:		Upstream Latitude:		Stream Type:	Click Here	Macro Collection Season:	Click Here
		Upstream Longitude:		Flow Type:	Click Here	Macro Collection Method:	Click Here
		Downstream Latitude:		Stream Slope (%):			
Ecoregion:	Click Here	Downstream Longitude:		Drainage Area (sq mi):			
Bankfull/Non-bankfull:	Click Here	Valley Type:	Click Here	Bed Material:	Click Here		

Table 7.10. Quantification tab – Existing condition score (ECS) site information with stream data cells highlighted.

Site Information							
Metadata		Stream Data				Macroinvertebrate Data	
Reach ID:		Upstream Latitude:		Stream Type:	Click Here	Macro Collection Season:	Click Here
		Upstream Longitude:		Flow Type:	Click Here	Macro Collection Method:	Click Here
		Downstream Latitude:		Stream Slope (%):			
Ecoregion:	Click Here	Downstream Longitude:		Drainage Area (sq mi):			
Bankfull/Non-bankfull:	Click Here	Valley Type:	Click Here	Bed Material:	Click Here		

Table 7.11. Quantification tab – Existing condition score (ECS) site information with macroinvertebrate data cells highlighted.

Site Information							
Metadata		Stream Data				Macroinvertebrate Data	
Reach ID:		Upstream Latitude:		Stream Type:	Click Here	Macro Collection Season:	Click Here
		Upstream Longitude:		Flow Type:	Click Here	Macro Collection Method:	Click Here
		Downstream Latitude:		Stream Slope (%):			
Ecoregion:	Click Here	Downstream Longitude:		Drainage Area (sq mi):			
Bankfull/Non-bankfull:	Click Here	Valley Type:	Click Here	Bed Material:	Click Here		

Table 7.12: Quantification tab – Existing condition score (ECS) condition.

Condition Assessment											
Functional Category	**Parameter**	**Metric**		**Notes**	**Field Value**	**Index Value**	**Parameter Score**	**Category Score**	**Category**	**Condition Score**	**Condition**
Hydrology	Catchment Hydrology		Watershed Land Use Runoff Score				/0.33	0.00	Not Functioning	0.00	Not Functioning
	Reach Runoff		Stormwater Infiltration				/0.33				
	Floodplain Storage		Infiltration Potential	Reach Description data entry incomplete			/0.33				
Hydraulics	Floodplain Connectivity		Bank-height Ratio	Reach Description data entry incomplete			/0.50	0.00	Not Functioning		
			Entrenchment Ratio	Reach Description data entry incomplete			/0.50				
			Floodplain Inundation Frequency	Reach Description data entry incomplete			/0.50				
			Channel Incision (shear stress ratio)	Reach Description data entry incomplete			/0.50				
		Optional	Aggradation Ratio	Not reported							
Geomorphology I	Large Woody Debris		LWD Count				/0.50	0.00	Not Functioning		
	Riparian Corridor		Buffer Width (ft)				/0.50				
			Canopy Cover (densiometer count)								
			% Invasive Woody Spp.								
			Average Tree Diameter at Breast-height (DBH; in)								
Geomorphology II	Channel Stability		% Streambank Erosion				/0.50	0.00	Not Functioning		
			% Streambank Armoring								
			Rapid Geomorphic Assessment								
	Physical Habitat		Wolman Pebble Count (p-value)				/0.50				
			% Riffle								
			Pool-Pool spacing ratio								
			Pool depth ratio	Reach Description data entry incomplete							
Biology / Water Quality	Biology	Total TMI Score	Total Tennessee Macroinvertebrate Index	TMI score not entered			/1.00	0.00	Not Functioning		
		Partial TMI Data	% Clingers	Partial TMI data not entered, default to Total TMI Score							
			% EPT - Chuematopsyche								
			% Oligo. & Chironom.								
	Water Quality	*Optional*	% Nutrient Tolerant macro	Not reported							
			Mean Nitrate-Nitrite (mg/L)	Not reported							
			Mean Total Phosphorous (mg/L)	Not reported							
			Geomean E. coli (Cfu/100 mL)	Not reported							

the bankfull/non-bankfull approach selection impacts the availability of metrics to be utilized in the condition assessment component while the ecoregion selection impacts the reference standards that are used in the calculations of index scores, specifically the percent riffle metric.

Stream data includes manual entry of the upstream and downstream latitudinal and longitudinal coordinates for future reference of site delineation, the stream slope as a percentage, and drainage area in square miles, which are utilized for the determination of stream type as well as the calculation of various metric field values in the condition assessment component. The drainage area is also functional within the invertebrate metric, discussed below, to determine the reference standard that calculates the resulting index score. Additionally, the valley type, stream type, flow type, and bed material are selected from dropdown menus and are utilized as reference in the calculation of various metric field scores as well as distinguishing the reference standard to be used for the entrenchment ratio metric based on stream type.

The macroinvertebrate component is comprised of the collection season and collection method, selected from dropdown menus. These entries are used along with the drainage area and ecoregion, discussed above, determine the appropriate reference standard that is applied to the field value, entered in the condition assessment, to generate the index scores for the Biology parameter metrics.

Finally, the condition assessment area is used to enter the appropriate field values, calculated in Section 6, for each individual metric. Please note that some metrics require site information to properly calculate index scores, mainly due to a need for reference standard determination. These metrics will remain blacked out until the necessary site information is entered. These are noted in the notes column until the requirements have been satisfied. Similarly, data entered in the site information component will affect the metric being used in the survey. As such, the corresponding index value cells will automatically black out. Also, the parameter score column will black out and denominators will adjust accordingly. While data can still be entered into the field value of these metrics, the calculations will not include these entries. When all data has been entered properly, the spreadsheet will automatically calculate and readout scores for each index, metric and category as well as determining the functionality of each functional category and the final condition and condition score of the survey segment.

7.4.2.5 Proposed Condition Score (PCS)

The proposed condition score subsection is functionally identical to the existing condition score (ECS) subsection (section 7.4.2.4). This subsection is included to allow for the evaluation of a proposed project based on individual metrics as well as comparisons of individual functional categories and overall potential mitigation credits.

7.4.3 Monitoring Data

Each monitoring data tab is used to document on-going monitoring of a given stream segment. Beginning with the “as-built” condition, each tab contains space for up to 10 years of monitoring efforts. Data entry in each monitoring effort is exactly as described in section 7.4.2.4.

7.4.4 Data Summary

The data summary tab is fully automated and read only (Table 7.13). Data for a reach is entered in the quantification tool tab and monitoring data tab, which is then automatically carried forward to the function-based parameters summary and functional category report card (Table 7.14). Additionally, the functional category condition scores, overall condition scores and effective functional feet are tabulated and presented in graphical form, for easy viewing and analysis. Overall condition score tracking is illustrated in Figures 7.1, 7.2, and 7.3.

Table 7.13. Data Summary tab – Function-based parameters summary.

FUNCTION BASED PARAMETERS SUMMARY													
Functional Category	Function-Based Parameters	Existing Parameter	Proposed Parameter	Monitoring Year									
				1 (As-built)	2	3	4	5	6	7	8	9	10
Hydrology	Catchment Hydrology	0.00	0.00										
	Reach Runoff	0.00	0.00										
	Floodplain Storage	0.00	0.00										
Hydraulics	Floodplain Connectivity	0.00	0.00										
Geomorphology I	Large Woody Debris	0.00	0.00										
	Riparian Corridor	0.00	0.00										
Geomorphology II	Channel Stability	0.00	0.00										
	Physical Habitat	0.00	0.00										
Biology / Water Quality	Biology	0.00	0.00										
	Water Quality	0.00	0.00										

Table 7.14. Data Summary tab – Functional category report card.

FUNCTIONAL CATEGORY REPORT CARD												
Functional Category	ECS	PCS	Monitoring Year									
			1	2	3	4	5	6	7	8	9	10
Hydrology	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydraulics	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Geomorphology I	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Geomorphology II	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Biology / Water Quality	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Overall Score	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Functional Feet	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

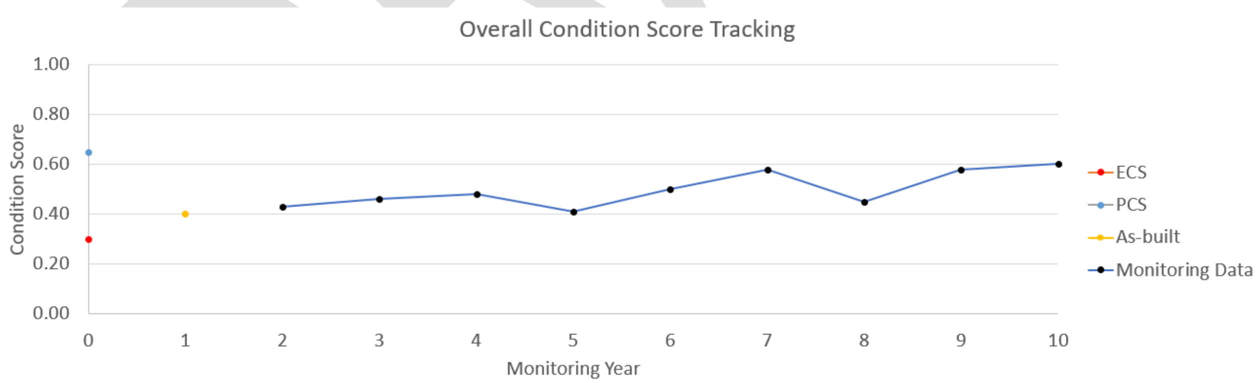


Figure 7.1. Data Summary tab – Overall condition score tracking.

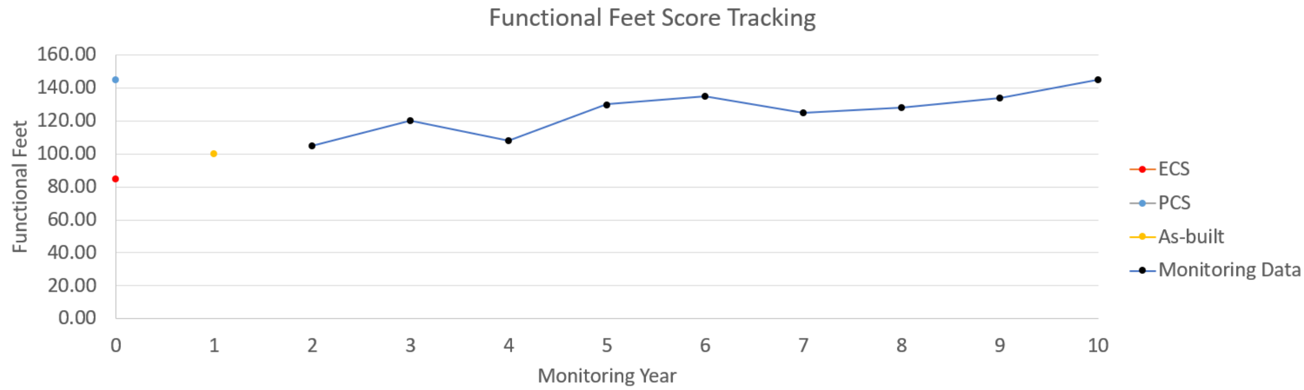


Figure 7.2: Data Summary tab – Functional feet score tracking.

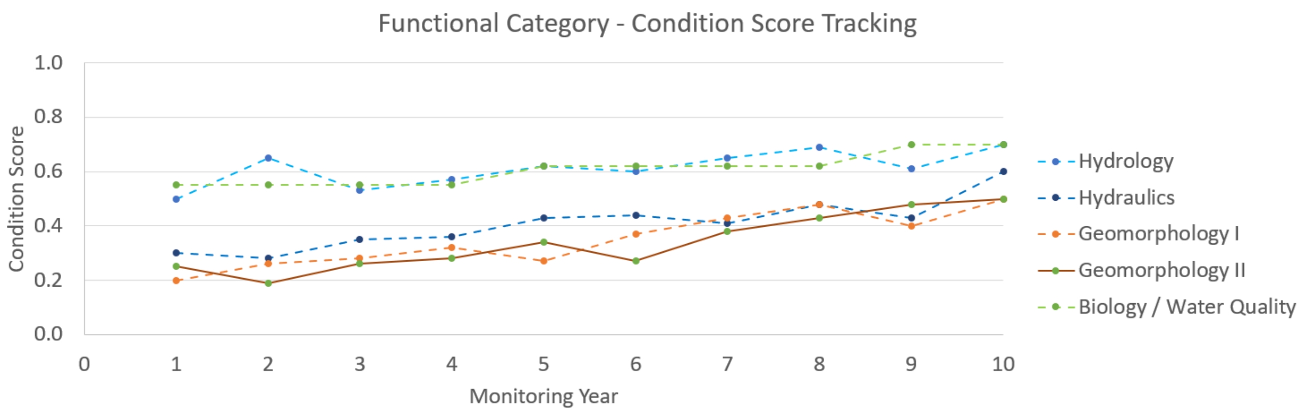


Figure 7.3. Data Summary tab – Functional category - condition score tracking.

8. References

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9. Appendices

9.1 Federal and State Statutes and Regulations

Compensatory mitigation is subject to one or more of the following statutes, regulations, policies, and guidelines:

Federal Regulations and Guidance

a. Clean Water Act (33 U.S.C. §§ 1251, et seq.)

b. Memorandum of Agreement (MOA) Between the Department of the Army and the Environmental Protection Agency: The Determination of Mitigation Under the Clean Water Act ("CWA") Section 404(b)(1) Guidelines (February 6, 1990).

c. Section 404(b)(1) Guidelines for Specification of Disposal Sites for Dredged or Fill Material (40 C.F.R. Part 230)

d. Section 10 of the Rivers and Harbors Act of 1899 (33 U.S.C. § 403)

e. National Environmental Policy Act ("NEPA") (42 U.S.C. §§ 4321, et seq.)

f. Endangered Species Act ("ESA") (16 U.S.C. §§ 1531, et seq.)

g. Fish and Wildlife Coordination Act (16 U.S.C. §§ 661, et seq.)

h. Regulations of the U.S. Army Corps of Engineers Regulatory Program (33 C.F.R. Parts 320–332)

i. Regulatory Guidance Letter (RGL) 05-01. Guidance on the Use of Financial Assurances, and Suggested Language for Special Conditions for Department of the Army (DA) Permits Requiring Performance Bonds

j. RGL 08-03. Minimum Monitoring Requirements for Compensatory Mitigation Projects Involving the Restoration, Establishment, and/or Enhancement of Aquatic Resources.

State of Tennessee Regulations and Guidance

Section 401 of the Clean Water Act: 33 U.S.C § 1341

Tennessee Water Quality Control Act (TWQCA) of 1977:
Tenn. Code Ann. §§ 69-3-101 to -147

Rules of the Tennessee Board of Water Quality, Oil, and Gas:

- Chapter 0400-40-07 Aquatic Resource Alteration
- Chapter 0400-40-03 General Water Quality Criteria (including Rule 0400-40-03-.06, Antidegradation Statement)
- Chapter 0400-40-04 Use Classification for Surface Waters

9.2 Summary of Watershed Characterization Support Document Web Links

Section 5.3.3 for watershed characterization within Chapter 5 for Site Assessment Preparation and Data Collection suggests the use of many information/data sources. As a summary and for document use conveyance they are listed below.

Ecoregions Levels II and IV:
https://gaftp.epa.gov/EPADataCommons/ORD/Ecoregions/reg4/reg4_eco.pdf

FEMA Flood Maps: https://www.fema.gov/flood-maps

Google Earth Pro: https://earth.google.com

NRCS Nat'l Engr. Handbook Part 654: https://directives.sc.egov.usda.gov/17807.wba

TDEC Stream Mitigation Guidelines: [DWR-NR-G-01, 2019] - https://www.tn.gov/content/dam/tn/environment/water/policy-and-guidance/dwr-nr-g-01-stream-mitigation-guidelines-052019.pdf.

Tennessee Surficial Geology: https://www.tn.gov/content/dam/tn/environment/geology/images/geology_geologic-map-lg.jpg

TDEC Data and Map Viewer: https://tdeconline.tn.gov/dwr/

Tennessee 303d List: https://www.tn.gov/content/dam/tn/environment/water/watershed-planning/wr_wq_303d-2022-final.xlsx

TDEC Hydrological Determinations:

https://www.tnhdt.org/PDF/HD%20Guidance.pdf

https://tdeconline.tn.gov/hydrostatus/

Topographic Terrain: USGS topoView - https://ngmdb.usgs.gov/topoview/viewer/#4/39.98/-100.06

USGS Multi-Resolution Land Characteristics Consortium (MRLC): mrlc.gov/view

USDA Web Soil Survey: https://websoilsurvey.nrcs.usda.gov/app/

USGS StreamStats: https://streamstats.usgs.gov/

Watershed Characteristics: *Model My Watershed*® - https://modelmywatershed.org/

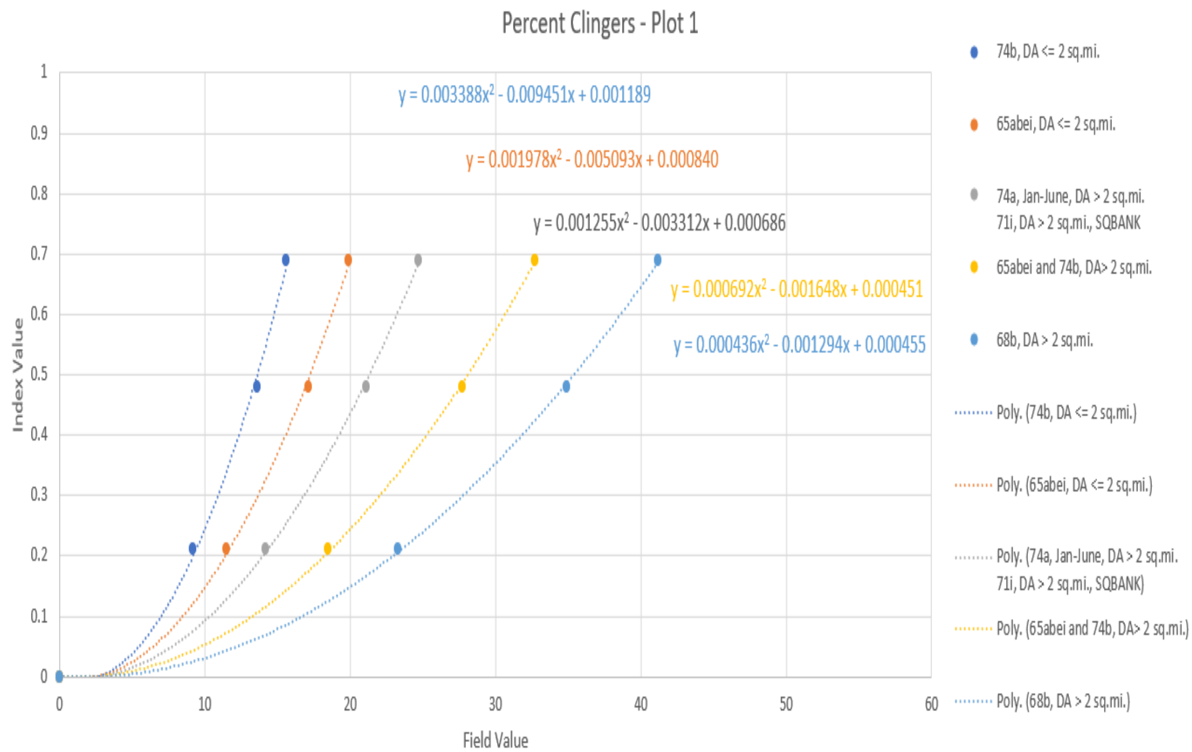
Bankfull Indicators Support Documents:

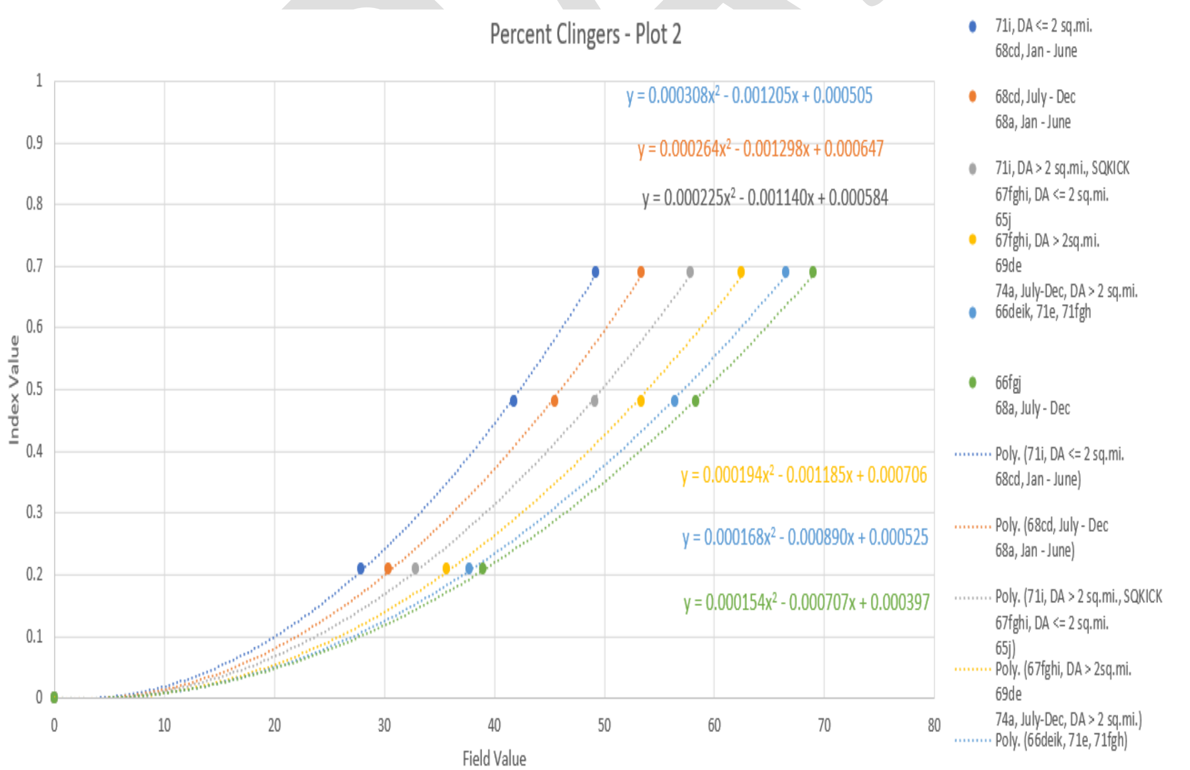
https://content.ces.ncsu.edu/finding-bankfull-stage-in-north-carolina-streams#section_heading_9234

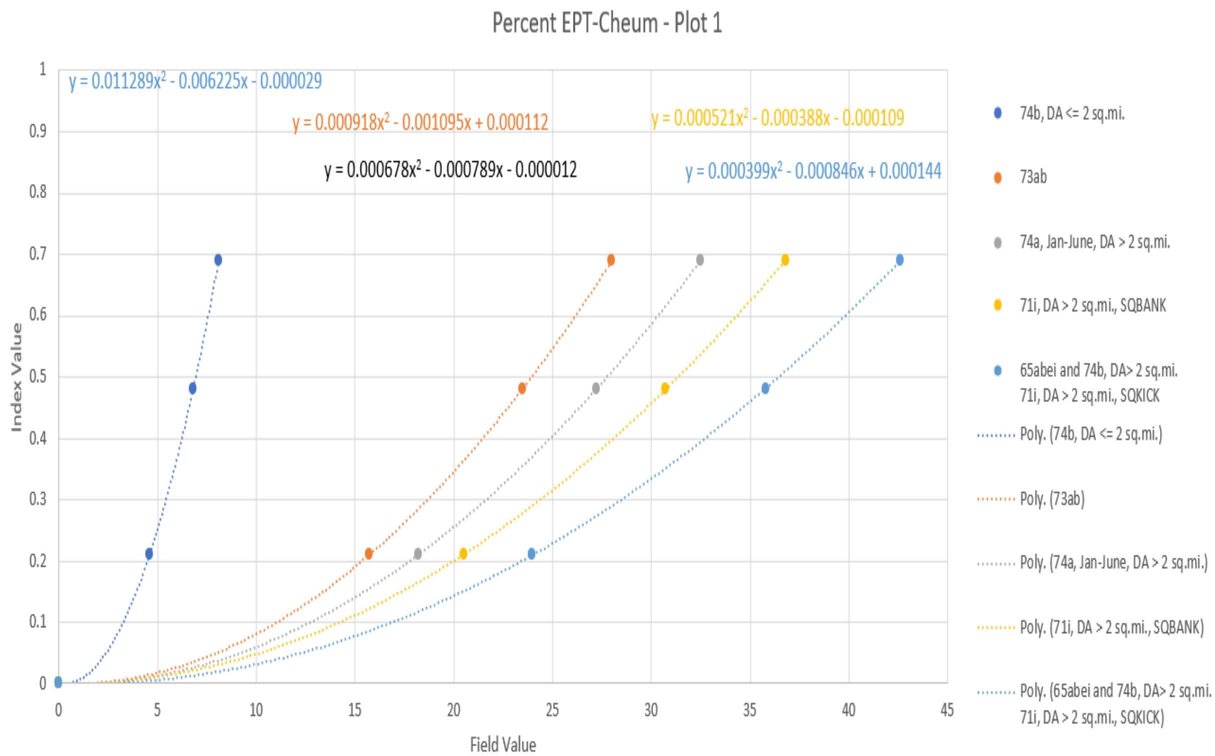
https://nctc.fws.gov/courses/csp/csp3200/resources/documents/Bankful_AFG2013.pdf

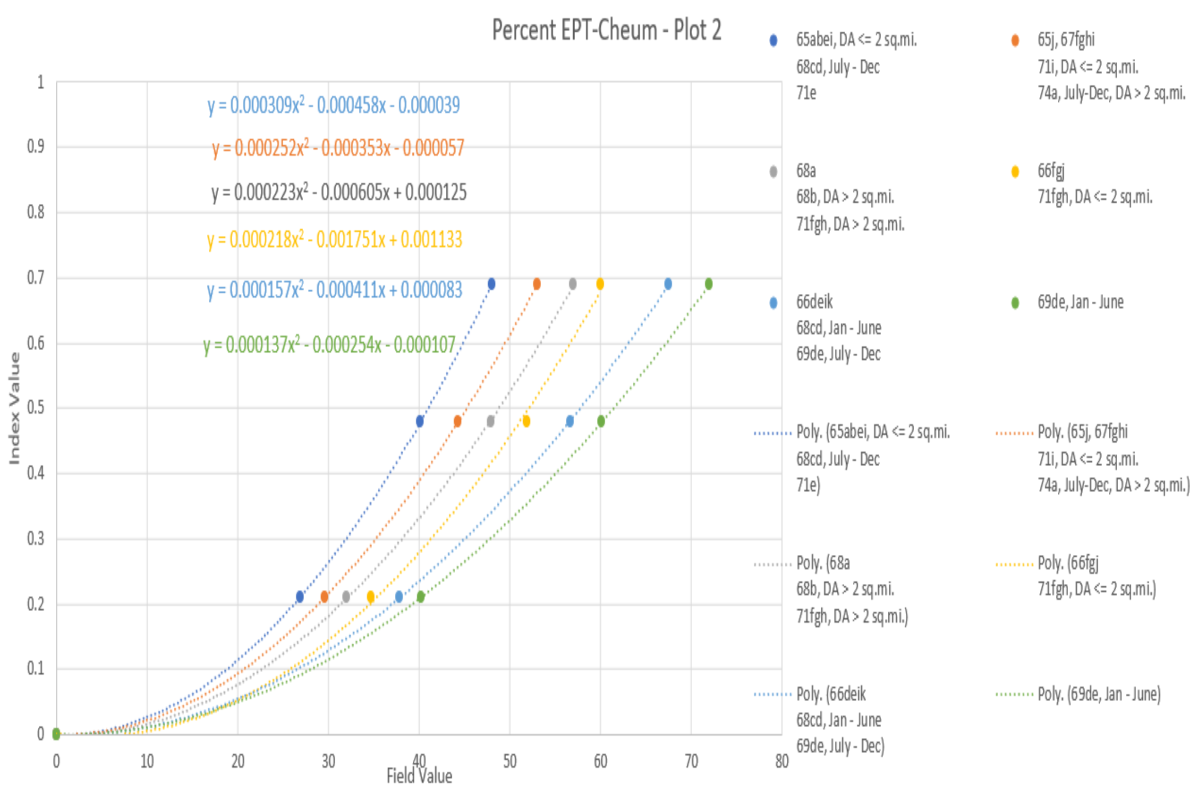
https://www.tn.gov/environment/permit-permits/water-permits1/aquatic-resource-alteration-permit--arap-/permit-water-arap-compensatory-mitigation.html

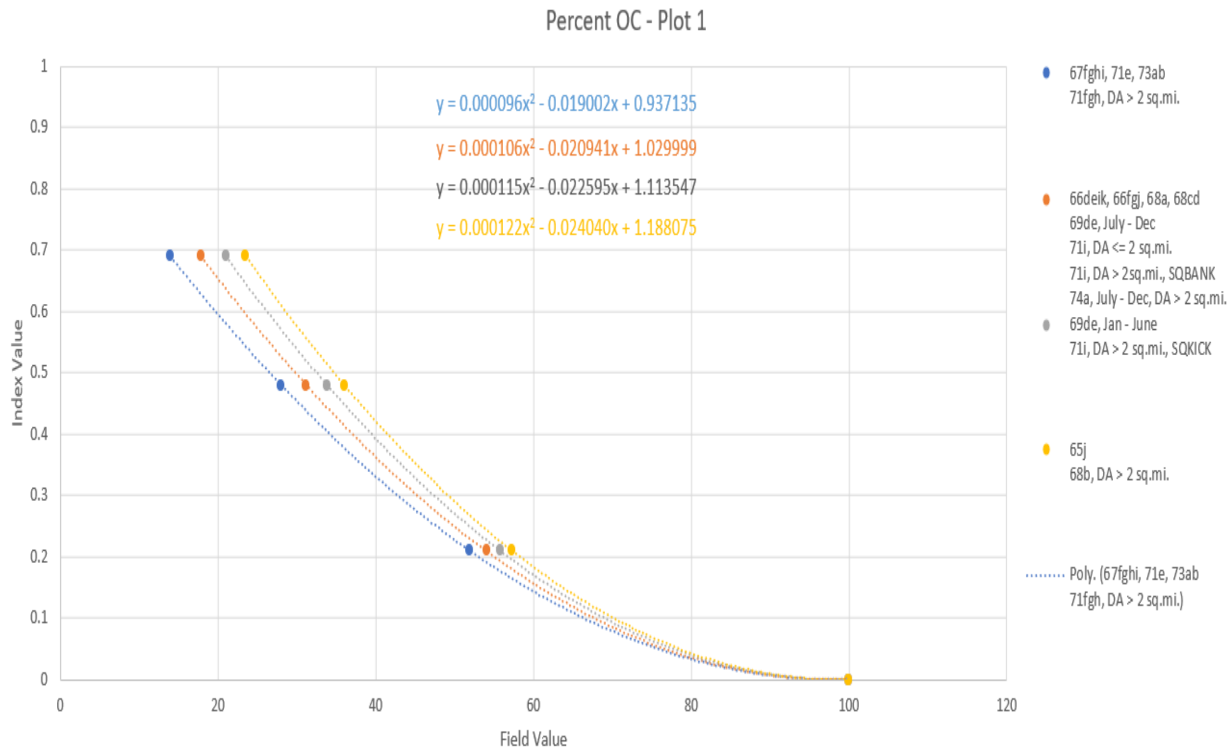
9.3 Reference Standards for TMI sub-Biometrics

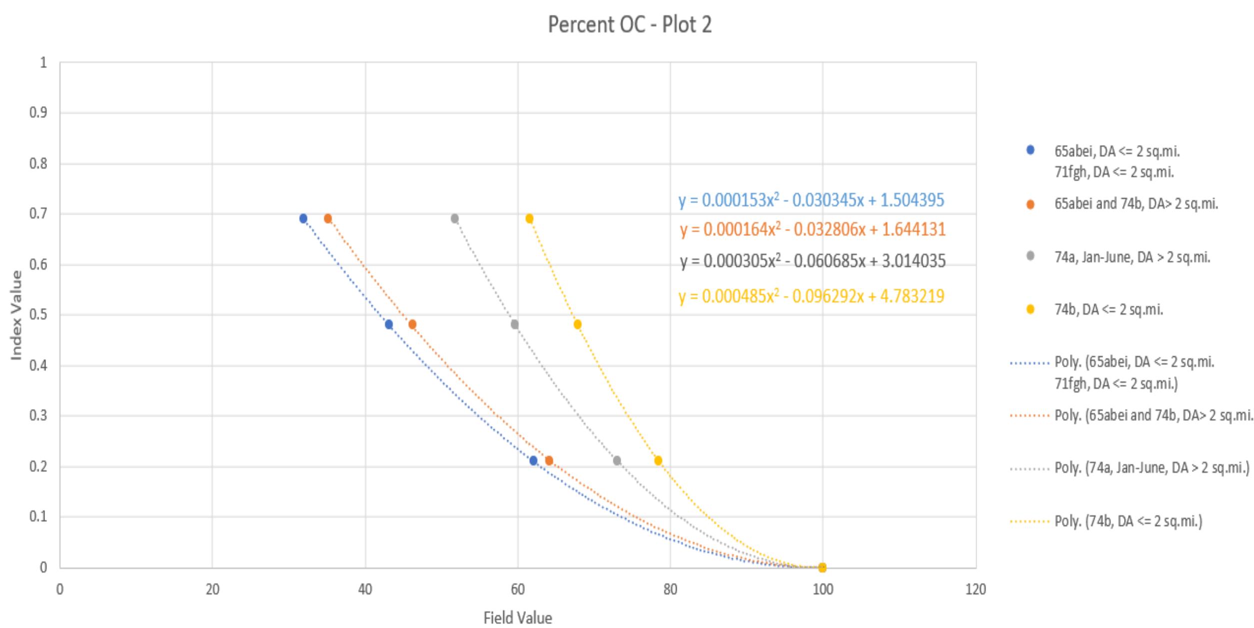




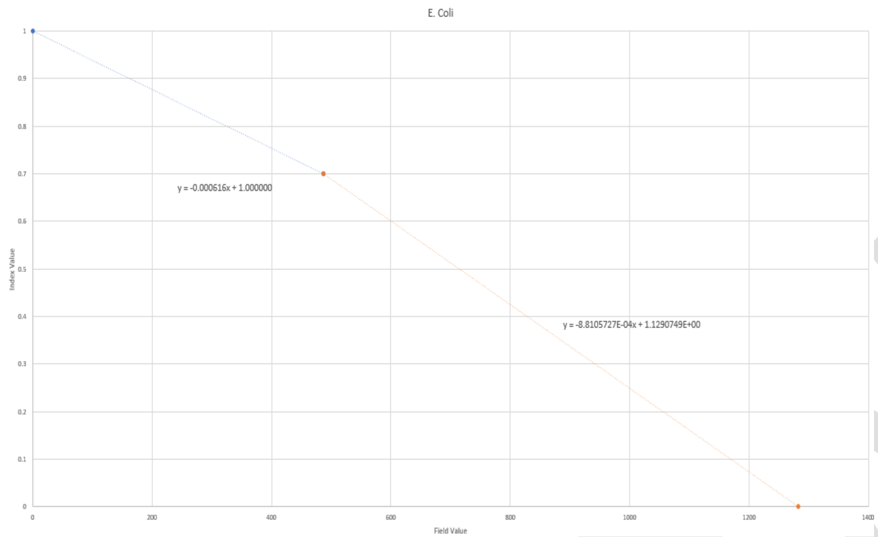

Percent EPT-Cheum - Plot 1
y = 0.011289x² - 0.006225x - 0.000029
y = 0.000918x² - 0.001095x + 0.000112
y = 0.000521x² - 0.000388x - 0.000109
y = 0.000678x² - 0.000789x - 0.000012
y = 0.000399x² - 0.000846x + 0.000144
Index Value
Field Value
74b, DA <= 2 sq.mi.
73ab
74a, Jan-June, DA > 2 sq.mi.
71i, DA > 2 sq.mi., SQBANK
65abei and 74b, DA> 2 sq.mi. 71i, DA > 2 sq.mi., SQKICK
Poly. (74b, DA <= 2 sq.mi.)
Poly. (73ab)
Poly. (74a, Jan-June, DA > 2 sq.mi.)
Poly. (71i, DA > 2 sq.mi., SQBANK)
Poly. (65abei and 74b, DA> 2 sq.mi. 71i, DA > 2 sq.mi., SQKICK)

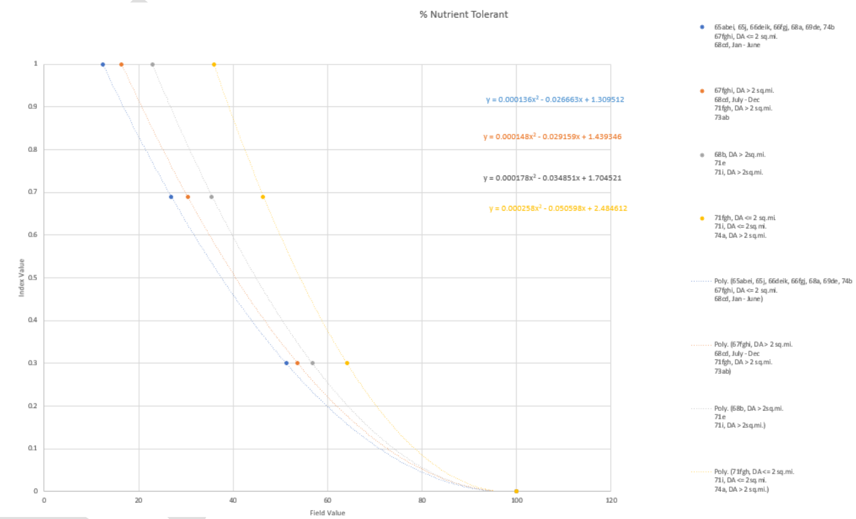

Percent EPT-Cheum - Plot 2
y = 0.000309x² - 0.000458x - 0.000039
y = 0.000252x² - 0.000353x - 0.000057
y = 0.000223x² - 0.000605x + 0.000125
y = 0.000218x² - 0.001751x + 0.001133
y = 0.000157x² - 0.000411x + 0.000083
y = 0.000137x² - 0.000254x - 0.000107
Index Value
Field Value
65abei, DA <= 2 sq.mi. 68cd, July - Dec 71e
65j, 67fghi 71i, DA <= 2 sq.mi. 74a, July-Dec, DA > 2 sq.mi.
68a 68b, DA > 2 sq.mi. 71fgh, DA > 2 sq.mi.
66fgj 71fgh, DA <= 2 sq.mi.
66deik 68cd, Jan - June 69de, July - Dec
69de, Jan - June
Poly. (65abei, DA <= 2 sq.mi. 68cd, July - Dec 71e)
Poly. (65j, 67fghi 71i, DA <= 2 sq.mi. 74a, July-Dec, DA > 2 sq.mi.)
Poly. (68a 68b, DA > 2 sq.mi. 71fgh, DA > 2 sq.mi.)
Poly. (66fgj 71fgh, DA <= 2 sq.mi.)
Poly. (66deik 68cd, Jan - June 69de, July - Dec)
Poly. (69de, Jan - June)

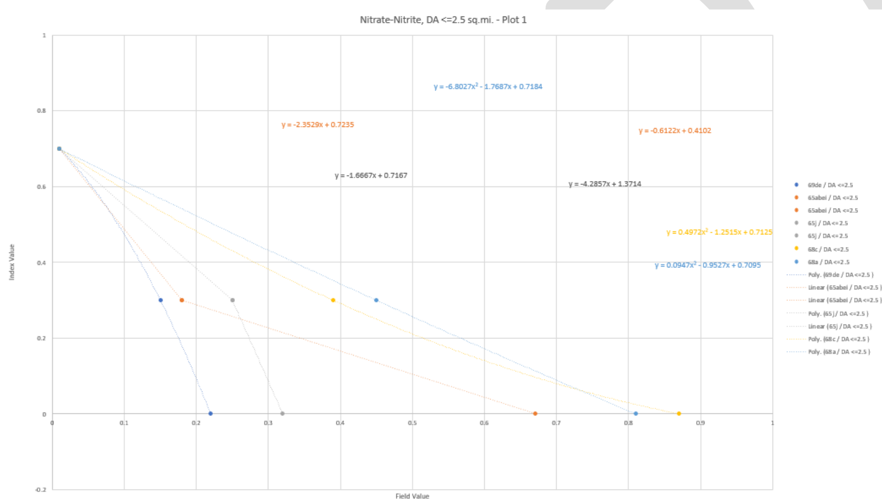

Percent OC - Plot 1
y = 0.000096x² - 0.019002x + 0.937135
y = 0.000106x² - 0.020941x + 1.029999
y = 0.000115x² - 0.022595x + 1.113547
y = 0.000122x² - 0.024040x + 1.188075
Index Value
Field Value
67fghi, 71e, 73ab
71fgh, DA > 2 sq.mi.
66deik, 66fgj, 68a, 68cd
69de, July - Dec
71i, DA <= 2 sq.mi.
71i, DA > 2sq.mi., SQBANK
74a, July - Dec, DA > 2 sq.mi.
69de, Jan - June
71i, DA > 2 sq.mi., SQKICK
65j
68b, DA > 2 sq.mi.
Poly. (67fghi, 71e, 73ab
71fgh, DA > 2 sq.mi.)

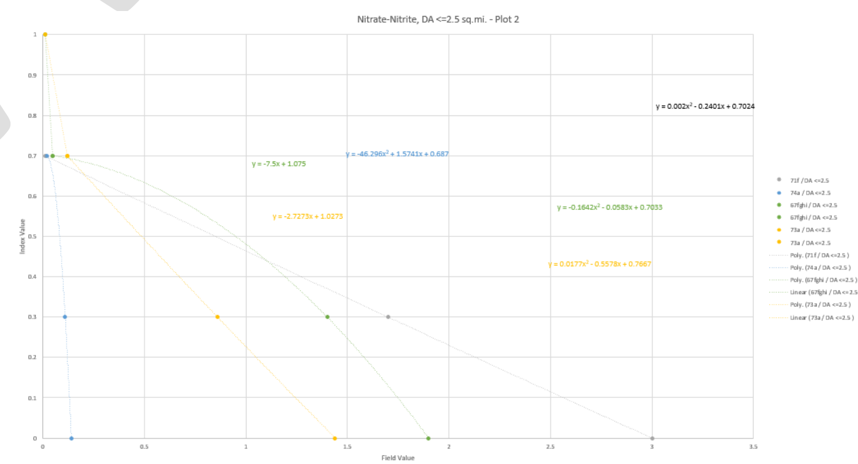

Percent OC - Plot 2
y = 0.000153x² - 0.030345x + 1.504395
y = 0.000164x² - 0.032806x + 1.644131
y = 0.000305x² - 0.060685x + 3.014035
y = 0.000485x² - 0.096292x + 4.783219
Index Value
Field Value
65abei, DA <= 2 sq.mi.
71fgh, DA <= 2 sq.mi.
65abei and 74b, DA> 2 sq.mi.
74a, Jan-June, DA > 2 sq.mi.
74b, DA <= 2 sq.mi.
Poly. (65abei, DA <= 2 sq.mi.
71fgh, DA <= 2 sq.mi.)
Poly. (65abei and 74b, DA> 2 sq.mi.)
Poly. (74a, Jan-June, DA > 2 sq.mi.)
Poly. (74b, DA <= 2 sq.mi.)

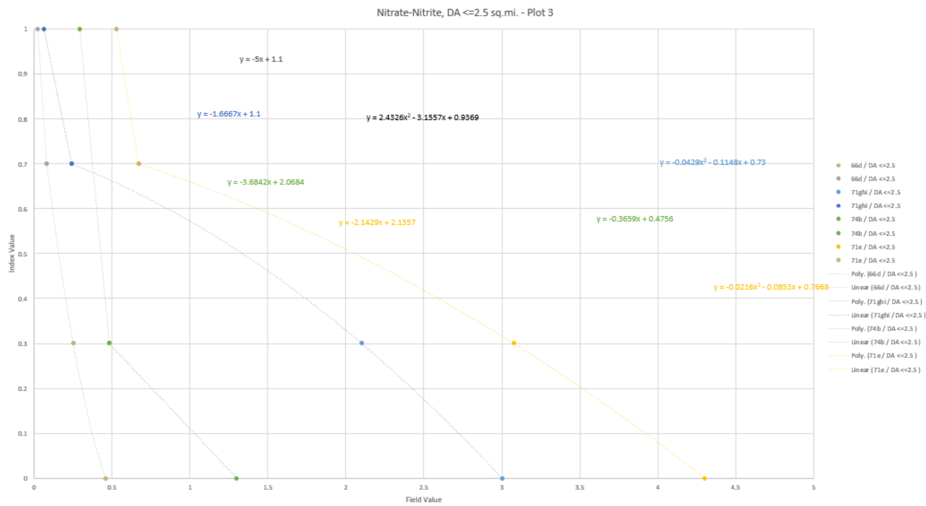
9.4 Reference Standards for Water Quality Metrics

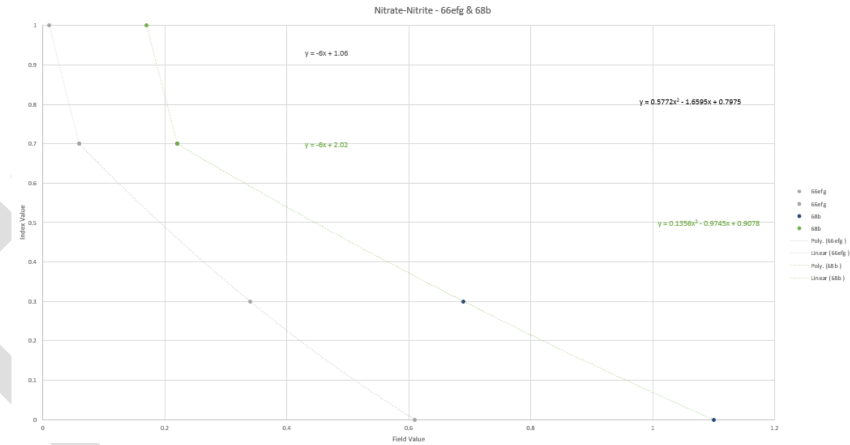


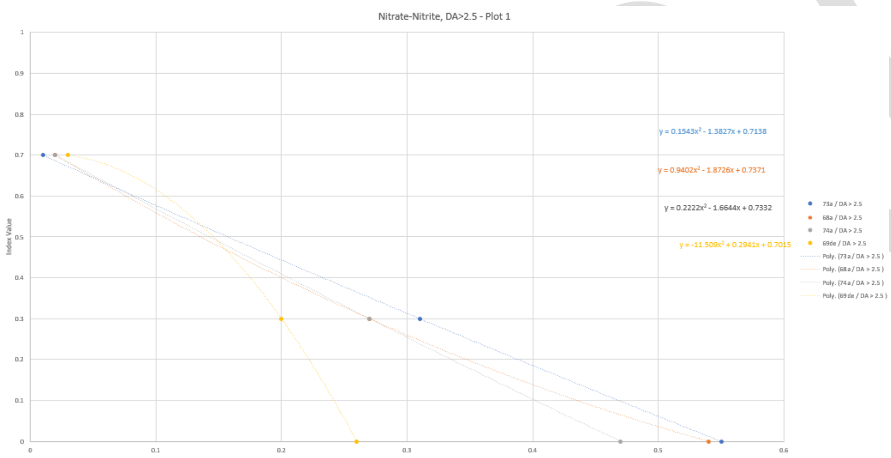


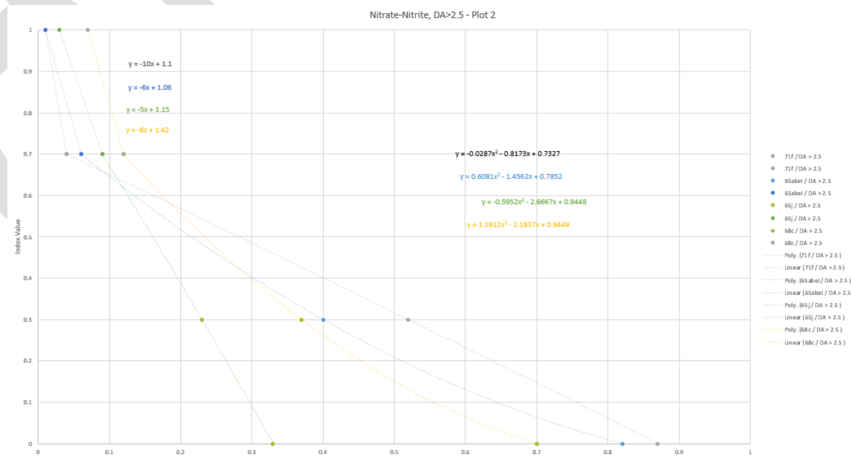


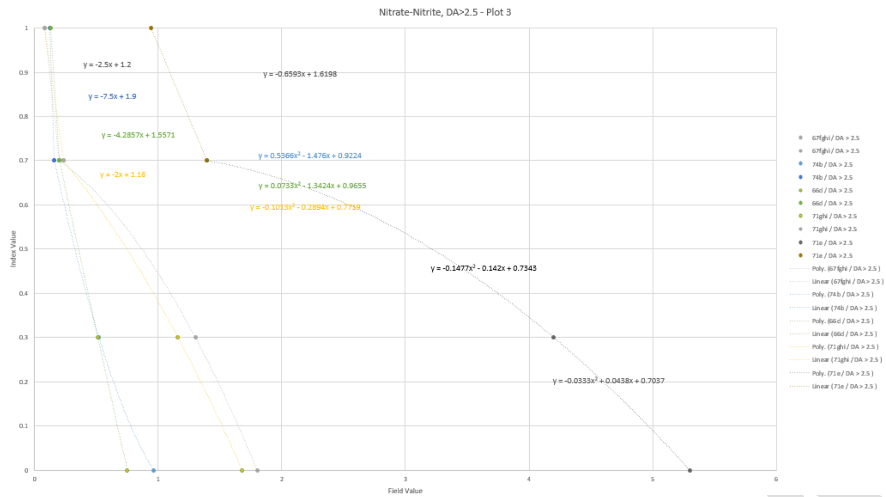


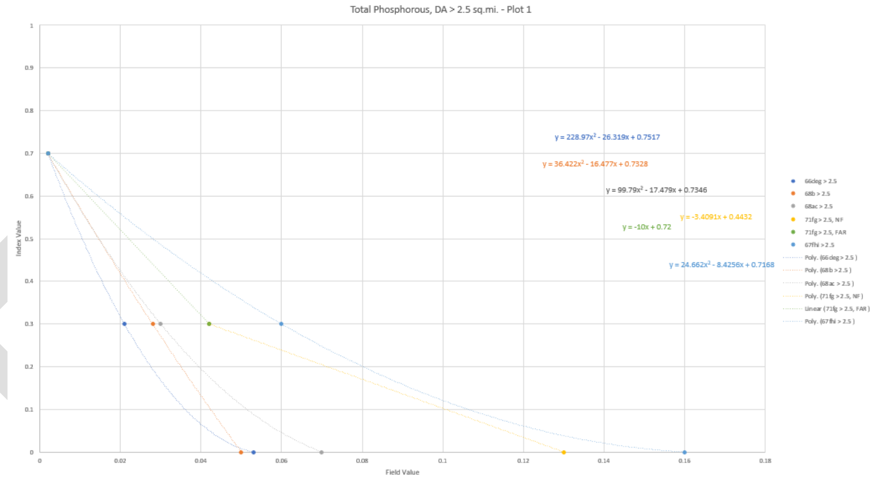

Nitrate-Nitrite, DA <=2.5 sq.mi. - Plot 3
y = -5x + 1.1
y = -1.6667x + 1.1
y = 2.4326x² - 3.1557x + 0.9369
y = -0.0429x² - 0.1148x + 0.73
y = -3.6842x + 2.0684
y = -2.1429x + 2.1357
y = -0.3659x + 0.4756
y = -0.0216x² - 0.0853x + 0.7668
66d / DA <=2.5
66d / DA <=2.5
71ghi / DA <=2.5
71ghi / DA <=2.5
74b / DA <=2.5
74b / DA <=2.5
71e / DA <=2.5
71e / DA <=2.5
Poly. (66d / DA <=2.5)
Linear (66d / DA <=2.5)
Poly. (71ghi / DA <=2.5)
Linear (71ghi / DA <=2.5)
Poly. (74b / DA <=2.5)
Linear (74b / DA <=2.5)
Poly. (71e / DA <=2.5)
Linear (71e / DA <=2.5)
Index Value
Field Value

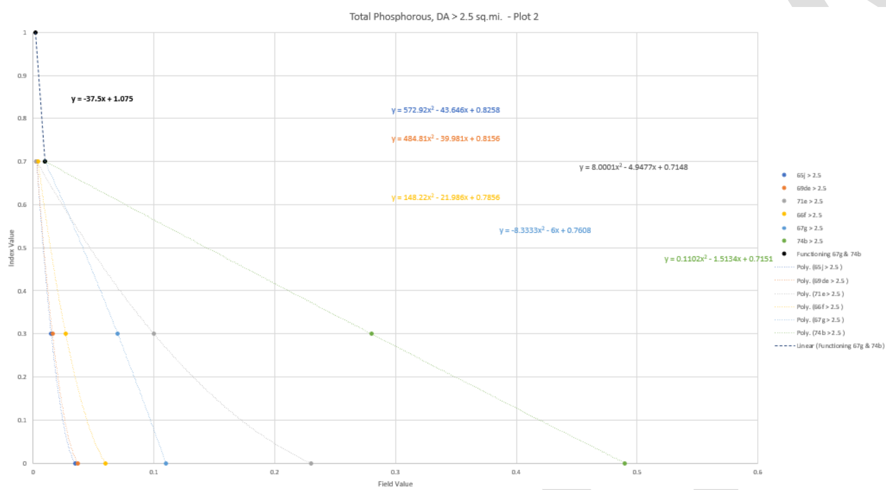

Nitrate-Nitrite - 66efg & 68b
y = -6x + 1.06
y = 0.5772x² - 1.6595x + 0.7975
y = -6x + 2.02
y = 0.1356x² - 0.9745x + 0.9078
66efg
66efg
68b
68b
Poly. (66efg)
Linear (66efg)
Poly. (68b)
Linear (68b)
Index Value
Field Value

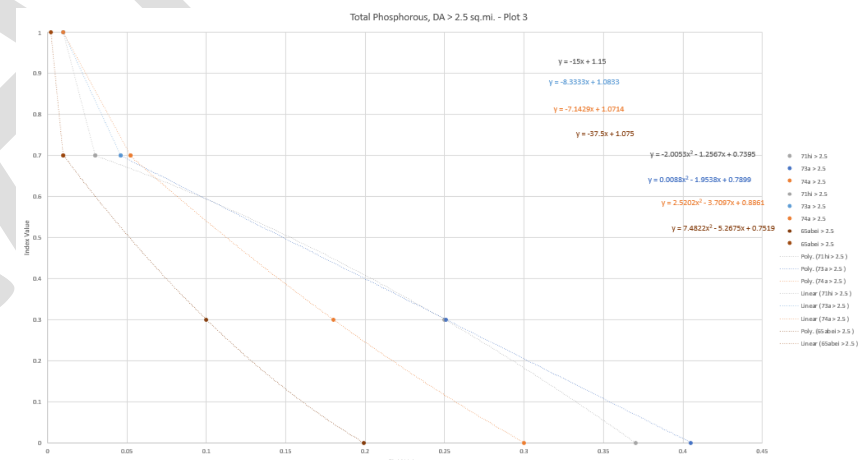

Nitrate-Nitrite, DA>2.5 - Plot 1
y = 0.1543x² - 1.3827x + 0.7138
y = 0.9402x² - 1.8726x + 0.7371
y = 0.2222x² - 1.6644x + 0.7332
y = -11.509x² + 0.2941x + 0.7015
73a / DA > 2.5
68a / DA > 2.5
74a / DA > 2.5
69de / DA > 2.5
Poly. (73a / DA > 2.5)
Poly. (68a / DA > 2.5)
Poly. (74a / DA > 2.5)
Poly. (69de / DA > 2.5)
Index Value
Field Value

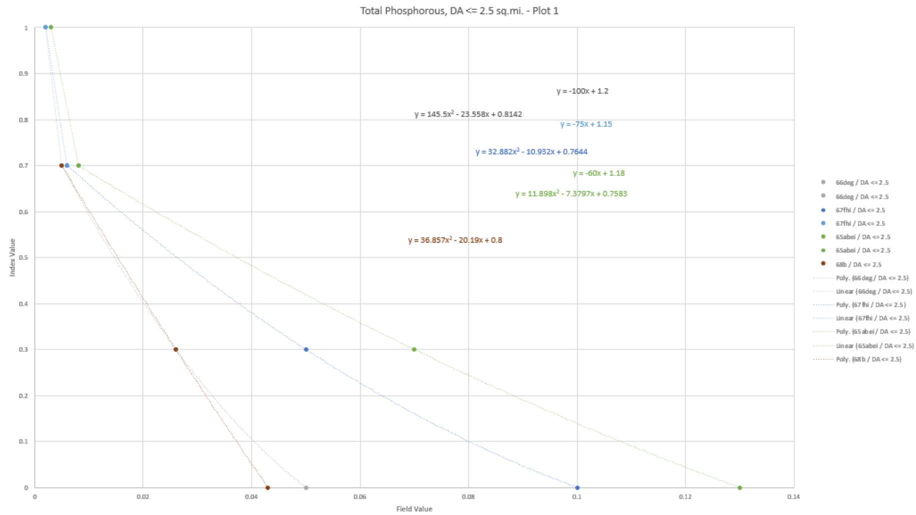

Nitrate-Nitrite, DA>2.5 - Plot 2
y = -10x + 1.1
y = -6x + 1.06
y = -5x + 1.15
y = -6x + 1.42
y = -0.0287x² - 0.8173x + 0.7327
y = 0.6081x² - 1.4562x + 0.7852
y = -0.5952x² - 2.6667x + 0.9448
y = 1.1912x² - 2.1837x + 0.9449
71f / DA > 2.5
71f / DA > 2.5
65abei / DA > 2.5
65abei / DA > 2.5
65j / DA > 2.5
65j / DA > 2.5
68c / DA > 2.5
68c / DA > 2.5
Poly. (71f / DA > 2.5)
Linear (71f / DA > 2.5)
Poly. (65abei / DA > 2.5)
Linear (65abei / DA > 2.5)
Poly. (65j / DA > 2.5)
Linear (65j / DA > 2.5)
Poly. (68c / DA > 2.5)
Linear (68c / DA > 2.5)
Index Value
Field Value

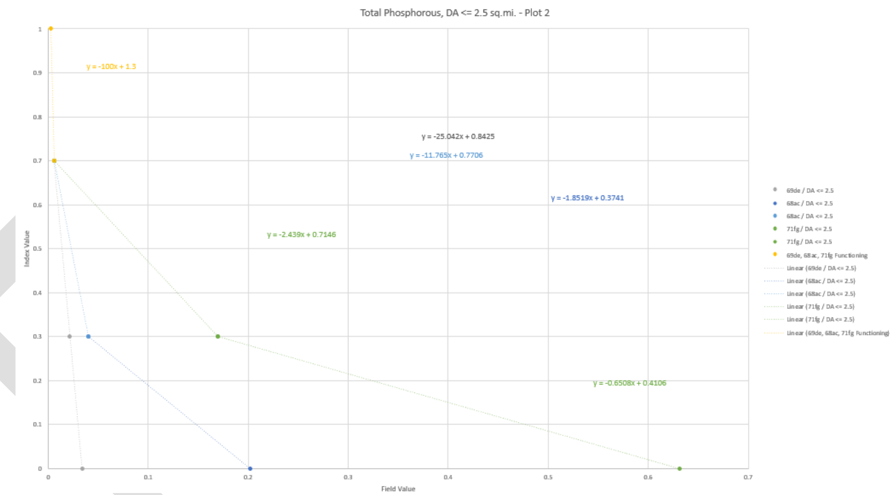

Nitrate-Nitrite, DA>2.5 - Plot 3
y = -2.5x + 1.2
y = -0.6593x + 1.6198
y = -7.5x + 1.9
y = -4.2857x + 1.5571
y = 0.5366x² - 1.476x + 0.9224
y = -2x + 1.16
y = 0.0733x² - 1.3424x + 0.9655
y = -0.1013x² - 0.2894x + 0.7719
y = -0.1477x² - 0.142x + 0.7343
y = -0.0333x² + 0.0438x + 0.7037
Index Value
Field Value
67fghi / DA > 2.5
67fghi / DA > 2.5
74b / DA > 2.5
74b / DA > 2.5
66d / DA > 2.5
66d / DA > 2.5
71ghi / DA > 2.5
71ghi / DA > 2.5
71e / DA > 2.5
71e / DA > 2.5
Poly. (67fghi / DA > 2.5)
Linear (67fghi / DA > 2.5)
Poly. (74b / DA > 2.5)
Linear (74b / DA > 2.5)
Poly. (66d / DA > 2.5)
Linear (66d / DA > 2.5)
Poly. (71ghi / DA > 2.5)
Linear (71ghi / DA > 2.5)
Poly. (71e / DA > 2.5)
Linear (71e / DA > 2.5)

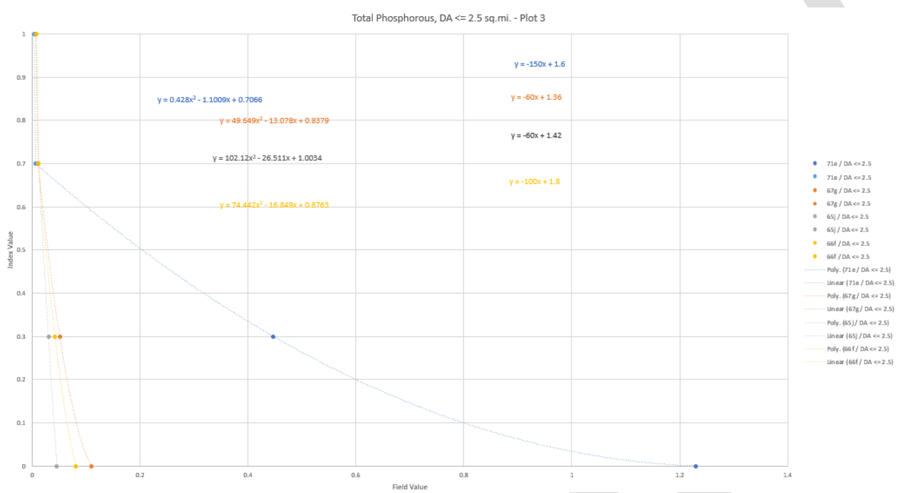

Total Phosphorous, DA > 2.5 sq.mi. - Plot 1
y = 228.97x² - 26.319x + 0.7517
y = 36.422x² - 16.477x + 0.7328
y = 99.79x² - 17.479x + 0.7346
y = -3.4091x + 0.4432
y = -10x + 0.72
y = 24.662x² - 8.4256x + 0.7168
Index Value
Field Value
66deg > 2.5
68b > 2.5
68ac > 2.5
71fg > 2.5, NF
71fg > 2.5, FAR
67fhi > 2.5
Poly. (66deg > 2.5)
Poly. (68b > 2.5)
Poly. (68ac > 2.5)
Poly. (71fg > 2.5, NF)
Linear (71fg > 2.5, FAR)
Poly. (67fhi > 2.5)

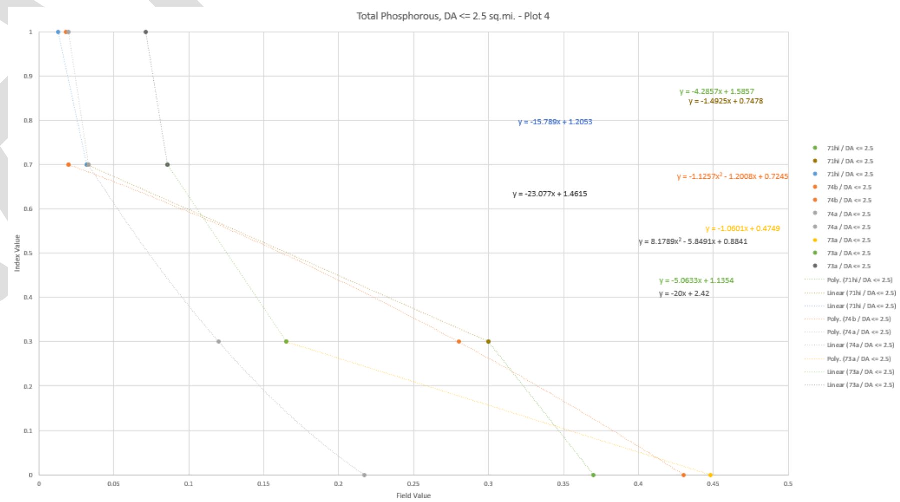

Total Phosphorous, DA > 2.5 sq.mi. - Plot 2
y = -37.5x + 1.075
y = 572.92x² - 43.646x + 0.8258
y = 484.81x² - 39.981x + 0.8156
y = 8.0001x² - 4.9477x + 0.7148
y = 148.22x² - 21.986x + 0.7856
y = -8.3333x² - 6x + 0.7608
y = 0.1102x² - 1.5134x + 0.7151
Index Value
Field Value
65j > 2.5
69de > 2.5
71e > 2.5
66f > 2.5
67g > 2.5
74b > 2.5
Functioning 67g & 74b
Poly. (65j > 2.5)
Poly. (69de > 2.5)
Poly. (71e > 2.5)
Poly. (66f > 2.5)
Poly. (67g > 2.5)
Poly. (74b > 2.5)
Linear (Functioning 67g & 74b)


Total Phosphorous, DA > 2.5 sq.mi. - Plot 3
y = -15x + 1.15
y = -8.3333x + 1.0833
y = -7.1429x + 1.0714
y = -37.5x + 1.075
y = -2.0053x² - 1.2567x + 0.7395
y = 0.0088x² - 1.9538x + 0.7899
y = 2.5202x² - 3.7097x + 0.8861
y = 7.4822x² - 5.2675x + 0.7519
Index Value
Field Value
71hi > 2.5
73a > 2.5
74a > 2.5
71hi > 2.5
73a > 2.5
74a > 2.5
65abei > 2.5
65abei > 2.5
Poly. (71hi > 2.5)
Poly. (73a > 2.5)
Poly. (74a > 2.5)
Linear (71hi > 2.5)
Linear (73a > 2.5)
Linear (74a > 2.5)
Poly. (65abei > 2.5)
Linear (65abei > 2.5)


Total Phosphorous, DA <= 2.5 sq.mi. - Plot 1
y = -100x + 1.2
y = 145.5x² - 23.558x + 0.8142
y = -75x + 1.15
y = 32.882x² - 10.932x + 0.7644
y = -60x + 1.18
y = 11.898x² - 7.3797x + 0.7583
y = 36.857x² - 20.19x + 0.8
Index Value
Field Value


Total Phosphorous, DA <= 2.5 sq.mi. - Plot 2
y = -100x + 1.3
y = -25.042x + 0.8425
y = -11.765x + 0.7706
y = -1.8519x + 0.3741
y = -2.439x + 0.7146
y = -0.6508x + 0.4106
Index Value
Field Value


Total Phosphorous, DA <= 2.5 sq.mi. - Plot 3
y = -150x + 1.6
y = 0.428x² - 1.1009x + 0.7066
y = -60x + 1.36
y = 49.649x² - 13.078x + 0.8379
y = -60x + 1.42
y = 102.12x² - 26.511x + 1.0034
y = -100x + 1.8
y = 74.442x² - 16.849x + 0.8763
Index Value
Field Value


Total Phosphorous, DA <= 2.5 sq.mi. - Plot 4
y = -4.2857x + 1.5857
y = -1.4925x + 0.7478
y = -15.789x + 1.2055
y = -1.1257x² - 1.2008x + 0.7245
y = -23.077x + 1.4615
y = -1.0601x + 0.4749
y = 8.1789x² - 5.8491x + 0.8841
y = -5.0633x + 1.1354
y = -20x + 2.42
Index Value
Field Value

9.5 Manning's n Computational Procedure

Computational procedures for Manning's n when the Width-to-Depth Ratio is greater than 2. Procedure extracted from NRCS (2007), Chapter 7.

Fundamental Equations:

Frictional resistance: $u = [2.83 + 5.66 \cdot \mathrm{LOG}(R_h/D84) \cdot u^*$

Manning's Equation (Velocity): $V = (1.486/n) \cdot R^{h2/3} \cdot S^{1/2}$

Bed Shear Velocity: $u^* = g \cdot R_h \cdot S$

u = Local velocity (ft/s)
V = cross-sectional velocity (ft/s)
R_h = hydraulic radius (cross-sectional area divided by wetted perimeter) (ft)
D84 = bed sediment particle 84th percentile in particle size distribution (Pebble count) (ft)
n = Manning's roughness coefficient
S = channel slope
u* = shear velocity
g = gravity, 32.2 ft/s^2

Derivation equation for Manning's n:

$n = 1.486/[2.83+5.66 \cdot \mathrm{LOG}(R_h/D84) \cdot g \cdot R_h^{1/3} \cdot S^{1/2}]$

9.6 TMAT and Debit Tool Datasheet

Field Datasheet pages 1 through 13 are provided on the following pages.

TMAT and Debit Tool Datasheet — October 2025

Investigators: ____ Date: ____________________

Project Reach Information

Stream Name: ____ County: ___________________

Project Name: ____ Reach ID: _________________

<u>Project Reach</u> Upstream Latitude: ___________________ Longitude: ___________________

<u>Boundary</u>: Downstream Latitude: _________________ Longitude: ___________________

Provide map of project reach

Project Stream Reach Length (ft): __________________ Drainage Area (sq. mi.): ___________

Ecoregion: ____________________________ ETW/ONRW Listing: ____________________

Flow Type: ____________________________ Valley Type: ___________________________

<u>Bankfull Indicators</u>: Present / Adequate Present / Not Adequate Absent *< circle >*

<u>Regional Curve</u>: Curve Used ___________________________ *provide bankfull (BF) data below*

BF Width: ____________ (ft) BF Depth: ____________ (ft) BF Area: ______________ (ft²)

<u>Rosgen Stream Type</u>: _________________ Hydrological Determination Score: _________

<u>Channel Slope</u>: __________ (ft/ft) <u>Sinuosity</u>: _________ Valley Length: ___________ ft

Stream Length: __________ ft

<u>Dominant Bed Substrate Type</u>: *< circle >*

Bedrock Boulders Cobble Gravel Sand Silt/Clay

<u>Channel Evolution Model Stage</u>: I II III IV V VI *< circle >*

<u>TN Macroinvertebrate Index</u>: Evaluation Method: Total Partial *< circle >*

Collection Method: SQKICK SQBANK Collection Season: Jan-Jun July-Dec

If project reach is longer than assessment reach, provide assessment location information below

<u>Assessment Reach Boundary Locations</u>: Assessment Reach Length: ______________

Upstream Latitude: _____________ Longitude: _____________ Station Distance (ft): _______

Downstream Latitude: ____________ Longitude: ____________ Station Distance (ft): _______

Desktop Data

Catchment Hydrology: Watershed Land Use Metric

Composite curve number (CN) weighted by % areas of land use types and their CN.

Land Use / Land Cover Type	% Land Area	Land Use CN	% Land Area x CN
Forest: Deciduous, Evergreen, Mixed		45	
Woody, Emergent Herbaceous Wetlands		30	
Grassland/Herbaceous, Pasture/Hay		68	
Shrub/Scrub		60	
Open Water		0	
Cultivated Crops		75	
Barren Land (Rock/Sand/Clay)		88	
Developed Open space		70	
Developed, Low Intensity		65	
Developed, Medium Intensity		75	
Developed, High Intensity		95	
Composite Curve Number: *(Sum product of % Land Area x CN & divide by 100)*			

Composite Curve Number = Field Value

Floodplain Storage/Infiltration Potential Metric:

Data Source: (*check box or enter information*)

☐ USGS TopoView & Google Earth ☐ FEMA Flood Map

☐ GIS-based DEM or Local Lidar Data ☐ Other ____________________________

(km² / mi² /acres) (*id units used*)

TFSA (Total Surface Area of Floodplain) = ________________

DFSA (Developed Area on Floodplain) = ________________

CA (Area of Converted/Restored Land) = ________________

Floodplain Storage/Infiltration Potential (FPSI) Index = ________________

FSIP = [TFSA - DFSA + CA] / TFSA

Provide project area map with delineated TFSA, DFSA, and CA

TMAT Datasheet   Reach ID # ______________   Date: ________________
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Desktop Data

Reach Runoff / Stormwater Infiltration Metric:

Check box for approach used; (1) existing condition; (2) proposed conditions

☐ Land Use Conversion Approach   RRSI = [LDA – RSA + ∑CA]/LDA | RRSI = ________

LDA = _________ acres(1)   RSA = ___________ acres(1)   ∑CA = __________ acres(2)

CA = _________ acres – define area = ____

CA = _________ acres – define area = ____

CA = _________ acres – define area = ____

☐ Runoff SCM Treatment Approach   RRSI = [LDA – RSA + ∑(DA$_{SCM}$ x SIF) ∑CA]/LDA

LDA = _________ acres(1)   % Impervious Surface = ________   RSA = ___________ acres(1)

CA = _________ acres – define area = ____

CA = _________ acres – define area = ____

CA = _________ acres – define area = ____

CA = _________ acres – define area = ____

∑CA = __________ acres(2)

Parameter	SCM	SCM	SCM	SCM	SCM
DA$_{SCM}$ (acres)	______	______	______	______	______
SCM Design Storm (in)	______	______	______	______	______
SCM Infiltration Depth (in)	______	______	______	______	______
V$_{inf}$ (acre-in) =	______	______	______	______	______
V$_{DA}$ (acre-in) =	______	______	______	______	______
SIF = V$_{inf}$ / V$_{DA}$ =	______	______	______	______	______
HSG (A, B, C, or D) =	______	______	______	______	______
SIR (in/hour) =	______	______	______	______	______
SCM Area (A$_{SCM}$) (acres) =	______	______	______	______	______
SCM Depth (D$_{SCM}$) (in) =	______	______	______	______	______
T = D$_{SCM}$ /SIR (hour) =	______	______	______	______	______
T < 72 hours (*check box*)	☐	☐	☐	☐	☐
DA$_{SCM}$ x SIF =	______	______	______	______	______

∑(DA$_{SCM}$ x SIF) = _________   RRSI = ______________

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Channel Water Surface Slope / Bankfull Indicators and Slope:

Channel Water Surface (WS) Slope: *Work from upstream project reach boundary downstream*

Longitudinal Station Location		Distance (ft)	Stadia Rod		Elevation Drop (ft) [1]
Begin	End		u/s reading	d/s reading	
Sum Total Distance =			Sum Elevation Drop =		
[1] Eye Height (ft) =		Channel Reach WS % Slope [2] =			

(1) Using a rangefinder, just record vertical drop reading / (2) % Slope = Sum Elevation Drop/Total Distance x 100

Bankfull Elevation Slope: *Work from upstream to downstream; BF indicator listed in table below*

Longitudinal Station Location		Distance (ft)	Stadia Rod		Elevation Drop (ft) [1]
Begin	End		u/s reading	d/s reading	
Sum Total Distance =			Sum Elevation Drop =		
[1] Eye Height (ft) =		Channel Reach BF % Slope [2] =			

(1) Using a rangefinder, just record vertical drop reading / (2) % Slope = Sum Elevation Drop/Total Distance x 100

Percent Difference between WS and BF Elevation % Slopes: ________________ %

Bankfull Indicators: *Work from upstream project reach boundary downstream*

Longitudinal Station Location (ft)	Difference between BF and WS stages (ft)	Description of Bankfull Indicator
Average =		

TMAT Datasheet → Reach ID # ________________ → Date: __________________
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Hydraulics & Geomorphology — Non-Bankfull Metrics

If bankfull indicators present, skip Datasheet pages 5 and 6. Go to Page 7

Riffle and Pool Habitat Metrics (*measured in sequence from upstream to downstream*)

Riffle	**1**	**2**	**3**	**4**	**5**	**6**
Station distance (ft) (upstream location)						
Station distance (ft) (downstream location)						
Riffle length (ft)						
Active Channel Width (ft)*						
Total Riffle Length (ft) =						
Average Active Channel Width (ft) =						

* Measured at mid-channel length.

Pool	**1**	**2**	**3**	**4**	**5**	**6**
Station Distance (ft) Maximum Depth Location						
Maximum Pool Depth (ft)						
Pool to Pool Spacing (ft)	→					
Pool Spacing Ratio Pool Spacing / AC Width*	→					

* Active Channel Width is the reach average taken at riffles.

Cross-Section Survey Data of Assessment Reach (*tape and level measurements in feet*)

Upstream Boundary

Distance											
Elevation											

Downstream Boundary

Distance											
Elevation											

For longer assessment reaches, use additional Page 5 sheets.

TMAT Datasheet Reach ID #: ______________ Date: ________________
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Hydraulics – Floodplain Connectivity: Non-Bankfull Metrics

Floodplain Inundation Frequency and Channel Incision metrics require desktop and field data.

Flow Data: USGS StreamStats ☐ USGS Regression Eqns. ☐ Other: ________________

Q_2 = _____________ cfs Q_5 = ___________ cfs Q_{10} = ___________ cfs

Q_{25} = ____________ cfs Q_{50} = ___________ cfs Q_{100} = ___________ cfs

Surveyed Cross-Sectional Areas (A) and Wetted Perimeter (Pw) at Boundaries

(data from Page 5)

Upstream Boundary: $A_{u/s}$ = __________ ft² Downstream Boundary $A_{d/s}$ = ___________ ft²

Upstream Boundary: $Pw_{u/s}$ = _________ ft Downstream Boundary $Pw_{d/s}$ = __________ ft

Average A = _________ ft² Average Pw = __________ ft R_h = Avg. (A/Pw) = ________ ft

Floodplain Inundation Frequency Metric:

Reach Manning n = ______________ Reach Slope (S) = ____________ (ft/ft) *from Page 5*

$(\text{Avg. A})^{5/3} / (\text{Avg. Pw})^{2/3}$ = ________________

Is greater than $(\text{Avg. A})^{5/3} / (\text{Avg. Pw})^{2/3}$ ☐ *Check Box*

$(Q_2 \times n) / (1.49 \times S^{1/2})$ = _____________ ☐

$(Q_5 \times n) / (1.49 \times S^{1/2})$ = _____________ ☐ FIFM Field Value = _____________

$(Q_{10} \times n) / (1.49 \times S^{1/2})$ = ____________ ☐ *Report FIFM value as the* $Q_{(\cdot)}$ *from checked box*

$(Q_{25} \times n) / (1.49 \times S^{1/2})$ = ____________ ☐

$(Q_{50} \times n) / (1.49 \times S^{1/2})$ = ____________ ☐

$(Q_{100} \times n) / (1.49 \times S^{1/2})$ = ___________ ☐

Channel Incision Metric:

Channel Bed Permissible Shear Stress (τ_p) = ___________ lb/ft²

Reach Hydraulic Shear Stress (τ) = ____________ lb/ft² ($\tau = \gamma \times R_h \times S$)
Use assessment reach values

γ (gamma) = 62.4 lb/ft³

Field Value = (τ / τ_p) = _______________

TMAT Datasheet → Reach ID # ______________ → Date: ________________
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Hydraulics & Geomorphology – Bankfull Metrics

Riffle Data: *Collecting data for riffles with bankfull indicators starting at upstream reach boundary*

Data Entry	Riffle ___	Riffle ___	Riffle ___	Riffle ___
Begin Station (Tape *Distance*)				
End Station (Tape *Distance*)				
Low Bank Height (ft)				
Bankfull Width (ft)				
Bankfull Depths (ft) across cross-section				
Bankfull Max. Depth (ft)				
Flood Prone Width (ft)				
Mean Bankfull Depth (ft)				
Width/Depth Ratio (WDR)				
Riffle/Run Length (RL_i) (ft)				
Bank Height Ratio (BHR_i)				
Weighted BHR =			= Σ (BHR_i * RL_i) / ΣRL_i	
Entrenchment Ratio (ER_i)				
Weighted ER =			= Σ (ER_i * RL_i) / ΣRL_i	

BHR = Low Bank Height / BF Max. Depth **ER** = Flood Prone Width / BF Width **WDR** = BF Width / Mean BF Depth

Riffle Data: *Collecting riffle data where bankfull indicators not recorded along longitudinal profile*

Data Entry	Riffle ___	Riffle ___	Riffle ___	Riffle ___
Begin Station (Tape *Distance*)				
End Station (Tape *Distance*)				
Riffle/Run Length (ft)				
Total Riffle/Run Length (ft) * =		Assessment Reach Length (ft) * =		
Percent Riffle/Run (%) =		= Total Riffle Length/Assessment Reach Length x 100		

* = *Total Riffle/Run Length is the sum of all riffles/run (both tables); Assessment Reach Length from Page 1*

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Hydraulics & Geomorphology Bankfull Metrics *continued*

	Pool 1	Pool 2	Pool 3	Pool 4	Pool 5
Geomorphic Pool (Y/N)					
Station Distance at Maximum Pool Depth					
Pool to Pool Spacing (ft) ----------→		1-2	2-3	3-4	4-5
Mean BF Width (ft) (1) =		--------	Mean BF Depth (ft) (1) =		
Pool Spacing Ratio: ---------------→ Pool Spacing / Mean BF Width					
Median Pool Spacing Ratio =		---			
Maximum Pool Depth (ft) measured from WS					
Maximum Pool Depth (ft) measured from BF					
Pool Depth Ratio (PDR)					
Average Pool Depth Ratio =	---				

PDR = Maximum Pool Depth / Mean BF Riffle Depth // (1) *Take BF Width from Page 7*

Aggradation Ratio: ______________ = Max. WDR/Expected WDR → → *(optional metric)*

Maximum WDR = ________________ → Expected WDR per Stream Type: __________

Project Reach Stream Walk → → Assessment Stream Length (ft): _______________

Large Woody Debris (LWD)	Total Number of Pieces ↓	Number of Pieces per 100 m ↓
% Streambank Erosion		
Left Bank (*sum length, ft*) =		**Total %** = Sum L&R Bank length / (2 x Reach length) x 100 ↓
Right Bank (*sum length, ft*) =		
Sum Left/Right Bank Lengths (ft) =		% =
% Streambank Armoring --------------* Project Stream Length (ft) = ____________ *from Page 1*		
Left Bank (*sum length*, ft*) =		**Total %** = Sum L&R Bank length / (2 x Reach Length*) x 100 ↓
Right Bank (*sum length*, ft*) =		
Sum Left/Right Bank Lengths (ft) =		% =

TMAT Datasheet Reach ID #: ______________ Date: ________________

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Geomorphology Metric: Rapid Geomorphic Assessment

CHANNEL STABILITY – RGA RANKING SCHEME						
Sub-Metric						**Score**
1. Primary Bed Material						
Bedrock	Boulder/Cobble	Gravel	Sand	Silt/Clay		
0	1	2	3	4		
2. Bed/Bank Protection						
Bed = Yes	Bed = No	with	Yes = 1 bank	Yes – 2 banks		
0	1		2	3		
3. Degree of Channel Incision						
0-10%	11-25%	26-50%	51-75%	76-100%		
4	3	2	1	0		
4. Degree of Channel Constriction						
0-10%	11-25%	26-50%	51-75%	76-100%		
0	1	2	3	4		
5. Stream Bank Erosion .... *<circle each bank value>*						
	None	Fluvial	Mass Failure			
Left Bank	0	1	2			
Right Bank	0	1	2			
6. Stream Bank Instability from Mass Failures (Wasting) .... *<circle each bank value>*						
	0-10%	11-25%	26-50%	51-75%	76-100%	
Left Bank	0	0.5	1	1.5	2	
Right Bank	0	0.5	1	1.5	2	
7. Established Streambank Woody Vegetation Cover .... *<circle each bank value>*						
	0-10%	11-25%	26-50%	51-75%	76-100%	
Left Bank	2	1.5	1	0.5	0	
Right Bank	2	1.5	1	0.5	0	
8. Occurrence of Bank Accretion .... *<circle each bank value>*						
	0-10%	11-25%	26-50%	51-75%	76-100%	
Left Bank	2	1.5	1	0.5	0	
Right Bank	2	1.5	1	0.5	0	
Total RGA Score (*sum sub-points 1 through 8*) .... ↓						

Stage of Channel Evolution: ______________________ (I, II, III, IV, V, or VI)

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Geomorphology Metrics: Physical Habitat & Riparian Corridor

Bed Sediment Pebble Count					
Sediment Size Class Name	**Sediment Particle Size Class (mm)**	**Number of Particles**	**Sediment Size Class Name**	**Sediment Particle Size Class (mm)**	**Number of Particles**
Silt/Clay (Mud Bottom)	If channel is a mud bottom (*check here*) →	[..........]	VC Gravel	45.3 - 64.0	
Sand	< 2		Sm. Cobble	64.0 - 90.5	
VF Gravel	2.0 - 2.8		Sm. Cobble	90.5 - 128.0	
VF Gravel	2.8 - 4.0		Lg. Cobble	128.0 - 181.0	
Fine Gravel	4.0 - 5.6		Lg. Cobble	181.0 — 256.0	
Fine Gravel	5.6 - 8.0		Sm. Boulder	256.0 — 362.0	
Med. Gravel	8.0 - 11.3		Sm. Boulder	362 — 512	
Med. Gravel	11.3 - 16.0		Med. Boulder	512 — 1024	
Coarse Gravel	16.0 - 22.6		Lg. Boulder	1024 — 2048	
Coarse Gravel	22.6 - 32.0		VL Boulder	2048 - 4096	
VC Gravel	32.0 - 45.3		Bedrock	> 4096	

Separate Pebble Count Field Form provided for individual particle size counts

USFS Pebble Count Analyzer: Size Criterion = __________ mm p-value = _____________

<u>Riparian Corridor Width Metric</u>

Corridor Width	**Riparian Corridor Width Measurements (ft)**							**Bank Average ↓**
	1	**2**	**3**	**4**	**5**	**6**	**7**	
Above Bank Left								
Above Bank Right								
Average Both Left and Right Sides of Riparian Corridor =								

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Geomorphology Riparian Corridor Metrics:

Riparian Canopy Cover Metric *Densiometer Counts per covered cells*

Location / Riffle	Station Distance (ft)	Densiometer Stream Orientation				Site Average
		Upstream	Left	Downstream	Right	
Reach Total: Sum the count averages for three locations =						
Metric Percent Average (*divide reach sum of count averages by 288 and multiple by 100*) =						

Riparian Plots: DBH and % Invasive Species Metrics

Station Location (ft)	Plot Number	DBH (inch)			Plot # DBH Average	% Invasive Species
1	1 Left Bank					
	1 Right Bank					
2	2 Left Bank					
	2 Right Bank					
3	3 Left Bank					
	3 Right Bank					
4	4 Left Bank					
	4 Right Bank					
DBH (inch, average of all plots) =						--
% Invasive Species (Average % area of all plots) =						

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Water·Quality/·Biology·Category·Metrics:··¶

¶

Biology:·Tennessee·Macroinvertebrate·Index·(TMI)·Metric¶

¶

Site·Sampled:→ ☐ ···Other·/·Data·Source· ☐ ···Describe:·_____________________________¶

¶

····TMI·Score:·____________________¶

¶

Biology·TMI·Sub-Metrics:···*(optional·metrics)*¶

¶

Site·Sampled:→ ☐ ···Other·/·Data·Source· ☐ ···Describe:·_____________________________¶

¶

TMI·Sub·Metric¤	**Sub-Metric·Score¤**
%·Clingers¤	¤
%·EPT·-·Chuematopsyche¤	¤
%·Oligochaetes·&·Chironomids¤	¤
%·Nutrient·Tolerant·¤	¤
Sum·of·Sub-Metrics·=¤	¤

¶

Water·Quality·Metrics:¶

¶

Site·Sampled:→ ☐ ···Other·/·Data·Source· ☐ ···Describe:·_____________________________¶

¶

Water·Quality·Metric¤	**Metric·Value¤**
TMI·Sub-Metric:·%·Nutrient·Tolerant¤	¤
Mean·Nitrate·/Nitrite·(mg/L)¤	¤
Mean·Total·Phosphorus·(mg/L)¤	¤
Escherichia·coli·(*E.·coli*·geomean)·(#/100·ml))¤	¤

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