



Tennessee Stream Quantification Tool

Data Collection and Analysis Manual





**Tennessee Stream Quantification Tool
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TN SQT v1.0**

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Disclaimer:

The Tennessee Stream Quantification Tool (TN SQT), including the spreadsheet and measurement methods manuals are intended for the evaluation of impact sites and compensatory mitigation projects and their departure from reference conditions in terms of functional lift or loss. In part or as a whole, the function based parameters, measurement methods, and index values 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 TN SQT. Designers should evaluate evidence from hydrologic and hydraulic monitoring, modeling, nearby stream morphology, existing stream conditions, and site constraints in order to determine appropriate restoration design variables and specifications.

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Acronyms

BEHI/NBS – Bank Erosion Hazard Index / Near Bank Stress

BHR – Bank Height Ratio

BMP – Best Management Practice

CFR – Code of Federal Register

CN – Curve numbers

ECS – Existing Condition Score

EPT – Ephemeroptera, Plecoptera, and Trichoptera

ER – Entrenchment Ratio

F – Functioning

FAR – Functioning-At-Risk

FFS – Functional Foot Score

IBI – Index of Biotic Integrity

IRT – Interagency Review Team

LDA – Lateral Drainage Area

LWD – Large Woody Debris

NF – Not Functioning

NPDES – National Pollutant Discharge Elimination System

PCS – Proposed Condition Score

RSA – Runoff Source Area

SDA – Stormwater Design Area

SFPF – Stream Function Pyramid Framework

SIF – Stormwater Infiltration Factor

SQSH – Semi-Quantitative Single Habitat

TDEC – Tennessee Department of Environment and Conservation

TDOT – Tennessee Department of Transportation

TMI – Tennessee Macroinvertebrate Index

TN – Tennessee

TN SQT – Tennessee Stream Quantification Tool

TP – Total Phosphorus

UT – Unnamed Tributary

Glossary of Terms

Alluvial Valley – Valley formed by the deposition of sediment from fluvial processes.

Best Management Practice (BMP) – A method that is recognized as an efficient, effective, and practical means of preventing or reducing the movement of pollutants into the waters of the state. A BMP may be a physical facility or a management practice achieved through action.¹

Buffer – Zone or area extending outwards from top of bank on either side of the channel, to the edge of the conservation easement.

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

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. (see 33CFR 332.2)

Condition Score – A value between 1.00 and 0.00 that expresses whether the associated parameter, functional category, or overall restoration reach is functioning, functioning-at-risk, or not functioning compared to a reference condition.

- ECS = Existing Condition Score
- PCS = Proposed Condition Score

Confined Alluvial Valley – Valley formed by the deposition of sediment from fluvial processes but confined between adjacent hillslopes. These valleys typically have noticeable slope changes in very short distances.

Credit – A unit of measure (e.g., a functional or areal measure or other suitable metric) representing the accrual or attainment of aquatic functions at a compensatory mitigation site. The measure of aquatic functions is based on the resources restored, established, enhanced, or preserved. (see 33CFR 332.2)

Debit – A unit of measure (e.g., a functional or areal measure or other suitable metric) representing the loss of aquatic functions at an impact or project site. The measure of aquatic functions is based on the resources impacted by the authorized activity. (see 33CFR 332.2)

¹ <http://tnpermanentstormwater.org/manual.asp>

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

Functions – The physical, chemical, and biological processes that occur in ecosystems. (see 33CFR 332.2)

Functional Category – The levels of the stream functions pyramid: Hydrology, Hydraulics, Geomorphology, Physicochemical, and Biology. Each category is defined by a functional statement.

Functional Foot Score (FFS) – The product of a condition score and stream length.

- Existing FFS = Existing Functional Foot Score. Calculated by measuring the existing stream length and multiplying it by the ECS.
- Proposed FFS = Proposed Functional Foot Score. Calculated by measuring the proposed stream length and multiplying it by the PCS.

Function-Based Parameter – A metric that describes and supports the functional statement of each functional category.

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

Rapid Method – Collection of office and field techniques specific to the TN SQT for collecting quantitative data to inform functional lift and loss calculations. Rapid methods, if available, are provided in this manual for each measurement method and collected in the *Rapid Assessment Method Manual*. The rapid method will typically take one to three hours to complete per project reach.

Reference Condition – A stream condition that is considered fully 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 Standard – Determines functional capacity of a measurement method using a 0.00 to 1.00 scale. Reference standards are stratified by functioning, functioning-at-risk, and not functioning. Measurement method reference standards are then averaged to create parameter reference standards.

Stream Functions Pyramid Framework (SFPF) – The Stream Functions Pyramid is comprised of five functional categories (see above) stratified based on the premise that lower-level functions support higher-level functions and that they are all influenced by local geology and climate. The Framework includes the organization of function-based parameters, measurement methods, and reference standards.

Stream Restoration - Restoration means the manipulation of the physical, chemical, or biological characteristics of a site with the goal of returning natural/historic functions to a former or degraded aquatic resource. (see 33CFR 332 / 40CFR 230)

1. Purpose and Background

The purpose of this document is to provide instruction on how to collect and analyze data needed to use the Tennessee Stream Quantification Tool (TN SQT). This manual covers how to delineate individual assessment stream reaches within a project, collect data for the Watershed Assessment worksheet, and collect and calculate field values for each measurement method in the reach condition assessments. Few measurements are unique to the TN SQT and procedures are often detailed in other instruction manuals or literature. Where appropriate, this document will reference other data collection manuals and make clear any differences in data collection or calculation methods needed for the TN SQT. This manual will refer to stream restoration in accordance with the definition used by the federal mitigation rule (33CFR 332 / 40 CFR 230):

“Restoration means the manipulation of the physical, chemical, or biological characteristics of a site with the goal of returning natural/historic functions to a former or degraded aquatic resource.”

This definition encompasses all activities aimed to improve stream functions performed for compensatory mitigation or other purposes.

In 2006, the Ecosystem Management and Restoration Research Program of the US Army Corps of Engineering (Corps) 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 Corps programs, an international committee of scientists, engineers, and practitioners defined 15 key stream and riparian zone functions aggregated into 5 categories. These five categories include system dynamics, hydrologic balance, sediment processes and character, biological support, and chemical processes and pathways. This work informed the development of the Stream Functions Pyramid Framework (SFPF; Harman et al., 2012) which provides the scientific basis of the TN SQT. The functional pyramid enables restoration practitioners and reviewers to develop and identify clear goals, have improved site selection and key in on a suite of measurements for assessing these functions in an objective manner. This document, the TN SQT Spreadsheet User Manual, assumes the reader has a basic knowledge of stream processes and the SFPF; therefore, it does not provide extensive definitions of terms such as bankfull, thalweg, riffle, etc.

TN SQT Manual Guide

1. *Spreadsheet User Manual* – Rules and procedures for entering data into the Microsoft Excel Workbook.
2. *Data Collection and Analysis Manual* – Provides instruction on how to collect and analyze data needed to run the TN SQT. (This document)
3. *Rapid Data Collection Methods* – Provides data collection and analysis instruction for applying the TN SQT rapid assessment method.

This Data Collection and Analysis Manual supports and compliments the *Tennessee Stream Quantification Tool Spreadsheet User Manual* (Spreadsheet User Manual) and does not provide

guidance on using the TN SQT or the supporting science for the reference standards. For background, purpose and uses of the TN SQT, see the Spreadsheet User Manual.

Frequently asked questions about the SQT and its development have been collected in Appendix A of the *Spreadsheet User Manual*. It is recommended that anyone using the TN SQT read through this document to gain a better understanding of the TN SQT and how it has been developed.

This version of the TN SQT and this Data Collection and Analysis Manual have been tailored for Tennessee.

1.1. Downloading the Stream Quantification Tool and Supporting Information

The TN SQT and supporting documents can be downloaded from the TDEC website at www.BLANK.org

The following documents are available at the above website:

- TN Stream Quantification Tool (TN SQT) – Microsoft Excel Workbook described in detail in the Spreadsheet User Manual.
- TN SQT Example – A populated version of the TN SQT provided as an example.
- List of Metrics – The List of Metrics is a spreadsheet file that provides a comprehensive list of the function-based parameters with their measurement methods, reference standards, stratification methods, and references.
- Spreadsheet User Manual – A manual describing the TN SQT and all calculations performed by the workbook.
- Data Collection and Analysis Manual – This manual. A manual describing how to collect data and calculate input for the TN SQT.
- Rapid Data Collection Methods – A manual outlining the rapid assessment method for the TN SQT.

The TN SQT and accompanying documents will be updated periodically as additional data are gathered and reference standards and measurement methods are refined. The latest version of the TN SQT manuals and tool can be downloaded from the TDEC website.

2. Reach Segmentation

Stream restoration projects, especially for mitigation, are getting longer. It is now common for project length to be measured in miles rather than feet and to include main-stem channels with numerous tributaries. Some are even catchment-scale, which include all stream channels within the catchment.

The TN SQT is a reach-based assessment methodology, and each reach is evaluated separately. A large project may be subdivided into multiple reaches (each requiring its own TN SQT workbook), as stream condition or character can vary widely from the upstream end of a project to the downstream end.

2.1. Reach Segmentation

Delineating stream reaches within a project area occurs in two steps. The first step is to identify whether there are multiple reaches within the project area based on differences in physical stream characteristics and differences in project designs. The second step assists in identification of the appropriate sub-reach lengths to meet measurement method assessment

requirements. The process to define a project reach is described in detail below. The process to delineate a reach is described first, followed by specific guidance on selecting sub-reaches by parameter.

Step 1: Physical Segmentation

For segmentation based on physical stream characteristics, a reach is first defined as a stream segment with similar discharge or flow type (perennial, intermittent, or ephemeral), valley morphology, Rosgen stream type (Rosgen, 1996), stability condition, streambank and riparian vegetation type, and bed material composition. Stream length is not used to delineate a stream reach as part of step one. Stream reaches can be short or long depending on their characteristics. For example, a reach proposed for culvert removal may be short and a channelized reach through cropland in an alluvial valley may be long.

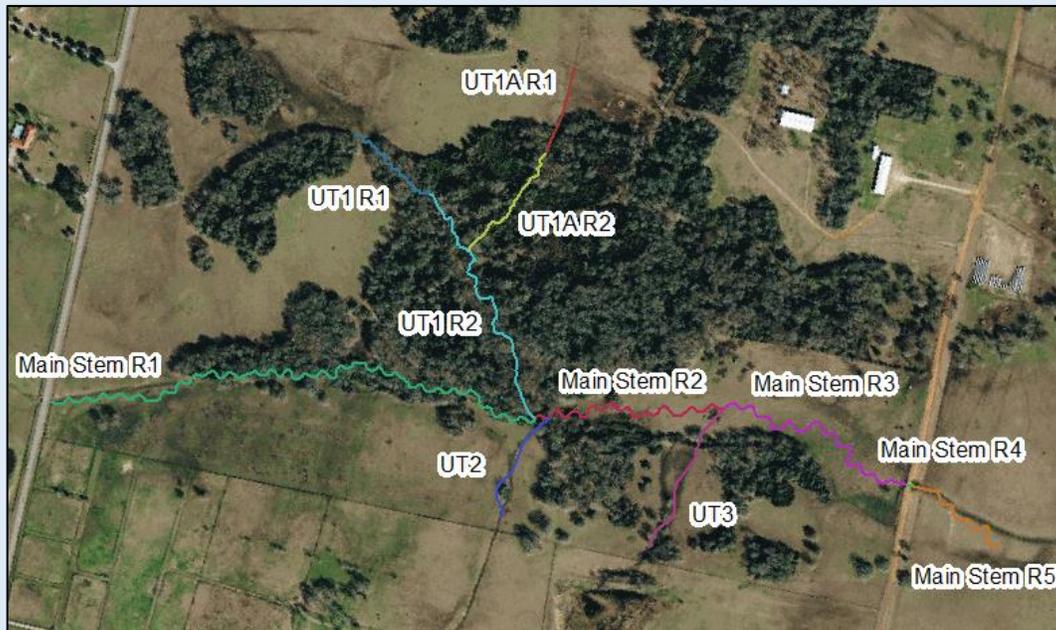
Professional judgement is required to make the physical-based reach selection. Therefore, the practitioner should provide justification for the final reach breaks. Specific examples are provided below to assist in making consistent reach identifications:

- Separate channels, i.e. tributaries and the main stem, are considered separate reaches.
- A significant increase in drainage area or change in flow type should lead to a reach break. When the drainage area for a channel increases significantly, the design criteria will change. Typically, when a large tributary enters the main stem, the main stem would consist of one reach upstream and one reach downstream of the confluence. Small tributaries, as compared to the drainage area of the main stem channel, may not indicate the need for a reach break.
- Changes to anthropogenic constraints such as the presence of a road embankment, which narrows the valley, or a culvert crossing.
- Changes to mitigation approach. This typically occurs where proposed restoration activities or practices change, e.g., restoration versus enhancement or Rosgen Priority 1 versus Priority 3.
- Additionally, reach breaks should occur when a large change is expected between the existing and proposed condition, as compared to the adjacent reaches. For example, a culvert removal project would assess the culvert's footprint as a separate reach because significant lift is generated from converting a pipe into a natural channel—probably much more lift than restoration efforts elsewhere along the stream. Therefore, a culvert removal project may include reach segments above and below the culvert, as well as the location of the culvert removal itself.

REACH SEGMENTATION EXAMPLE

Reach breaks are described below for the project site shown in Figure 1. The main-stem channel is broken into five reaches, two unnamed tributaries (UT) broken into two reaches each, and the remaining two UTs as individual reaches. This project has a total of 11 reaches; therefore, 11 TN SQT Excel Workbooks are required.

Figure 1: Reach Identification Example

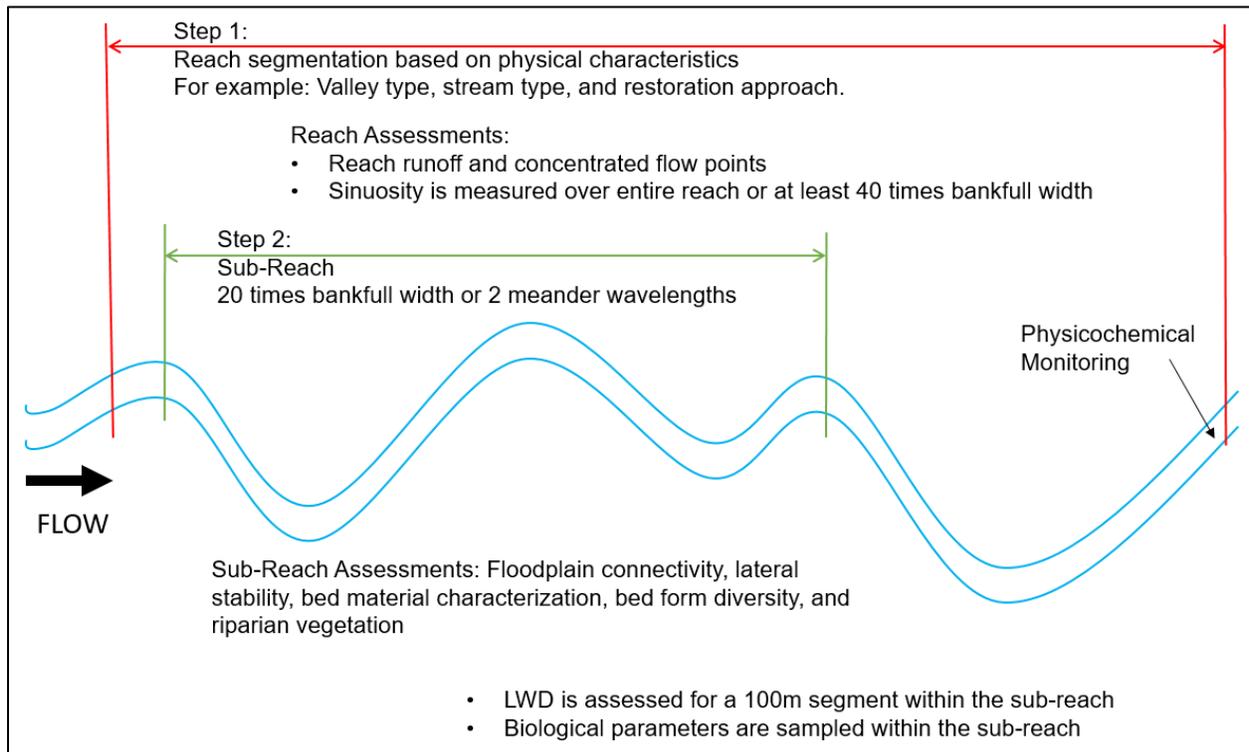


| <u>Reach</u> | <u>Reach Break Description</u> |
|--------------|---|
| Main Stem R1 | Beginning of project to UT1 confluence where drainage area increases by 25%. |
| Main Stem R2 | To UT3 confluence where there is a change in slope. |
| Main Stem R3 | To culvert that is backwatering reach 3. Bed material 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 project. |
| 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 to preserve riparian buffer. |
| UT2 & UT3 | Beginning of project to confluences with Main Stem. Reaches are actively downcutting and supplying sediment to the main stem. |

Step 2: Parameter-Based Segmentation (Sub-Reach Determination)

Some parameters, such as sinuosity and reach runoff, will be evaluated along the entire stream length within the project area, but other parameters will only be evaluated within a representative sub-reach (Figure 2). Selecting a representative sub-reach is necessary to avoid having to quantitatively assess very long reaches with similar physical conditions. The stream length evaluated will vary by functional category and parameter. For smaller projects, the representative reach may encompass the entire project area. Guidelines and examples are provided below for each functional category.

Figure 2: Reach and Sub-Reach Segmentation



1. *Hydrology Functional Category:*

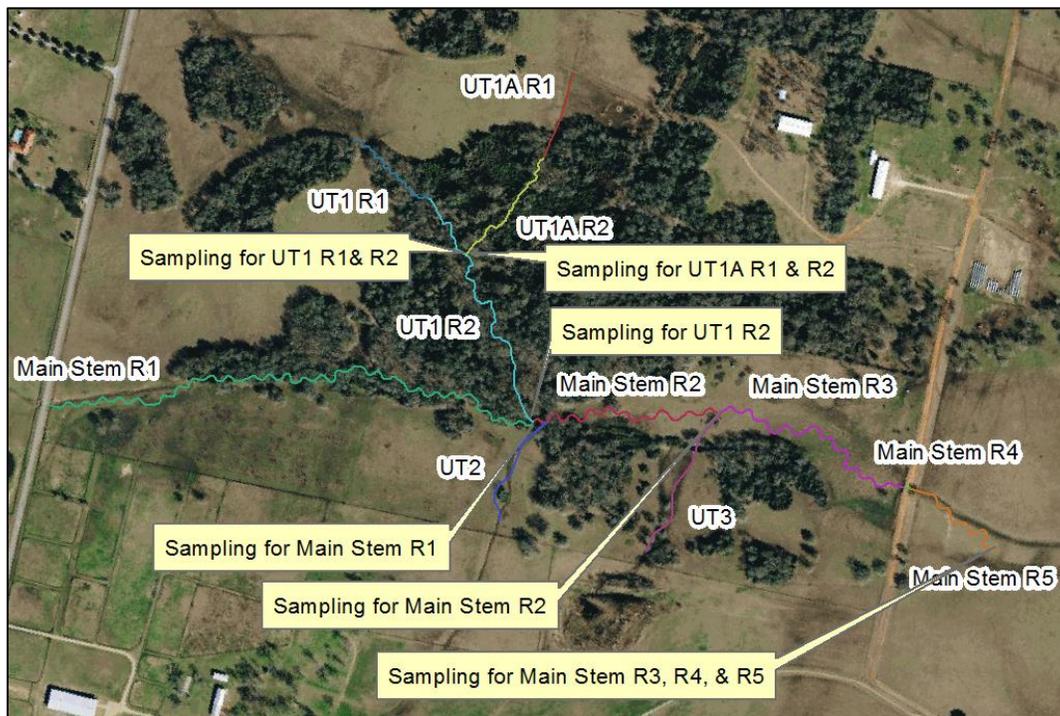
- a. The catchment hydrology parameter is assessed at the catchment or sub-catchment scale rather than the reach scale.
- b. Reach runoff parameters are evaluated for the entire length of each reach.

2. *Hydraulic and Geomorphology Functional Categories:*

- a. Riparian vegetation, floodplain connectivity, lateral stability, bed material characterization, and bed form diversity are assessed for a length that is at least 20 times the bankfull width encompassing at least two meander wavelengths (Harrelson et al., 1994). If the entire reach is shorter than 20 times the bankfull width, then the entire reach should be assessed.

- b. For large woody debris (LWD), the reach length is 100 meters (Davis et al., 2001). If the project reach is less than 100 meters (m), the LWD assessment must extend proportionally into the upstream and downstream reach to achieve the 100m requirement. In addition, if the 100m is less than the length of 20 times the bankfull width, the 100m section should be within the same reach as the bed form diversity assessment.
 - c. Sinuosity is assessed over a length that is at least 40 times the bankfull width (Rosgen, 2014) and preferably for the entire reach. If the project reach is less than 40 times the bankfull width, sinuosity must extend proportionally into the upstream and downstream reach to achieve a length of at least 40 times the bankfull width. For small streams that are not long enough to meet this criterion, the entire length of stream should be used to calculate sinuosity.
3. *Physicochemical and Biology Functional Categories*: Sampling locations are described for each measurement method in these categories. Note that the user may choose to assess a location at the upstream end of the reach, thus providing an upstream/downstream comparison. This information is ancillary to the TN SQT input in that it provides supporting information about functional lift or loss. However, the TN SQT does not provide a *direct* method for showing changes based on an upstream/downstream comparison; it shows changes before and after restoration. However, if subsequent reaches were assessed, the TN SQT could show scoring differences in a downstream direction.

Figure 3: Physicochemical and Biological Sampling Points Example



3. Watershed Assessment

The Watershed Assessment is a worksheet within the TN SQT. The Watershed Assessment worksheet identifies stressors that exist outside of the project reach and watershed processes that may limit functional lift, and therefore, restoration potential. Instructions for collecting data and describing each watershed process and stressor are provided in this section.

The form contains twelve defined categories with space for an additional user-defined category when needed. For each category there are three choices to describe the watershed condition: Good, Fair and Poor. Descriptors for collecting the data needed to assess each category are provided below. Once collected, this information should be documented. Data collection will be via digital data gathering available from various online or local resources, windshield surveys and/or site walks. Footnotes provide links to online data resources.

A complete Watershed Assessment can aid the user in determining the overall watershed condition based on the identified conditions and site constraints. The overall watershed condition is left as a subjective determination so that the user can assess and interpret the information gathered about the watershed. It is possible that the watershed condition score is heavily influenced by one or more categories that severely limits the ability to implement a restoration project. If the proposed functional lift cannot overcome certain watershed stressors, practitioners may see fit to abandon the project. Critical and substantive evaluation of watershed stressors, costs to overcome impacts, and any other site constraints need to be considered carefully to determine project feasibility. For example, a high specific conductivity in a stream impacted by mining operations could indicate there is little potential for biological lift even if the other categories in the Watershed Assessment showed a good condition. If the project was being considered to restore biomass of a rare species, then this goal may be unachievable at this site. However, this specific conductivity impairment would not prevent the restoration from achieving goals related to stability and limiting sediment input to a receiving water body.

3.1. Impervious Cover in Watershed

Runoff from impervious surfaces arrives at a stream channel faster and with poorer water quality than runoff from undeveloped ground. While stormwater BMPs can help reduce pollutant loads from urban runoff, the percent of impervious cover in a watershed has been found to be highly correlated with stream health (Schueler et al., 2009). Therefore, this category can provide insight into the quality of water entering a restoration reach as well as the potential for altered stream hydrology due to excessive responsiveness to storm events or decreases in base flow.

An estimate of percent impervious cover can be determined using the Multi-Resolution Land Characteristic (MRLC) Consortium hosted by the DOI and USGS to gather information from the National Land Cover Data (NLCD).² For smaller watersheds, it is possible to delineate impervious surfaces using recent orthoimagery, which provides a more accurate estimate than the NLCD.

When impervious cover makes up more than 20% of the drainage area, the watershed condition is considered poor. Where impervious cover makes up less than 10% of the drainage area, the watershed condition is considered good (Schueler et al., 2009). A poor or fair watershed

² <https://www.mrlc.gov/>

condition in this category would indicate that a restoration potential of level 4 or 5 would be difficult or impossible unless a large percent of the watershed is being restored (i.e. good condition rating is achieved for Category 13 of the Watershed Assessment).

3.2. Percent Land Use Change in Watershed

Land use is temporally variable and watersheds that are currently in good or fair condition can degrade quickly with development. Active construction within a watershed can cause excessive erosion and sediment supply. Urban and residential development can drastically change the hydrology and quality of water coming into the project reach. A watershed in good condition based on land use change consists of rural, or otherwise slow growth potential, communities. Watersheds evaluated as poor in this category, such as urban or urbanizing communities, have ongoing development or imminent large-scale development. The rate of urbanization in the watershed can be estimated using the percent increase in impervious cover. As noted in the previous section, impervious cover is correlated with stream health. Delineations between watersheds in good condition or poor condition were based on quartile breaks observed in percent impervious surface area changes recorded for states between 2001 and 2006 by the NLCD (Xian et al., 2011).

Trends in land use can be determined by examining orthoimagery from the last 20 years or using the NLCD 2006 to 2011 Land Cover Change dataset available from the MRLC. Zoning designations and development plans can also be obtained from local governments and assessed for the project watershed.

3.3. Road Density in Watershed

The presence of roads adjacent to or crossing a restoration reach is a design constraint that often limits the design and restoration potential of the project. Road embankments alter hydraulics while roads themselves can directly connect impervious surfaces to the stream channel. A project reach sharing its valley with a road, or that includes a road crossing in or near the project reach, is evaluated as poor condition. Major roads in, or planned to be built in, the watershed that are not directly connected to the project reach would indicate a fair watershed condition in this category. Delineations between watersheds in good condition or poor condition were based on quartile breaks observed in HUC12 watersheds within Tennessee (USEPA, 2017).

The presence of roads near the project site can be determined in the field or using available orthoimagery and/or Geographic Information System (GIS) data. GIS data are available from TDOT and county government websites. The Statewide Project Overview Tracker (SPOT)³ is available from TDOT to determine what projects are expected to receive funding during a 10-year time span. The Watershed Assessment of River Stability and Sediment Supply (WARSSS; Rosgen 2006) provides a more detailed method for evaluating the sediment impact risk of roads. The result provides an overall risk rating that could be used to determine the Watershed Assessment rating (See Figure 4-6 in Rosgen, 2006).

3.4. Percent Forested (Catchment)

Forested land has a lower runoff potential than developed land. The processes that prevent or lower runoff include: interception, surface retention, plant uptake, flow resistance caused by

³ <https://www.tdot.tn.gov/projectneeds/spot#/>

vegetation, and higher rates of soil infiltration. Forested ecosystems also provide more groundwater contributions to stream channels than their urban counterparts. The lack of forested land cover can limit the restoration potential as less forest cover indicates lower water quality and potentially altered hydroperiods for the project reach. Watershed areas that are 70% or more forested are in good condition. Watersheds that consist of 20% or less forested land are in poor condition. These numeric criteria are based on best professional judgment of the TN SQT development team and select reviewers.

The forested percent of the watershed can be derived from the NLCD. For smaller watersheds, it is possible to delineate forested areas using recent orthoimagery.

3.5. Catchment Impoundments

Catchment impoundments are features or structures that can cause flow alteration in the main stem reach or tributaries to the project reach. These include impoundments greater than 20 feet in height or structures with the capacity to have 30 acre-feet in storage. These can include small dams, large impoundments and farm ponds. Watersheds in good condition have no impoundments upstream of the project area. A watershed that contains at least one large impoundment or multiple small impoundments that limit flow in the project is in poor condition.

The location of dams or other impoundments near the stream reach can be determined through field walks, recent orthoimagery, or by performing a windshield survey.

3.6. Catchment Forested Riparian Corridor

Riparian vegetation protects the stream channel from erosive runoff velocities and provides physicochemical benefits to surface runoff and groundwater contributions to stream channels. Wider riparian corridors provide more nutrient and pollutant removal benefits, but the relationship between width and benefit is not linear (Mayer et al., 2005). Riparian corridors estimated as more than 25-feet wide provide stream stability. Watersheds in good condition will have more than 80% of the channel and tributary length *upstream* of the project reach with streamside vegetation that is more than 25-feet wide on average. Watersheds in poor condition will have 50% or less of the channel and tributary length upstream of the project reach with streamside vegetation that is more than 25-feet wide on average. These numeric criteria are based on best professional judgment of the TN SQT development team and select reviewers.

The prevalence of riparian vegetation on streams draining to the project reach can be determined using recent orthoimagery and/or by performing a windshield survey of the catchment. An estimate of the forested riparian corridor can also be derived from the NLCD.

3.7. Fine Sediment Deposition

The sediment supply entering a restoration reach plays an important role in determining restoration potential. High sediment loads from upstream bank erosion or from the movement of sediment stored in the bed creates a challenging design problem (Figure 4). If the design does not adequately address the sediment load, the restoration project could aggrade.

Users should walk the stream reach and estimate the percent of the stream bed that is affected by recent sediment deposition. This includes pools, bends, bars, or behind channel constrictions. Only areas of new unvegetated deposition on bars or islands should be considered. If the pools are too turbid or deep another method may be used to measure deposition in these areas. Alluvium may be deposited as sand or silt. Freshly deposited alluvium may be distinguished from older deposits using color (newer deposits may be lighter), level of consolidation (newer deposits are usually looser, less compacted), and absence of colonizing vegetation.

Figure 4: Recent deposits of fine sediment indicating potential upstream erosion concerns and/or high sediment loads.



3.8. Streams within the Catchment Area Currently Assessed as Impaired

TDEC maintains a dataset and map of the Use Support Assessment status of Waterbodies within the state.⁴ Impaired waters have exceeded one or more water quality standards for their designated uses. Stream restoration projects may not restore a sufficient portion of the stream or watershed to overcome poor water quality or other sources of impairment in the catchment. A poor watershed condition in this category may indicate that the restoration potential is limited and would be difficult to overcome unless a large percent of the watershed is being restored.

There are many impaired reaches or segments of waters that are not documented in the dataset and map, either because they are unassessed, or are too small to impair the use support for the entire waterbody. The rest of the categories in this Watershed Assessment will assist in identifying impairments and possible impairments for waters that are not previously identified.

⁴ <http://tdeconline.tn.gov/dwr/>

3.9. Agricultural Land Use

Runoff from agricultural lands often carries fecal bacteria, pesticides, and excess sediment and nutrients. The presence of pasture or crop land along streambanks, especially when there is little or no riparian buffer, can degrade water quality sufficiently to limit restoration potential of a stream restoration project (See Figure 5). A watershed in good condition will have little to no agricultural land uses that drain water directly into stream channels; or, there are wide buffers between the agricultural land and the stream channel. A watershed in fair condition will have agricultural land uses adjacent to the stream channel but sufficiently upstream of the project that the associated impacts are reduced in the project reach. In areas where there is livestock access and/or cropland immediately upstream of the project reach, the watershed condition is considered poor and the restoration potential is limited.

Figure 5: Cropland immediately adjacent to stream channel and without a sufficient vegetated buffer. If this condition is immediately upstream of a project reach, it can limit the restoration potential.



The prevalence and location of agricultural land uses near the stream reach can be determined during a stream walk. The prevalence of agricultural lands throughout the watershed can be determined using recent orthoimagery, the NLCD, or through windshield surveys.

3.10. Process Wastewater Outfalls in Watershed

TDEC hosts maps of the minor and major National Pollutant Discharge Elimination System (NPDES) permitted facilities and process wastewater outfalls (PWOs).⁵ The NPDES program regulates water quality standards and monitoring procedures for point source discharges to water bodies. While the program ensures discharged water meets minimum water quality standards, these discharges are impairments to stream ecosystems and may limit restoration potential for water quality and biology, level 4 and level 5 of the stream functional pyramid. A watershed in good condition would have no NPDES facilities in the watershed or near the project reach while a poor watershed in this category would have one or more major or several minor PWOs within one mile of the project reach.

3.11. Impoundments and Fish Barriers

This category captures structures that can impede landscape (river corridor) connectivity. The presence of a dam downstream of the project would make a goal of increasing fish biomass in the project reach difficult without sufficient fish passage over the dam. A dam upstream of the project may allow organism recruitment from downstream; however, it may still limit landscape connectivity, impact stream hydrology, and impede delivery of organic material to the project reach. Watersheds in good condition have no impoundments upstream or downstream of the project area, including farm ponds. If the impoundment has a beneficial effect on the project area and allows for fish passage (such as a beaver dam) then the watershed is in good

⁵ Map viewer: <http://tdeconline.tn.gov/tdecwaterpermits/>
Permit data viewer: http://environment-online.tn.gov:8080/pls/enf_reports/f?p=9034:34001:::

condition. A watershed that contains an impoundment or other barrier that has a negative effect on the project area and fish passage is in poor condition.

The location of impoundments or other fish barriers near the stream reach can be determined through field walks, recent orthoimagery, or by performing a windshield survey.

3.12. Organism Recruitment

Recruitment and colonization of aquatic organisms in streams is affected by the presence of desired communities in close proximity to the project site (Blakely et al., 2006; Hughes, 2007; Lake et al., 2007; Sundermann et al., 2011; Tonkin et al., 2014). The most important source of recolonization of benthic insects is drift from upstream. Impairments to the channel, such as hardened substrates, excessive sedimentation, culverts or piping, and catchment-scale stream and landscape conditions may prevent macroinvertebrate communities from colonizing a mitigation stream reach. Even in idealized reach-scale environments, an extended length of channel impairment upstream of the project reach may reduce the potential for organism recruitment via drift. If there are substantial channel and/or riparian impairments preventing desirable taxa from inhabiting stream reaches within 5 km upstream of the project, this should be scored as poor condition. If streams that are physically, chemically and biologically intact (i.e. support desirable aquatic communities), lie greater than 1 km, but less than 5km upstream of the project reach, then the watershed is in fair condition. If streams supporting desirable aquatic communities are located within 1 km upstream of the project reach, then the watershed is in good condition.

If the biological community of upstream reaches or unimpacted tributaries are degraded, recolonization of reference quality biological assemblages in restored reaches may never occur. Emphasis needs to be given to the quality of upstream reaches for organism recruitment. This category can be assessed by walking the site and the stream reaches immediately upstream and downstream of the project reach to determine if there are any impairments to organism recruitment including concrete, piped or hardened stretches of channel.

3.13. Other

This option is provided for the user to identify and document any stressor observed in the watershed that is not listed above but could limit the restoration potential or impair the hydrologic functioning of the project reach.

4. Getting Started with the TN SQT

Before performing a field assessment, the user needs to make several decisions to determine how data are collected and used.

- The first step is to select the appropriate function-based parameters. A Parameter Selection Guide is provided in the TN SQT and section 3.3 of the *Spreadsheet User Manual*.
- Measurement method(s) need to be selected for each parameter being used to evaluate the reach. Some parameters have multiple measurement methods that complement each other while some measurement methods are redundant. These distinctions will be discussed in detail in section 5 of this manual. Guidance is also provided in the Parameter Selection Guide.

- All measurement methods are assessed within the project reach and some are also assessed at a reference reach.
- The third step is to determine if the assessment will be rapid-based or detailed. If the user is deciding between multiple sites, rapid assessment methods can be used to collect data and estimate functional lift using the TN SQT. This estimate of lift, along with the data collected to complete the Watershed Assessment form, and an assessment of whether the site is able to achieve programmatic and project goals can assist in site selection. Rapid assessment methods are compiled in *Rapid Data Collection Methods for the TN SQT*. Once a site has been selected for a project, a detailed assessment should be completed.
- Some of the measurement methods use bankfull dimensions. It is important to verify the bankfull stage when these measurement methods are used. There are both rapid and detailed methods to verify bankfull provided in this chapter.

4.1. Rapid Versus Detailed Assessment Methods

The TN SQT can be used with rapid-based assessments or detailed assessments. A rapid assessment will typically take one to three hours to complete per project reach. Required level 2 and 3 parameters are quantitatively measured; however, standard surveying equipment like laser levels or a total station are not used. Instead, hand levels, survey tapes and rods are used to collect the measurements in the field. Keep in mind that cross sections and profiles are not tied to a survey datum and profiles cannot be easily plotted using this method. Instructions for carrying out the rapid method are provided in section 5 of this manual and collected in the *Rapid Assessment Method Manual*. A field form for collecting rapid-based measurements is also provided in the *Rapid Assessment Method Manual*.

Rapid assessments are appropriate during the site selection process, one-time only condition assessments, or other applications where cross section and profile plots are not required. The rapid method should not be used once a stream mitigation project has been selected, and the TN SQT is being used as part of a mitigation plan or monitoring report. These applications require the detailed method for baseline, as-built and monitoring assessments.

The detailed method makes the same measurements as the rapid method, but using a survey level or total station to measure longitudinal profiles and cross sections. Detailed assessments require a longitudinal profile and cross section survey within the project reach using a level, total station, or similar equipment. Four profiles are surveyed, including: thalweg, water surface, bankfull, and top of low bank. The advantage to the detailed method is that the calculations can be used to create plots/graphs that are all tied to a common datum. In addition, the measurement method calculations can be replicated in an office setting by others. The only way to replicate measurements from the rapid method is to repeat the field survey. For parameters described in the next chapter, rapid and detailed techniques will be provided as appropriate.

4.2. Bankfull Verification

Multiple parameters in the TN SQT require bankfull dimensions. These include: floodplain connectivity, large woody debris, lateral stability, and bed form diversity. Prior to making the field measurements, the practitioner should identify and verify the bankfull stage and associated dimensions. Methods for identifying the bankfull stage and calculating the bankfull dimensions can be found in Harrelson et al. (1994) and Rosgen (2014). Detailed and rapid methods to verify bankfull are described below.

4.2.1. Verifying Bankfull Stage and Dimension with Detailed Assessments

Detailed assessments require longitudinal profiles of thalweg, water surface, bankfull, and top of low bank within the project reach using a level, total station, or similar equipment. From these data, a best-fit-line is plotted through the bankfull stage points. Harrelson et al. (1994) provides instructions on how to survey a longitudinal profile. The bankfull determination is suspect if the bankfull slope is different from the water surface slope and/or if the best-fit line through the bankfull points has a low correlation coefficient (Rosgen, 2014).⁶

If possible, a moderately stable to stable riffle cross section should be located for each study reach. The primary purpose of the cross section is to measure the bankfull width and calculate the mean bankfull depth (cross sectional area divided by width). These two values are then used to create dimensionless ratios for pool spacing and pool depth, which are measurement methods for the bedform diversity parameter. Dimensions from a stable riffle are used in these ratios in order to quantify the departure from a stable condition.

A second reason for the cross section is to assist in verifying the bankfull feature. Prior to surveying the cross section, the practitioner should select a bankfull feature based on multiple observations throughout the reach. If bankfull regional curves are available, the surveyed cross sectional area can be compared to the regional curve as part of a verification process.

There are three options for selecting a stable riffle: within the reach, upstream/downstream of the reach, and a regional curve. The criteria for each is described below.

Option 1: Cross Section Within Project Reach

This is the preferred option because the bankfull width and mean depth used to create the ratios represent actual site conditions.

- 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.
- No signs of bank erosion.
- No headcutting and the bank height ratio is near 1.0.
- Cross-sectional area plots within the range of scatter of a representative regional curve. More information is provided in the following paragraphs.

Option 2: Cross Section Upstream or Downstream of Project Reach

In a highly degraded reach, a stable riffle cross section from an adjacent upstream or downstream reach may be used if available. Ideally, the riffle section will be very close to the project reach. The same criteria as option one is applied to option 2.

⁶ These instructions are also available here:
https://nctc.fws.gov/courses/csp/csp3200/resources/documents/Bankful_AFG2013.pdf

Option 3: Use of Regional Curves

If a stable riffle cannot be located within or upstream/downstream of the project, then a regional curve that is representative of the project watershed can be used as a surrogate. In this case, the bankfull width and mean depth curves are used.

Again, the primary purpose of this cross section is to obtain a bankfull width and mean depth needed for the bedform diversity calculations. For options 1 and 2, the cross section data can also be used to calculate the bankfull discharge, as long as the channel slope and roughness coefficient are also known.

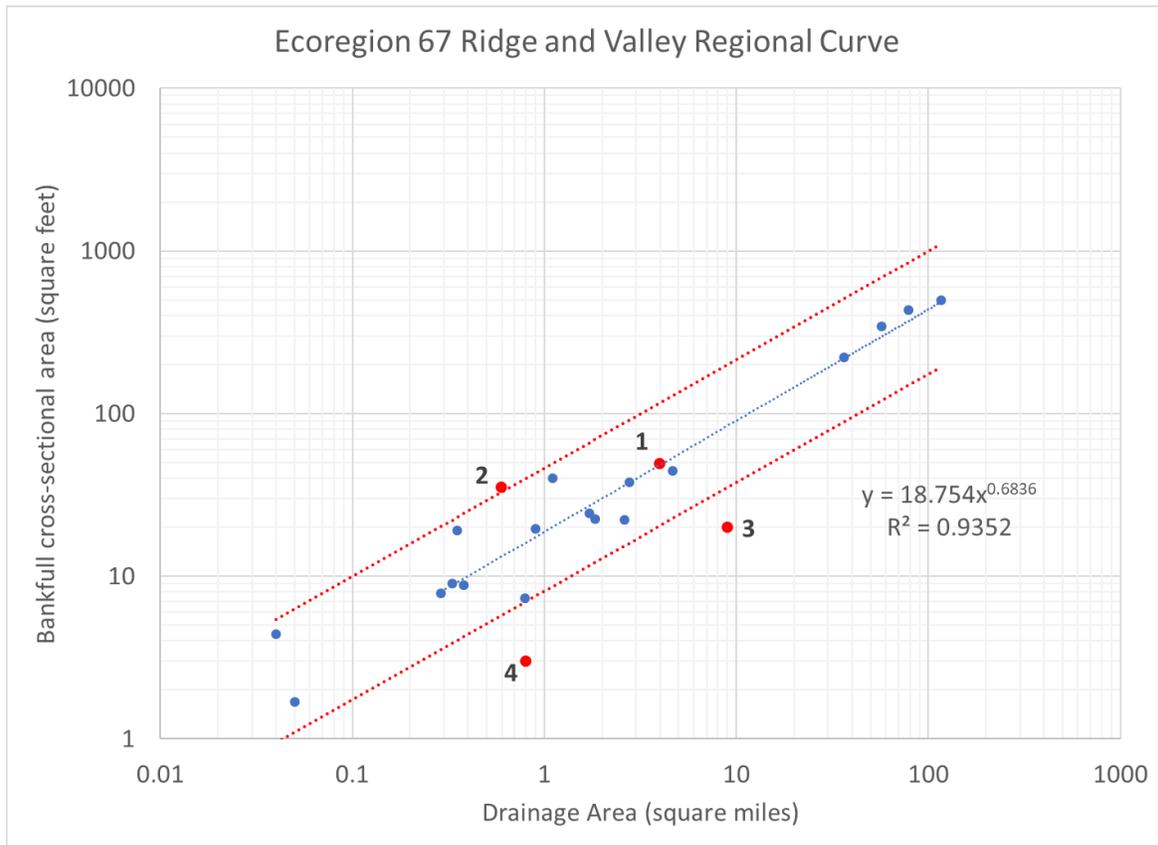
For bankfull verification, riffle cross sectional areas are plotted on their corresponding bankfull regional curve. The field data should fall within the range of scatter of the regional curve. If the field data are outside the range of scatter, the practitioner will need to determine if the wrong indicator was selected or if the regional curve represents a different hydro-physiographic region. Ideally the regional curve has been developed specifically for the study watershed. If watershed-specific regional curves are not available, the user can overlay the field data with established curves. TDEC provides regional curves for Level III Ecoregions of Tennessee.⁷ For Tennessee, established curves are available for Ecoregion 67 Ridge and Valley, Ecoregion 68 Southwestern Appalachians and 69 Central Appalachians, and Ecoregion 71 Interior Plateau.

Figure 6 shows the regional curve for the Ridge and Valley ecoregion of TN, the 95% prediction interval for the regional curve, and four sample points, numbered and shown in red.

- Sample point 1 plots within the prediction interval for the regional curve and can be considered verified.
- Sample point 2 falls outside of the prediction interval for the regional curve. As the point is above the regional curve, the practitioner should check the percent impervious cover in the watershed. The practitioner should also check the surveyed cross section and profile to determine if there is another dominant feature at a lower elevation. For suburban watersheds, it is common for bankfull values to fall above regional curves developed in primarily forested or rural watersheds. If the field bankfull determination is confirmed by assessing the cross section/profile and the percent impervious is high, around 15% or greater, then sample point 2 can be considered verified.
- Sample points 3 and 4 are outside the range of scatter for the regional curve. The cross sections should be compared to field photographs to determine if there is a higher bankfull feature. Note, an adjustment should only be made if there is a higher feature representing a breakpoint between channel formation and floodplain processes. If there is, then an adjustment can be made. If not, consider visiting multiple sites within the watershed of the field site and developing a local regional curve.

⁷ <http://www.tn.gov/environment/article/permit-water-arap-compensatory-mitigation>

Figure 6: Verifying Bankfull with Regional Curves Example



4.2.2. Verifying Bankfull Stage and Dimension with Rapid Assessments

Rapid methodologies rely on a stadia rod and a hand or line level to record the vertical difference between water surface and bankfull indicators throughout the reach. A riffle cross section should be surveyed (with a level, tape, and stadia rod or just with a tape and stadia rod) and the dimension calculated from the bankfull indicator. If a cross section cannot be surveyed, the user should still measure the bankfull width and take several depth measurements from a level tape stretched across the channel at the bankfull indicator location. The depths can then be averaged and multiplied by the width to get a rough estimate of the bankfull cross sectional area. This area can then be compared to the regional curve as described in the previous section.

5. Measurement Method Field Values

The Quantification Tool worksheet is the main sheet in the Tennessee Stream Quantification Tool (TN SQT) Microsoft Excel Workbook. It is a simple calculator where users enter data describing the existing and proposed conditions of the project reach and functional lift or loss is calculated. The TN SQT worksheet requires data entry in three areas: Site information and Reference Standard Stratification, Existing Condition Field Values, and Proposed Condition Field Values. For detailed information on the Site Information and Reference Standard

Stratification section of the TN SQT, refer to the *Spreadsheet User Manual*. This manual provides instruction for collecting and analyzing field data that is required for the Condition Assessments (Table 1) in the TN SQT. Note that there are Condition Assessments on the Quantification Tool worksheet and the Monitoring Data worksheet of the TN SQT. Data collection and analysis procedures for existing condition assessments and monitoring events need to follow the procedures outlined in this chapter. The proposed condition assessment is filled out with data from the project design and best professional judgement of expected results.

A project would rarely, if ever, enter field values for all measurement methods included in the TN SQT. The Parameter Selection Guide worksheet and section 3.3 of the *Spreadsheet User Manual* provide guidance on which parameters to assess.

The field methods to collect and calculate field values for each measurement method are provided below. Measurement methods are organized by functional category and function-based parameter.

5.1. Hydrology

The TN SQT contains two function-based parameters to describe the transport of water from the watershed to the channel: Catchment Hydrology and Reach Runoff.

5.1.1. Catchment Hydrology

Catchment hydrology assesses the hydrologic health of the catchment *upstream* of the project reach. The reach catchment directly effects reach baseflow, stormwater peak flows and pollution loads coming into a project reach. For projects that employ holistic catchment methods, functional lift can be captured by this parameter if the proposed condition score is higher than the existing condition score. This could only happen if the practitioner improves the runoff condition of the catchment, such as purchasing the entire catchment and converting the land use from pastureland to forest. Most stream restoration projects will have no effect on the catchment hydrology score.

There is one measurement method for catchment hydrology: an area-weighted curve number used to characterize the catchment land use *upstream* of the project reach. The curve number is used to represent the effect of land uses that are known to degrade stream ecosystems (impervious cover, agriculture, high or low density residential development, etc.) and is not used to calculate runoff volumes or estimate infiltration. The portion of the reach catchment that drains laterally to the project reach, the lateral drainage area (LDA; Figure 7), is assessed as the reach runoff parameter and should not be included in this calculation for catchment hydrology. Curve numbers were developed by the NRCS in their manual Urban Hydrology for Small Watersheds (NRCS, 1986), commonly known as TR-55.

To determine the field value, calculate an area-weighted curve number for the catchment upstream of the project reach. Delineate the different land use types and the underlying hydrologic soil group (HSG) and calculate the percent of the total area that is occupied by that land use. Look up the curve number in Tables 2-2a, 2-2b, and 2-2c in TR-55. Table 2 provides example curve numbers by land use type. The ranges represent different conditions with lower numbers equating with less runoff than higher numbers, i.e., a lower number is functionally better than a higher number.

Table 1: Condition Assessment from the TN SQT

| Functional Category | Function-Based Parameters | Measurement Method | Field Value |
|-------------------------|-------------------------------|--|-------------|
| Hydrology | Catchment Hydrology | Land Use Curve Number Value | |
| | Reach Runoff | Stormwater Infiltration Concentrated Flow Points Soil Compaction (inches) Soil Bulk Density (g/cm ³) | |
| Hydraulics | Floodplain Connectivity | Bank Height Ratio Entrenchment Ratio | |
| Geomorphology | Large Woody Debris | LWD Index # Pieces | |
| | Lateral Stability | Erosion Rate (ft/yr) Dominant BEHI/NBS Percent Streambank Erosion (%) | |
| | Riparian Vegetation | Left Canopy Coverage (%) Right Canopy Coverage (%) Left Basal Area (sq.ft/acre) Right Basal Area (sq.ft/acre) Left Buffer Width (ft) Right Buffer Width (ft) Left Density (stems/acre) Right Density (stems/acre) | |
| | Bed Material Characterization | Size Class Pebble Count Analyzer (p-value) | |
| | Bed Form Diversity | Pool Spacing Ratio Pool Depth Ratio Percent Riffle (%) Aggradation Ratio | |
| Physicochemical | Plan Form | Sinuosity | |
| | Bacteria | E. Coli (Cfu/100 ml) | |
| | Organic Enrichment | Percent Nutrient Tolerant Macros (%) | |
| | Nitrogen | Nitrate-Nitrite (mg/L) | |
| Biology | Phosphorus | Total Phosphorus (mg/L) | |
| | Macros | Tennessee Macroinvertebrate Index | |
| | | Percent Clingers (%) | |
| | | Percent EPT – Cheumatopsyche (%) | |
| | Fish | Percent Oligochaeta and Chironomidae (%) | |
| Native Fish Score Index | | | |
| | Catch per Unit Effort Score | | |

Table 2: Curve Numbers (NRCS, 1986)

| Land Use | Hydrologic Soil Group | | | |
|-----------------------------|-----------------------|-------|-------|-------|
| | A | B | C | D |
| Woods | 30-45 | 55-66 | 70-77 | 77-83 |
| Pasture, grassland or range | 39-68 | 61-79 | 74-86 | 80-89 |
| Row Crops | 61-72 | 70-81 | 77-88 | 80-91 |
| Impervious area | 98 | 98 | 98 | 98 |

Area-weighted curve numbers for both the existing and proposed conditions are calculated and entered into the TN SQT as field values. Reference standards in the TN SQT are based on the curve number values from TR-55 for woods in good condition over the varying HSGs (NRCS, 1986).

5.1.2. Reach Runoff

The lateral drainage area to a reach directly effects reach baseflow, stormwater peak flows and pollution loads, and supports the riparian vegetation community. The reach runoff parameter consists of four measurement methods: stormwater infiltration, concentrated flow points, soil compaction and soil bulk density. Stormwater infiltration and concentrated flow points should be assessed for all projects where reach runoff is measured. Soil compaction or bulk density are optional measurement methods for this parameter.

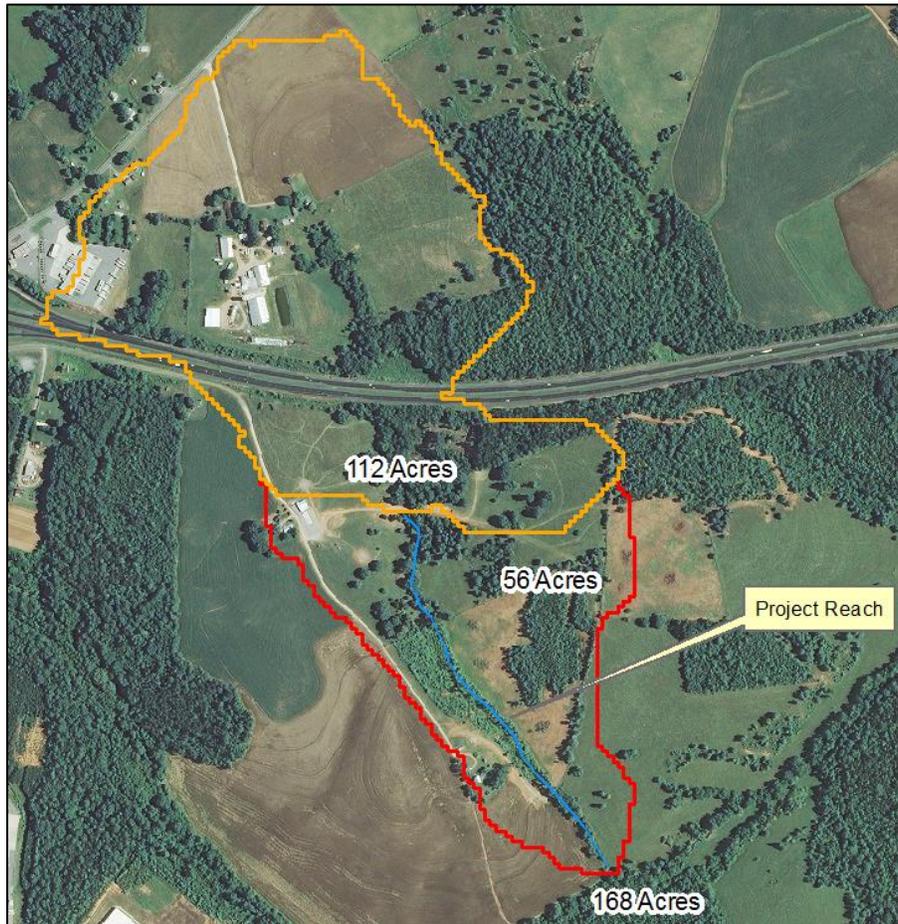
The reach runoff parameter evaluates the hydrologic functioning of the land that drains laterally into the stream reach, the lateral drainage area (LDA). The catchment above the stream reach is assessed by the catchment hydrology parameter. An example is shown in Figure 7. The orange polygon delineates the 112 acres draining to the upstream end of the project reach, while the catchment draining to the downstream extent of the reach is calculated to be 168 acres. Therefore, the LDA for the project reach is represented by the difference between the two measurements, or 56 acres (delineated in red in the figure).

a. Stormwater Infiltration

The stormwater infiltration measurement method characterizes the amount of the lateral drainage area (LDA) that is treated by a BMP or reforested. In order to calculate the field value for the TNSQT the user must delineate the following variables within the LDA:

- Runoff Source Area (RSA)
 - Drainage area from agricultural or urban land uses that increase runoff or generate pollutants.
- Stormwater Design Area (SDA)
 - Drainage area contributing runoff to be treated by the Stormwater BMP
 - Portion of RSA treated by the stormwater BMP that generates a design volume for the stormwater BMP.
 - Note that the SDA will be equal to 0 for the Existing Condition (i.e. pre-BMP implementation)
- Stormwater Infiltration Factor (SIF)
 - Ratio of the BMP design volume that will be infiltrated by the stormwater BMP during small storms.

Figure 7: Catchment Delineation Example for Reach Runoff.



Once these values are documented, Equation (1) can be used to calculate the field value for this measurement method.

$$\text{Equation (1)} \quad \text{Field value} = \frac{(SDA \times SIF) + (LDA - RSA)}{LDA}$$

This measurement method was developed for the TN SQT and the field value is equal to the index value (Table 3). Therefore, there is not a reference standard plot in the Reference Standard worksheet for this measurement method.

Table 3: Stormwater Infiltration Reference Standards

| Field Value | Index Value | Condition |
|-------------|-------------|---------------------|
| 1.00 | 1.00 | Functioning |
| 0.70 | 0.70 | Functioning-At-Risk |
| 0.30 | 0.30 | |
| 0.00 | 0.00 | Not Functioning |

b. Concentrated Flow Points

Overland flow typically erodes soils relatively slowly through splash and sheet erosion; however, anthropogenic impacts can lead to concentrated flow that erodes soils relatively quickly, transporting sediment into receiving stream channels (Al-Hamdan et al., 2013). This measurement method assesses the number of concentrated flow points, or ephemeral channels caused by anthropogenic impacts, that enter the project reach per 1,000 linear feet of stream. Anthropogenic causes of concentrated flow include agricultural drainage ditches, impervious surfaces, storm drains, land clearing, and others. Figure 8 is an example of an agricultural ditch (ephemeral channel) used to drain water from the adjacent cropland into the project reach.

Figure 8: Agricultural ditch draining water from field into stream channel.



Al-Hamden et al. (2013) cite three primary drivers that cause sheet flow to transition to concentrated flow: discharge, bare soil fraction, and slope angle. Stream restoration projects can reduce concentrated flow entering the channel by dispersing flow in the floodplain and increasing ground cover near the channel. Reference standards are based on best professional judgement and are provided in Table 4.

Table 4: Concentrated Flow Points Reference Standards

| Field Value (#/1,000 ft) | Index Value | Condition |
|-----------------------------|-------------|---------------------|
| 0 | 1.00 | Functioning |
| 1 | 0.60 | Functioning-At-Risk |
| 2 | 0.40 | |
| 3 | 0.30 | |
| >3 | 0.00 | Not Functioning |

c. Soil Compaction

High soil compaction can restrict root growth, impact nutrient uptake, and decrease soil porosity, thereby increasing runoff (Duiker 2004). Driving heavy equipment, such as construction and farm equipment, across soils can cause compaction, preventing vegetation growth and increasing runoff to the project reach. Restoration activities can include ripping floodplain soils and creating micro-topography to improve infiltration and storage as shown in Figure 9.

Soil compaction is measured as an average depth to a compacted layer (inches) using a penetrometer. For the TN SQT, the compacted layer is defined as soil resistance of 200 psi or greater. Monitoring procedures, including when to sample and how many samples to take are provided in Duiker (2002). For annual samples in an agricultural field or other land use, the recommended time to sample is in the spring, approximately 24 hours after a soaking rain. Samples taken for post-construction monitoring should be taken from the same site and at the same soil moisture condition. During a sampling event, a minimum of 4 readings for every acre is recommended to characterize representative conditions; more will be needed if the riparian area is not homogenous. A single value for the TN SQT can be obtained by averaging values from homogenous areas or calculating an area-weighted average as needed to accurately represent the riparian area for each stream reach.

Reference standards are based on the compaction that restricts root growth (NRCS 2003).

d. Soil Bulk Density

Soil bulk density (g/cm^3) is related to soil compaction and can similarly limit root growth. Soil bulk density is measured using the cylindrical core method as outlined in the Soil Quality Test Kit Guide (NRCS, 1999). This report provides guidance on when to sample, where to sample and how many samples to take. For annual samples in an agricultural field, the recommended time to sample is after harvest or at the end of the growing season. For other land uses, sample when there have not been recent disturbances. Samples taken for post-construction monitoring should be taken from the same site and at the same soil moisture condition. During a sampling event, a minimum of three samples per site is recommended to characterize representative conditions; more will be needed if the riparian area is not homogenous. A single value for the TN SQT can be obtained by averaging values from homogenous areas or calculating an area-weighted average as needed to accurately represent the riparian area for each stream reach.

Figure 9: Restoration activities to reduce soil compaction can include disking in a cross-disk pattern.



Performance standards are stratified by soil texture and based on the bulk density that restricts root growth (NRCS, 2008).

5.2. Hydraulic

The TN SQT currently contains one function-based parameters to describe the transport of water in the channel, on the floodplain, and through sediments: floodplain connectivity. Two measurement methods are used to quantify floodplain connectivity: the bank height ratio (BHR) and the entrenchment ratio (ER).

5.2.1. Floodplain Connectivity

This parameter and both measurement methods should be used for all projects. Note, the reference standards are stratified by Rosgen stream type to account for functional differences between streams in alluvial versus colluvial and v-shaped valleys.

Rapid and detailed assessments are available for both of the two measurement methods. Both BHR and ER should be assessed for a length that is 20 times the bankfull width or the entire reach length, using whichever is shorter (Harrelson et al., 1994).

a. Bank Height Ratio (BHR)

The BHR is a measure of channel incision and therefore the likelihood of floodplain inundation; the lower the ratio, the more frequently water accesses the floodplain. The most common calculation for the BHR is the Low Bank Height divided by the maximum bankfull riffle depth (D_{max}). The low bank height is the lower of the left and right streambanks, indicating the minimum water depth necessary to inundate the floodplain.

Equation (2)
$$BHR = \frac{\text{Low Bank Height}}{D_{max}}$$

To improve consistency, the TN SQT requires every riffle within the assessment segment to be measured. The BHR should be measured at the midpoint of the riffle, half way between the head of the riffle and the head of the run or pool if there isn't a run. Using this dataset, a weighted BHR is calculated as follows.

Equation (3)
$$BHR_{weighted} = \frac{\sum_{i=1}^n (BHR_i * RL_i)}{\sum_{i=1}^n RL_i}$$

Where, RL_i is the length of the riffle where BHR_i was measured.

Table 5 below provides an example of the weighted bank height ratio calculation in an assessment segment with four riffles.

Table 5: Example Weighted BHR Calculation

| Riffle ID | Length (RL) | BHR | BHR * RL |
|--------------------------------|---------------|--------------|--------------|
| R1 | 25 | 1.0 | 25 |
| R2 | 50 | 1.5 | 75 |
| R3 | 5 | 1.1 | 5.5 |
| R4 | 30 | 1.7 | 51 |
| Total | 110 ft | Total | 156.5 |
| Weighted BHR = 156.5/110 = 1.4 | | | |

The reference standards for the BHR measurement method follow the delineations for risk rating categories where very low and low risk banks are functioning; high, very high, and extreme risk banks are not functioning; and moderate risk banks are functioning-at-risk (Rosgen, 2014).

For the TN SQT, BHR can be calculated for each riffle within the reach using detailed or rapid field methods.

Detailed Method

For the TN SQT, the BHR is measured at riffle features from the longitudinal profile. Field instructions for surveying a longitudinal profile are provided by Harrelson et al. (1994). Rosgen (2014) shows examples of BHR calculations made at riffles along the longitudinal profile. This method is reproducible as it is measured directly from the surveyed longitudinal profile and is easily verified in the office.

Rapid Method

Rapid-based methods record measurements taken in the field using a stadia rod and a hand level and do not require a longitudinal profile survey. A line level can be used instead of a hand level for small streams.

Using a stadia rod and a hand level or line level for small streams:

1. Identify the middle of the riffle feature and the lower of the two streambanks.
2. Measure the difference in stadia rod readings from the thalweg to the top of the low streambank. This result is the Low Bank Height in Equation (2).
3. Measure the difference in stadia rod readings from the thalweg to the bankfull indicator, and enter this value in the denominator of Equation (2).
4. Measure the length of the riffle.
5. Repeat these measurements for every riffle to enter values into Equation (3).

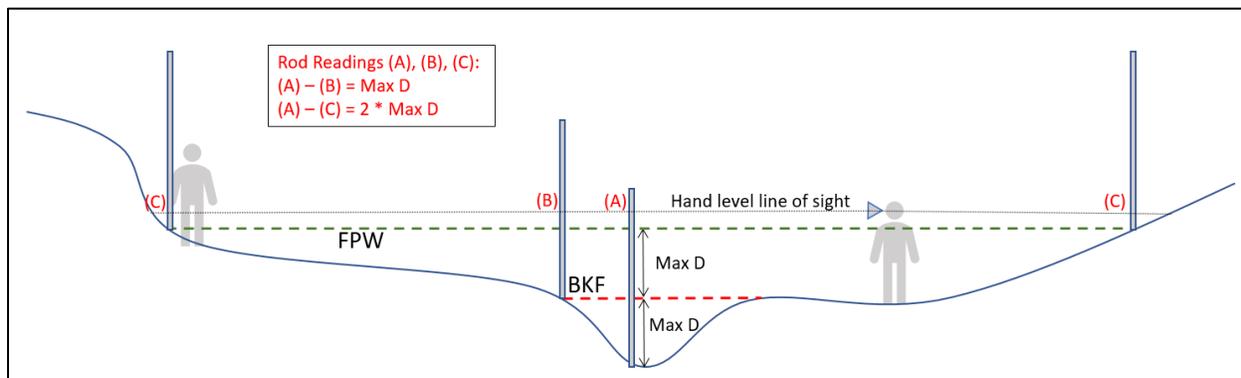
b. Entrenchment Ratio (ER)

The ER is used to describe the vertical containment of a channel. It is a measure of approximately how far the 2-percent-annual-chance (50-year) discharge will laterally inundate the floodplain (Rosgen, 1996).

Entrenchment Ratio is the flood prone width divided by the bankfull width of a channel, measured at a riffle cross section (See Equation (4) below). The flood prone width is measured as the cross section width at an elevation two times the bankfull max depth (Figure 10).

Equation (4)
$$ER = \frac{\text{Flood Prone Width}}{\text{Bankfull Width}}$$

Figure 10: Surveying Entrenchment Ratio using Rapid Methods.



Unlike the BHR, the ER does not necessarily 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 BHR's that range from 1.8 to 2.2, it is recommended that the ER be measured at each riffle and to calculate the weighted ER. The ER should be measured at the midpoint of the riffle, i.e. half way between the head of the riffle and the head of the run or pool if there isn't a run. Using this dataset, a weighted ER is calculated as follows:

Equation (5)
$$ER_{weighted} = \frac{\sum_{i=1}^n (ER_i * RL_i)}{\sum_{i=1}^n RL_i}$$

Where, RL_i is the length of the riffle where ER_i was measured. Refer to Table 6 for an example of the weighted entrenchment ratio calculation.

Table 6: Example Weighted ER Calculation

| Riffle ID | Length (RL) | ER | ER * RL |
|-----------------------------|---------------|--------------|------------|
| R1 | 25 | 1.2 | 30 |
| R2 | 50 | 2.1 | 105 |
| R3 | 5 | 1.6 | 8 |
| R4 | 30 | 1.8 | 54 |
| Total | 110 ft | Total | 197 |
| Weighted ER = 197/110 = 1.8 | | | |

There are two sets of reference standards for the ER, one for C and E type streams that are typically in alluvial valleys and one for A and B type streams that typically occur in higher

gradient systems with confined valleys. Note, the reference standard is for the proposed stream type and not the existing stream type. For example, if the existing stream type is a Gc and the proposed stream type (which should be the appropriate stream type for the given valley morphology) is a C, the practitioner should use reference standards for a C-type channel. The reference standards for this measurement method are based on the classification criteria for stream type with modifications based on best professional judgement.

For the TN SQT, ER can be calculated using detailed or rapid field methods.

Detailed Method

Measure ER at riffle features from surveyed cross sections. Field instructions for surveying a cross section are provided by Harrelson et al. (1994). Figure 2-7 in Rosgen (2014) shows examples of ER calculations. This method is reproducible as it is measured directly from the surveyed cross sections and is easily verified in the office.

Rapid Method

Rapid-based methods record measurements taken in the field using a stadia rod and a hand level and do not require surveyed cross sections. A line level can be used instead of a hand level for small streams. The rapid method measures the ER using bankfull and entrenchment widths measured from a riffle cross section (Figure 10), which are the same measurements as the detailed method, but not measured as part of a surveyed cross section.

Using a stadia rod and a hand level or line level for small streams:

1. Identify the middle of the riffle feature.
2. Measure the width between bankfull indicators on both banks and enter this value in the denominator of Equation (4).
3. Measure the difference in stadia rod readings from the thalweg to the bankfull indicator.
4. Locate and flag the point along the cross section in the floodplain where the difference in stadia rod readings between the thalweg and that point is twice that of the difference measured in the previous step.
5. Repeat step 4 on the other bank.
6. Measure the distance between the flags and enter this value as the numerator of Equation (4).
7. Measure the length of the riffle and repeat these measurements for every riffle to enter values into Equation (5) if needed.

5.3. Geomorphology

The TN SQT contains six function-based parameters to describe the transport of wood and sediment to create diverse bed forms and maintain dynamic equilibrium: large woody debris, lateral stability, riparian vegetation, bed material characterization, bed form diversity, and plan form. Few projects will enter values for all geomorphic parameters.

5.3.1. Large Woody Debris

There are two measurement methods to assess the large woody debris (LWD) parameter, one for the rapid method and a different method for detailed assessments. The rapid method is a LWD piece count per 100 meters of channel. The detailed method uses the large woody debris

index (LWDI; Davis et al., 2001). The user should not enter data for both measurement methods in the TN SQT.

For both measurement methods in the TN SQT, large woody debris is defined as dead wood over 1 m in length and at least 10 cm in diameter at the largest end. The wood must be within the stream channel or touching the top of the streambank. An assessment reach of 100 m is required. This reach should be within the same reach limits as the other geomorphology assessments and should represent the length that will yield the highest score. The highest score, rather than an average score, was selected to reduce subjectivity in identifying an average condition.

The current reference standards are based on data collected from 16 sites throughout the Piedmont and Mountain regions of North Carolina. A data collection effort is currently underway in Tennessee ecoregions to update the reference standards. At the time of publication, the reference standards developed for NC were verified using 16 reference sites in TN.

a. LWDI

The Large Woody Debris Index (LWDI) is used to evaluate large woody debris within or touching the active channel of a stream, but not on the floodplain. This index was developed by the USDA Forest Service Rocky Mountain Research Station (Davis et al., 2001).

Davis et al. (2001) provides a brief description and rating system for evaluating LWD pieces and dams. In addition, Stream Mechanics and EPR are preparing technical guidance to clarify and standardize the Forest Service instructions (in draft).

b. Piece Count

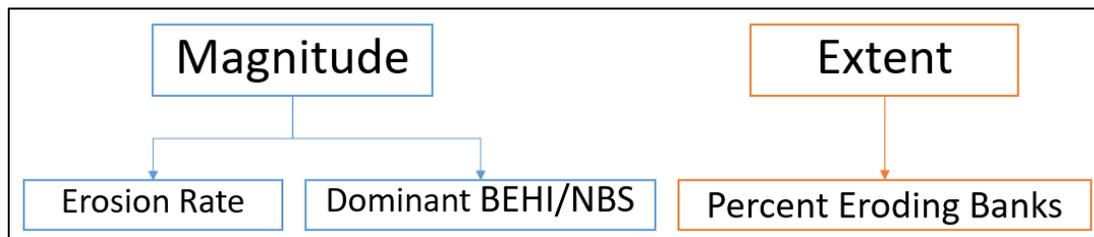
For this measurement method, the pieces of LWD within or touching the active channel of a stream are simply counted. For debris dams, each piece within the dam that qualifies as LWD is counted as a piece. This procedure and the rapid method data form are included in the *Rapid Assessment Method Manual*.

5.3.2. Lateral Stability

Lateral stability is a parameter that assesses the degree of streambank erosion relative to a reference condition, and should be assessed for all projects. Lateral stability should be assessed for a length that is 20 times the bankfull width or the entire reach length, using whichever is shorter (Harrelson et al., 1994).

There are three measurement methods for this parameter: erosion rate, dominant bank erosion hazard index (BEHI)/near bank stress (NBS), and percent streambank erosion. It is recommended that two of these measurement methods be used for all stream restoration projects: percent eroding banks and **either** erosion rate or dominant BEHI/NBS. Erosion rate and dominant BEHI/NBS characterize the magnitude of bank erosion while percent eroding bank characterizes the extent of bank erosion within a reach (Figure 11). Percent eroding bank should not be used alone to describe lateral stability.

Figure 11: Relationship between measurement methods of lateral instability.



The study banks can be measured by mapping the stream banks in the field with a GPS unit, or marking the eroding bank sites on an aerial, and delineating the banks evaluated.

a. Erosion Rate

The erosion rate of a bank can be measured using bank pins, bank profiles, or cross sections that are assessed annually. All of these measurements can produce an estimate of bank erosion in feet per year. However, several years of pre- and post-restoration data are needed to make an accurate calculation.

Methods for installing and monitoring cross sections, bank pins, and bank profiles can be found in Harrelson et al., (1994) and Rosgen (2014). Additional guidelines are provided below.

1. Select bank segments within the project reach that represent high, medium, and low bank erosion rates. Record the length and height of each bank segment.
2. Establish cross sections, bank profiles, and/or pins in each study bank. Bank profiles are recommended for undercut banks.
3. Establish a crest gauge or water level recorder. It is important to know the magnitude and frequency of moderate and large flow events between monitoring dates.
4. Perform annual surveys as close to the same time of year as possible. Measure changes in cross sectional area and record number of bankfull events. If there were no bankfull events between monitoring years, monitor for one more year.
5. Calculate erosion rate as cross sectional area of year 2 minus cross sectional area of year 1 divided by the bank height to get the erosion rate.
6. To use the results in the TN SQT, calculate the weighted average of the erosion rates using the lengths of each bank segment.

Equation (6)
$$Erosion\ Rate_{weighted} = \frac{\sum_{i=1}^n (Erosion\ Rate_i * L_i)}{\sum_{i=1}^n L_i}$$

It is also helpful to determine the BEHI/NBS rating of the banks being assessed as these data can be used to calibrate the Bank Assessment of Non-point source Consequences of Sediment (BANCS) model.

The reference standards for erosion rate are based on data collected in North Carolina streams and compared to national datasets. Datasets for Tennessee were not available at the time this was published, and these reference standards are under review.

b. Dominant BEHI/NBS

The dominant BEHI/NBS is used to estimate erosion rates based on bank measurements and observations. The BEHI/NBS methods are described on pages 3-50 through 3-90 of Rosgen (2014). On page 3-50, Rosgen states that “A BEHI and NBS evaluation must be completed for each bank of similar condition that is potentially contributing sediment (this may include both right and left banks); depositional zones are not necessary to evaluate.” For use with the TN SQT, riffle sections that are not eroding and have a low potential to erode are also not included. However, if a riffle is eroding, it is assessed. This means that the assessment will focus on meander bends and areas of active erosion to determine the dominant BEHI/NBS, which represents the dominant score of banks that are eroding or have a strong potential to erode. An example of how to calculate the dominant BEHI/NBS category is included below.

DOMINANT BEHI/NBS EXAMPLE

Data were collected in the field for 1100 feet of bank (left and right bank lengths). The banks actively eroding or with a strong potential to erode were assessed using the BEHI/NBS methods and the results provided in Table 7.

Table 7: Example Calculation for Dominant BEHI/NBS

| Bank ID (Left and Right) | BEHI/NBS | Length (Feet) | Percent of Total (%) |
|-----------------------------|-----------|---------------|----------------------|
| L1 | Low/Low | 50 | 50 / 155 = 32 |
| L2 | High/High | 12 | 8 |
| R1 | Mod/High | 22 | 14 |
| R2 | High/High | 31 | 20 |
| L3 | Low/Mod | 9 | 6 |
| R4 | High/High | 31 | 20 |
| Total Length | | 155 | 100 |

The dominant BEHI/NBS is determined by summing the percent of total (4th column of Table 7) of eroding bank in each BEHI/NBS category (2nd column). For the example in Table 7, there are four BEHI/NBS categories present: Low/Low, Low/Mod, Mod/High, and High/High. The dominant BEHI/NBS category is High/High since that score describes 48% of the eroding banks.

The dominant BEHI/NBS does not need to describe over 50% of the eroding banks, but rather is the category with the most bank length of the categories represented. If there is a tie between BEHI/NBS categories, the category representing the highest level of bank erosion should be selected.

The reference standards are based on the relationship developed for Colorado and North Carolina streams between erosion rates and BEHI/NBS scores (Harman et al., 2012). Table 8 shows the scoring associated with BEHI/NBS categories. Datasets for Tennessee were not available at the time this was published, and these reference standards are under review.

Table 8: BEHI/NBS Category Reference Standards

| Index | | Category |
|-------|---------------------|--------------------------------------|
| 0 | Not Functioning | Ex/Ex, Ex/VH |
| 0.1 | | Ex/H, VH/Ex, VH/VH, H/Ex, H/VH, M/Ex |
| 0.2 | | Ex/M, VH/H, H/H, M/VH |
| 0.3 | Functioning-At-Risk | Ex/L, VH/M, H/M, M/H, L/Ex |
| 0.4 | | Ex/VL, VH/L, H/L |
| 0.5 | | VH/VL, H/VL, M/M, L/VH |
| 0.6 | | M/L, L/H |
| 0.7 | Functioning | M/VL, L/M |
| 0.8 | | |
| 0.9 | | |
| 1 | | L/L, L/VL |

c. Percent Streambank Erosion

The percent streambank erosion is measured as the length of streambank that is actively eroding divided by the total length of bank (left and right) in the project reach. All banks with an erosion rate or BEHI/NBS score indicating that lateral stability is functioning-at-risk or not functioning (Table 8) should be considered as an eroding bank.

$$\text{Percent Streambank Erosion} = \frac{\text{Length of Eroding Bank}}{\text{Total length of Streambank in Reach}} * 100$$

The total length of stream bank is not equal to the stream length. Instead, the total length of bank is the sum of the left and right bank lengths, approximately twice the centerline stream length. In the example provided in Table 7 where the total length of bank was 1100 feet, the 96 feet of High/High and Mod/High categories would be considered eroding bank (12+22+31+31 from 3rd column in Table 7). Therefore, 96/1100 = 9% streambank erosion.

The reference standards for this measurement method are based on observations of impaired and reference condition streams using best professional judgement.

5.3.3. Riparian Vegetation

Riparian vegetation is a critical component of a healthy stream ecosystem. While riparian vegetation is a life form and could be included in the biology functional category, it directly effects channel stability (geomorphology) and supports denitrification and other water quality functions (physicochemical). Therefore, riparian vegetation is placed within the geomorphology functional category. The measurement methods in the TN SQT primarily measure the structure of riparian vegetation and the qualities of the buffer that support channel stability and function higher on the stream functions pyramid.

This parameter should be assessed for all projects. There are four measurement methods, which are assessed separately along the left and right stream bank/floodplain. The measurement methods include canopy coverage, basal area, stem density, and buffer width.

Buffer width and canopy coverage should be assessed for all projects. It is recommended to use either basal area or stem density to assess a restoration reach, not both. Selection guidance for basal area and stem density is provided below.

The Point-Centered Quarter method as described in Marcy (1988) will be used for sampling riparian vegetation. A minimum of 20 data points shall be collected along each side of the stream (between top of bank and the limits of the projects). The sampling points shall be randomly distributed across the sampling area.

a. Basal Area

Basal area is the cross-sectional area (ft²) of a tree at breast height (4.5 feet above ground) (Avery and Burkhart, 2002). Tree basal area is a measure of abundance in riparian forests that is proportional to tree biomass and floodplain roughness and is measured in representative sample plots. Detailed instructions on setting up sampling plots are provided in Marcy (1988). Measure the diameter at breast height (DBH) for all trees in each sampling plot (Figure 12). Trees are defined as woody stems, excluding vines, with a DBH equal to or greater than 3 inches and approximately 20 feet tall (USACE, 2012). Therefore, this method should only be used in forested riparian areas and not pastureland, cropland, or other land uses without trees. Compute the cross-sectional area (square feet) of the tree at DBH (measured in inches) using the following equation:



Figure 12. Measuring tree basal area.

Equation (7):
$$BA = 0.005454 * DBH^2$$

The measurement method for basal area is reported as the ratio of basal area per acre of riparian area (ft²/ac). This value should be calculated for each plot and then averaged to obtain a field value for the TN SQT.

Alternatively, the practitioner can use a wedge prism to estimate basal area as a rapid-based method. A 10 BAF (basal area factor of 10 ft²) wedge prism is recommended. Instructions for using a wedge prism are described in Avery & Burkhart (2002).

Reference standards are from *Guidance for Conserving and Restoring Old-Growth Forest Communities on National Forests in the Southern Region* (Gaines et al., 1997).

b. Stem Density

The stem density measurement method is common for stream mitigation projects; however, it is only recommended for sites where a new forest is being re-established and/or a basal area measurement is not practicable. Detailed instructions on setting up sampling plots are provided in Marcy (1988).

Reference standards are based on the compensatory mitigation reference standards that have been traditionally used within Tennessee. For purposes of this assessment, 300 stems per acre

is considered a reference standard at the end of a typical 7-year monitoring period for stream mitigation. Note that the maximum index score for this measurement method is 0.50 (functioning-at-risk), therefore the user cannot achieve a functioning score for this measurement method and the maximum parameter score would be 0.83.

c. Buffer Width

The riparian buffer width is measured horizontally from the top of the stream bank to the proposed conservation easement boundary, project limits, or edge of valley. Buffer width is measured perpendicular to the fall-line of the valley on the left and right sides of the channel. This measurement does not include the channel width. Measurements should be taken every 50 feet along the centerline length, and can be performed using recent orthoimagery; however, sufficient measurements need to be taken in the field to verify desktop measurements. An average buffer width is then calculated for the right and left side of the channel separately. Reference standards are based on the regulatory guidance for stream mitigation in Tennessee and meta-analysis findings published by Mayer et al. (2005).

d. Canopy Coverage

Canopy coverage is measured using a densiometer. For detail on how to use a densiometer refer to the device instructions or *Using Forest Densiometers* (Forestry Suppliers Inc., 2008). This measurement method is an assessment of riparian vegetation health rather than stream shading. Measurements should be taken within the riparian buffer rather than from the stream channel or on the stream banks.

At each sampling location, a canopy cover measurement is taken facing each of the four cardinal directions. These measurements are the number of dots (or 1/8" square corners of the squares etched in the densiometer) that are shaded by canopy cover. The count is averaged for each sampling location. The average canopy cover from all sampling locations is calculated for the left and right banks separately and are entered in the TN SQT as field values.

Reference standards are from a guidance document from the USFWS Chesapeake Bay Field Office (2013).

5.3.4. Bed Material Characterization

Bed material is an optional parameter assessed for projects in gravel bed streams with sandy banks where fining of the bed material is occurring due to bank erosion. Projects that implement lateral stability practices along a long project reach may be able to show a coarsening of the bed. Bed material is characterized using a Wolman Pebble Count procedure and the Size-Class Pebble Count Analyzer (v1).⁸

The following steps are required for the assessment reach and the reference reach. A reference reach for this measurement method is defined in Bevenger and King (1995). Read this paper carefully for a description of how to select and potentially combine reference reaches. Note, reference reach stratification may include Rosgen stream classification, catchment area, gradient, and lithology. When possible, pick reference reaches that are upstream of the project reach. For example, a stable C stream type with a forested watershed upstream of an unstable

⁸ www.fs.fed.us/biology/nsaec/assets/size-classpebblecountanalyzer2007.xls

C4 or Gc/F4 stream type is ideal for this analysis. If a reference reach cannot be located, this assessment cannot be completed. Be sure to document the location of reference and assessment reaches on a map.

Steps for Completing Field Assessment:

1. Download the Size-Class Pebble Count Analyzer and read the Introduction tab.
2. Read and complete the Sample Size worksheet. Note, keeping the sample size the same between the reference and project reach is recommended. At least 100 samples should be collected for both reaches. Keep the default values for Type I and Type II errors, which are 0.05 and 0.2 respectively. Set the study proportion to 0.25.
3. Complete a Representative Pebble Count using procedures described in Rosgen (2014). Note, only collect one bank sample every other transect per the instructions. This will ensure that bank material is not oversampled.
4. Enter the results for the reference and assessment reaches in the Data Input tab in the Size-Class Pebble Count Analyzer. Run the analyzer.
5. Review the contingency tables to determine if the assessment reach is statistically different from the reference condition for the 4mm and 8mm size classes. Depending on the size of gravel in your stream and the reference reach, change the size class if appropriate for your site.
6. The p-value from the contingency tables for the selected size class (typically either 4mm or 8mm) should be entered in as the field value for the existing condition assessment. A non-statistically significant value, such as 0.5, can be entered as the proposed condition assuming that the project will reduce the supply of fine sediment to the reach that is causing the fining.

A p-value of 0.05 is statistically significant and a p-value of 0.01 is highly statistically significant. Based on these values, reference standards for p-values associated with bed material characterization are provided in Table 9.

Table 9: Bed Material Characterization Reference Standards

| Index | | p-value |
|-------|---------------------|---------|
| 0 | Not Functioning | ≤0.01 |
| 0.29 | | 0.05 |
| 0.3 | Functioning-At-Risk | 0.06 |
| 0.69 | | 0.10 |
| 0.7 | Functioning | - |
| 1 | | >0.10 |

5.3.5. Bed Form Diversity

Bed forms include riffles, runs, pools and glides. Together, these bed features create important habitats for aquatic life. The location, stability, and depth of these bed features are symptomatic of sediment transport processes acting against the channel boundary conditions. Therefore, if the bed forms are representative of a reference condition it can be assumed that the sediment transport processes are functioning as well.

There are four measurement methods for this parameter: pool spacing ratio, pool depth ratio, percent riffle, and aggradation ratio. The first three should be used for all projects and are described below, including rapid and detailed methods. These bed form diversity measurement methods should all be assessed for a length that is at least 20 times the bankfull width (two meander wavelengths for meandering streams is preferable) or the entire reach length, using whichever is shorter (Harrelson et al., 1994). As knowing what constitutes a 'pool' is an integral part of this function-based parameter, guidance in identifying pools in different valley types is given below.

Aggradation ratio is optional for those projects where symptoms of aggradation are present, such as mid-channel or transverse bars. Rapid and detailed methods are described below.

Identifying Pools in Alluvial-Valley Streams

For use with the TN SQT, pools are only counted if they are geomorphically significant, large, and relatively permanent. In reference alluvial systems, this consists of pools located along the outside of meander bends and pools downstream of large, relatively stable flow obstructions such as steps formed by large trees or boulders. Small, temporary depressions within riffles are not counted. In determining whether a pool should be counted, it is important to consider where the pool is located and whether the feature is providing energy dissipation or just micro habitat. Large pools providing energy dissipation are counted, but micro pools providing habitat are not. Pools should be noticeably deeper than riffle features and, at low flow, the water surface slope of the pool should be lower than the riffle water surface slope.

Compound pools that are not separated by a riffle within the same bend are treated as one pool. The deeper of the compound pools is used for measuring spacing. Compound bends with two pools separated by a riffle are treated as two pools. Rosgen (2014) provides illustrations for these scenarios.

Figure 13 provides an illustration of what is and is not counted as a pool. The X marks the approximate location of the deepest part of the pool. The small, temporary depressions or scour areas associated with the boulder clusters in the riffle are not counted as the water surface slope does not change across these small depressions. The scour pool downstream of the large woody debris shown in the figure is counted as it is large enough to change the water surface slope within the straight section that would typically be a riffle.

Identifying Pools in Colluvial and V-Shaped Valleys

Pools in colluvial or v-shaped valleys should only be counted if they are downstream of a step or riffle/cascade. Small, temporary pools within a riffle or cascade are not counted, similar to the previous section. An example of pool spacing in a colluvial or v-shaped valley is shown in Figure 14. For these bed forms, pools are only counted at the downstream end of the cascade. Micro-pools within the cascade are not included.

Figure 13: Pool Spacing in Alluvial Valley Streams (X marks the Dmax location of pools counted for pool spacing)

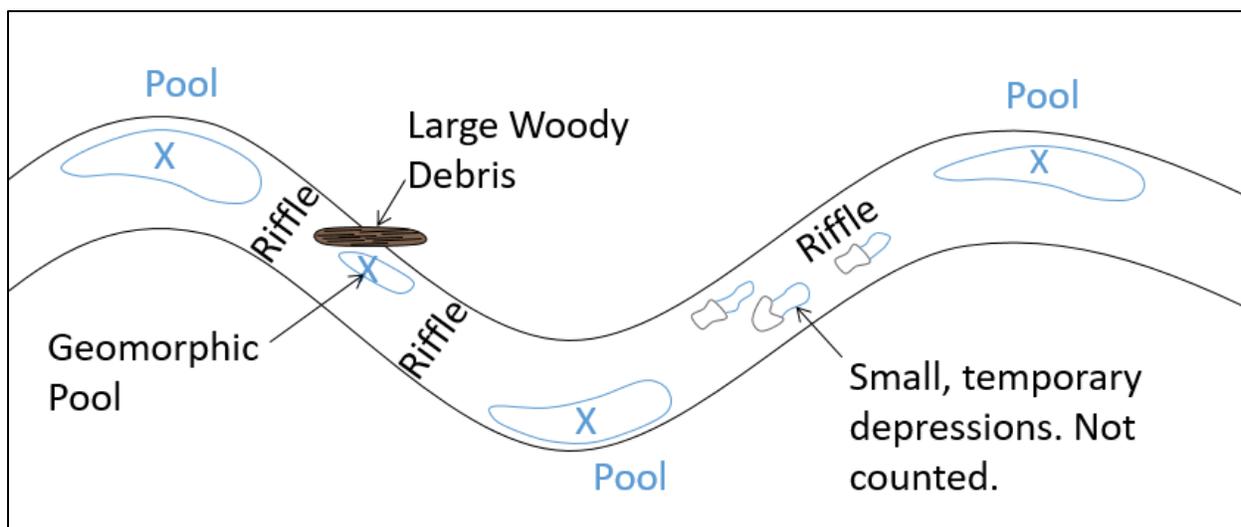
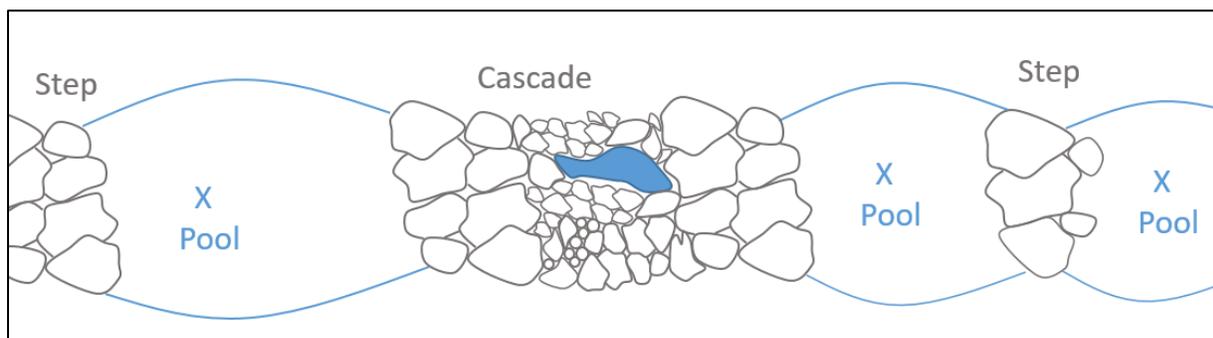


Figure 14: Pool Spacing in Colluvial and V-Shaped Valleys (X marks the Dmax location of pools counted for pool spacing)



a. Pool Spacing Ratio

The pool spacing ratio is the calculation of the pool spacing divided by the bankfull riffle width (Equation 8). The bankfull riffle width is from one stable riffle cross section rather than measured at each riffle. The stable riffle criteria are described in section 4.2 of this manual, dimensions from a stable riffle are used in this ratio in order to quantify the departure from a stable condition. In a meandering stream, pool spacing is only recorded between pools that occur within meander bends.

Equation (8)

$$P - P \text{ Spacing Ratio} = \frac{\text{Distance between sequential pools}}{\text{Bankful Width}}$$

The pool spacing ratio is calculated for each pair of sequential pools in the assessment reach. While the range of pool spacing ratios observed at a site should be assessed, the field value entered in the TN SQT is the median value based on at least three pool spacing measurements.

In a meandering stream, a moderate ratio is preferred over a very low or very high ratio. In other words, having too many pools or too many riffles can be detrimental to channel stability and geomorphic function. In steeper gradient systems, the frequency of pools often increases with slope. Channel stability concerns are greater with higher ratios. Reference standards are stratified by stream type and bed material. Reference standards were developed based on data collected throughout Tennessee and available through the TDEC publications *Morphological Stream Design and Assessment Tools*.⁹

Detailed Method

For the detailed method, pool-to-pool spacing is measured from the longitudinal profile as the distance between the deepest point of two pools. Harrelson et al. (1994) provides detailed methods on how to survey a cross section.

Rapid Method

For the rapid-based assessment, a tape is laid along the stream centerline or bank and the stations for the deepest point of each pool within the assessment reach are recorded in the field and used to calculate the pool-to-pool spacing. A stable riffle is selected from within the sampling reach and the bankfull width of this stable riffle is measured with a tape and recorded to calculate the pool-to-pool spacing ratio for each pair of pools using Equation (8).

b. Pool Depth Ratio

The pool depth ratio is calculated by dividing the maximum bankfull pool depth by the mean bankfull riffle depth. The mean bankfull riffle depth is from a stable riffle cross section rather than measured at each riffle. The stable riffle criteria are described in section 4.2 of this manual, dimensions from a stable riffle are used in this ratio in order to quantify the departure from a stable condition. The pool depth ratio is a measure of pool quality with deeper pools scored higher than shallow pools. The pool depth ratio is an important compliment to the pool spacing ratio; the combination of the two provides information about the proper frequency and depth of pool habitats. However, they do not provide information about the lengths of these features, which are assessed using the percent riffle measure (see below).

Equation (9)

$$\text{Pool Depth Ratio} = \frac{D_{\text{max pool}}}{D_{\text{mean riffle}}}$$

The pool depth ratio is calculated for each pool in the assessment reach. The minimum, maximum, and average values are then calculated. However, only the average value is used in the TN SQT. The detailed and rapid methods of field data collection are provided below.

Reference standards are stratified by stream type and bed material. Reference standards were developed based on data collected throughout Tennessee.

⁹ Data available by ecoregion in the Regional Curve reports: <http://www.tn.gov/environment/article/permit-water-arap-compensatory-mitigation>

Detailed Method

For the detailed assessment method, the pool depth is measured from a longitudinal profile of the stream thalweg as the elevation difference between the deepest point of each pool and the bankfull elevation. Instructions for measuring a longitudinal profile and cross sections are provided by Harrelson et al. (1994).

Rapid Method

The rapid-based assessment requires that the maximum bankfull depth of each pool in the reach be recorded. A stable riffle is then selected from within the reach. The mean bankfull depth is calculated as the average of multiple depth measurements across the cross section. Equation (9) is used to calculate the pool depth ratio of each pool within the assessment reach.

For very coarse, rapid assessments, simply measure the max pool depth from the baseflow elevation to the channel bottom. Then, add this value to the previously established difference between the water surface and the bankfull stage. This will provide the pool max depth estimate. Then, divide this value by the mean depth measured at the riffle cross section.

c. Percent Riffle

The percent riffle is the total length of riffles within the assessment reach divided by the total assessment stream length. Riffle length is measured from the head (beginning) of the riffle downstream to the head of the pool. Run features are included within the riffle length. Calculating the percent of pool features is optional and reference standards are not provided. However, if practitioners choose to calculate percent pool, the glide features should be included in the percent pool calculation.

Reference standards are stratified by stream type and bed material. Reference standards were developed based on data collected throughout Tennessee and available through the TDEC publications *Morphological Stream Design and Assessment Tools*.¹⁰

Detailed Method

For the detailed assessment method, the percent riffle is measured from a longitudinal profile of the stream thalweg. Instructions for surveying a longitudinal profile are provided by Harrelson et al. (1994).

Rapid Method

For the rapid-based assessment, a tape is laid along the stream centerline or bank and the stations at the beginning of each riffle and end of each run within the assessment reach is recorded in the field and used to calculate the individual riffle lengths.

d. Aggradation Ratio

Channel instability can result from excessive deposition that causes channel widening, lateral instability, and bed aggradation. Visual indicators of aggradation include mid-channel bars and bank erosion within riffle sections. The aggradation ratio is the bankfull width at the widest riffle

¹⁰ Data available by ecoregion in the Regional Curve reports:
<http://www.tn.gov/environment/article/permit-water-arap-compensatory-mitigation>

within the assessment reach divided by the mean bankfull riffle depth at that riffle. This ratio is then divided by a reference width to depth ratio (WDR) based on stream type (Equation 10; Table 10). This measurement method will be used mainly for C and E stream types, but could also apply to some Bc and B stream types.

Equation (10)

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

Table 10: Reference Bankfull WDR Values by Stream Type

| Stream Type | Reference WDR |
|-------------|---------------|
| B | 16 |
| C | 13 |
| E | 9 |

Reference standards are based on WDR stability ratings from (Rosgen, 2014).

Detailed Method

For the detailed method, complete a cross sectional survey at the widest riffle in the assessment reach, and use the width and mean depth calculations to determine the study riffle WDR. Then, divide the study WDR ratio by a reference WDR ratio given in Table 9.

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 project reach.

Rapid Method

For the rapid-based assessment, measure the widest bankfull riffle width and estimate the mean depth as the difference between the edge of channel and the bankfull stage. Use these calculations to determine the study riffle WDR. Then, divide the study WDR ratio by a reference WDR ratio, as given in Table 9.

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 project reach.

5.3.6. Plan Form

The plan form parameter is assessed using the sinuosity measurement method. Plan form should be assessed for all projects located in alluvial valleys with Rosgen C and E stream types. This parameter is optional for B stream types to ensure that practitioners do not propose sinuosity values that are too high.

The sinuosity of a stream is calculated by dividing the stream centerline distance by the straight-line valley length between two common points. These distances can be measured in the field or

using orthoimagery¹¹ in the office. Sinuosity calculations are described in more detail in Rosgen (2014).¹² Sinuosity should be assessed over a length that is 40 times the bankfull width (Rosgen, 2014).

The rapid way to measure sinuosity is from recent orthoimagery if it is available. If recent orthoimagery is not available, or the stream channel is not visible in the imagery, then sinuosity must be measured in the field. Field measurements of sinuosity are best accomplished using a GPS unit to map the stream centerline along a length that is at least 40 times the bankfull width. The stream length and valley length can then be measured in the office using the GPS data and then used to calculate sinuosity and enter the value in the TN SQT. As this method does not require the lengths to be measured in the field, no space is provided for this alternative on the field form.

Reference standards are primarily stratified by valley type but E type stream channels with sandy beds have their own reference standards. Reference standards are based on stream type classification, reference data and best professional judgement.

5.4. Physicochemical

The TN SQT contains five function-based parameters to describe the temperature and oxygen regulation; processing of organic matter and nutrients within a stream reach: temperature, bacteria, organic carbon, nitrogen and phosphorus. Few projects will enter values for all physicochemical parameters; refer to section 3.3 of the *Spreadsheet User Manual* for guidance on selecting parameters for a stream restoration project.

5.4.1. Bacteria

E. Coli is an indicator of the presence of pathogens in excessive amounts in some streams and can be a serious risk to human and animal health. Practitioners should measure and report bacteria, nitrate/nitrite and total phosphorus for lift through physicochemical. When livestock have free access to streams or pastureland with limited riparian buffer, manure can be deposited in the channel or washed in during a runoff event.

E. Coli will be measured by a laboratory. Practitioners will be required to follow the TDEC Quality System Standard Operating Procedure for Chemical and Bacteriological Sampling of Surface Water (TDEC, 2011). The field value entered in the TN SQT will be the geometric mean of five consecutive samples examined during any 30-day period within the growing season. Samples should not be collected during or immediately after a rain event.

For any project quantifying lift, the existing condition will need to be measured. For a rapid assessment during site selection, the existing conditions could be characterized using recent sampling data if available.¹³ These data should be reviewed for the project reaches or surrounding water bodies to determine whether bacteria levels are functioning, functioning-at-risk or not functioning for each reach. Data from sites outside of the project reach should be

¹¹ Aerial imagery available from: <http://www.tngis.org/imagery-orthophotos.htm>

¹² Guidance on calculating sinuosity also available from: https://nctc.fws.gov/courses/CSP/CSP3200/resources/documents/Geometry_AFG2013.pdf

¹³ http://environment-online.tn.gov:8080/pls/enf_reports/f?p=9034:34510:::

presented with discussion and justification of the assumptions made in interpreting the available data to score the project reach.

The reference standards for this measurement method are based on TN water quality standards for recreation (TDEC, 2016).

5.4.2. Organic Enrichment

The percentage of nutrient-tolerant macroinvertebrates may be assessed for projects where overall nutrient loadings and organic enrichment are expected to be improved by restoration activities, including mitigation of non-point source loadings. Direct measurements of nitrate/nitrite and/or phosphorus may be more appropriate if project goals include mitigating a known point source (including contaminated stormwater), or when biological monitoring is not otherwise being proposed for the project, or is not appropriate due to other factors such as stream size, habitat, or flow regime.

This measurement method is a component of the SQSH survey methodology found within the *Quality System Standard Operating Procedure (QSSOP) for Macroinvertebrate Stream Surveys* (2017) from TDEC. The collection, sorting, taxonomy and data reduction must be completed by a qualified biologist and follow the protocols outlined in the QSSOP exactly. This protocol is semi-qualitative and use kick nets or sweep nets, and the target habitat type is dependent on the ecoregion, drainage area, and stream type in which the stream is located. Specimens are collected, preserved in the field and identified in the laboratory. Care must be taken to note the location and data collection season when collecting benthic insect data.

For any project quantifying lift, the existing condition will need to be measured in addition to the post-construction condition. The reference standards for this measurement method are based on the individual metric ranges established by TDEC (TDEC, 2017).

5.4.3. Nitrogen

The concentration of Nitrate-Nitrite may be assessed for projects where nitrogen levels are expected to be improved by restoration activities, such as stormwater BMPs adjacent to the stream restoration project or other point source reductions. Practitioners should measure and report bacteria, nitrate/nitrite and total phosphorus for lift through physicochemical. Nitrate-Nitrite will be measured by a laboratory using EPA approved methods. Practitioners will be required to follow the TDEC Quality System Standard Operating Procedure for Chemical and Bacteriological Sampling of Surface Water (TDEC, 2011). For any project quantifying lift, the existing condition will need to be measured in addition to the post-construction condition. For a rapid assessment during site selection, the existing conditions could be characterized using existing sampling data if available.¹⁴ These data should be reviewed for the project reaches or surrounding water bodies to determine whether nitrogen is functioning, functioning-at-risk or not functioning for each reach. Data from sites outside of the project reach should be presented with discussion and justification of the assumptions made in interpreting the available data to score the project reach.

¹⁴ <http://tdeconline.tn.gov/dwr/>

Direct measurements of nitrate/nitrite and/or total phosphorus may be more appropriate than organic enrichment if project goals include mitigating a known point source (including contaminated stormwater), or when biological monitoring is not otherwise being proposed for the project, or is not appropriate due to other factors such as stream size or flow regime.

Reference standards for this measurement method were developed using data collected throughout the state on reference and non-reference streams. And are based on regional interpretations of narrative nutrient criteria (Denton et al, 2001).

5.4.4. Phosphorus

The concentration of Total Phosphorous may be assessed for projects where phosphorous levels are expected to be improved by restoration activities, such as stormwater BMPs adjacent to the stream restoration project or other point source reductions. Practitioners should measure and report bacteria, nitrate/nitrite and total phosphorus for lift through physicochemical. Total Phosphorus will be measured by a laboratory using EPA approved methods. Practitioners will be required to follow the TDEC Quality System Standard Operating Procedure for Chemical and Bacteriological Sampling of Surface Water (TDEC, 2011). For any project quantifying lift, the existing condition will need to be measured in addition to the post-construction condition. For a rapid assessment during site selection, the existing conditions could be characterized using existing sampling data if available.¹⁵ These data should be reviewed for the project reaches or surrounding water bodies to determine whether phosphorus is functioning, functioning-at-risk or not functioning for each reach. Data from sites outside of the project reach should be presented with discussion and justification of the assumptions made in interpreting the available data to score the project reach.

Reference standards for this measurement method were developed using data collected throughout the state on reference and non-reference streams. And are based on regional interpretations of narrative nutrient criteria (Denton et al, 2001).

5.5. Biology

The TN SQT contains two function-based parameters to evaluate the biodiversity and ecological integrity of aquatic life: macroinvertebrates and fish community structure. The macroinvertebrate bioclassification is a common metric applied throughout the state for determining the biological integrity and use support of a stream.

Where appropriate, both macroinvertebrates and fish should be assessed. The standard macroinvertebrate survey methodology for Tennessee is a single-habitat method, therefore fish surveys may provide additional information on functional lift provided by all aspects of instream habitat improvements. However, smaller streams may not have enough fish community biodiversity to allow for a meaningful index of biotic integrity (IBI) analysis. For a stream reach that is riffle dominated, yet scoring poorly in other aspects of bed form diversity, the macroinvertebrate Semi-Quantitative Single Habitat (SQSH) survey could score well since this habitat is present, while additional habitat for fish is missing. In this case, if macroinvertebrates are the only parameter assessed in the biology functional category then the TN SQT would

¹⁵ <http://tdeconline.tn.gov/dwr/>

indicate the biology functional category is functioning. If fish communities were also assessed, the biology functional category could more appropriately score as functioning-at-risk.

5.5.1. Macroinvertebrates

Macroinvertebrates are an integral part of the food chain that supports healthy aquatic ecosystems. There are four measurement methods for macroinvertebrates included in the TN SQT, all are components of the SQSH survey methodology found within the *Quality System Standard Operating Procedure (QSSOP) for Macroinvertebrate Stream Surveys* (2017) from TDEC. This protocol is semi-qualitative and use kick nets or dip nets, and the target habitat type is dependent on the stream type and ecoregion in which the stream 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 the QSSOP exactly. Care must be taken to note the ecoregion, drainage area and data collection season when collecting benthic insect data. The user should coordinate with the IRT to determine whether the Tennessee Macroinvertebrate Index (TMI) or the suite of three alternative measurement methods should be used. The suite of three consists of percent clingers - Cheumatopsyche, percent EPT- Cheumatopsyche, and percent Oligochaeta and Chironomidae. If the TMI is not used, then these three measurement methods should be used together.

For any project quantifying lift, the existing condition will need to be measured. For a rapid assessment during site selection, the existing conditions could be characterized using recent sampling data if available.¹⁶ These data should be reviewed for the project reaches or surrounding water bodies to determine whether macroinvertebrate communities are functioning, functioning-at-risk or not functioning for each reach. Data from sites outside of the project reach should be presented with discussion and justification of the assumptions made in interpreting the available data to score the project reach.

The reference standards for this measurement method are based on the individual metric ranges established by TDEC (TDEC, 2017).

5.5.2. Fish

Fish are an integral part of the food chain that supports healthy perennial river ecosystems. There are two measurement methods for fish included in the TN SQT: native fish score index and catch per unit effort (CPUE) score. Both of these metrics are a part of calculations for an index of biotic integrity (IBI) developed by Karr (1981) and Angermeier and Karr (1986) as implemented by Tennessee Valley Authority (TVA). Users must coordinate with the IRT to coordinate sampling procedures and determine IBI criteria to serve as reference standards for the stream restoration project. IBI scoring for fish communities developed by TVA and Tennessee Wildlife Resources Agency are available for many ecoregions in the state, but not all. If none are available in a given subregion, contact the IRT for assistance in choosing applicable criteria.

¹⁶ http://environment-online.tn.gov:8080/pls/enf_reports/f?p=9034:34510:::

An example of scoring criteria developed from Davis Creek in Campbell County are presented in that figure below.

Figure 15: Example Scoring Criteria for the Fish Measurement Methods

| Index of Biotic Integrity scoring, on fish collected from Davis Creek, Campbell Co., Habersham Road, upstream of old RR trestle, August 30, 2011. N36.49560/W84.06150 (drainage area app 15 sq. miles) | | | | | |
|--|------------------|-------|-----|----------|-------|
| Metric Description | Scoring Criteria | | | Observed | Score |
| | 1 | 3 | 5 | | |
| Total number of native fish | <6 | 6-12 | >12 | 15 | 5 |
| CPUE (Catch per unit effort) | <16 | 16-32 | >32 | 26.94 | 3 |

Note that fish communities in small streams typically chosen for restoration may be limited. For any project quantifying lift, the existing condition will need to be measured. For a rapid assessment during site selection, the existing conditions could be characterized using recent sampling data if available.¹⁷ These data should be reviewed for the project reaches or surrounding water bodies to determine whether fish communities are functioning, functioning-at-risk or not functioning for each reach. Data from sites outside of the project reach should be presented with discussion and justification of the assumptions made in interpreting the available data to score the project reach.

There are only three possible field values for these measurement methods and the reference standards are shown in the Table below. These reference standards are not included in the Reference Standards worksheet of the TN SQT since no plot is necessary to score these field values.

Table 11: Reference Standards for Fish Measurement Methods

| Field Value | Index Value |
|-------------|-------------|
| 1 | 0.15 |
| 3 | 0.50 |
| 5 | 0.85 |

6. References

- Al-Hamdan, O.Z., F.B. Pierson, M.A. Nearing, C.J. Williams, J.J. Stone, P.R. Kormos, J. Boll, and M.A. Weltz, 2013. Risk Assessment of Erosion from Concentrated Flow on Rangelands Using Overland Flow Distribution and Shear Stress Partitioning. American Society of Agricultural and Biological Engineers ISSN 2151-0032.
- Angermeier, P. L., and J. R. Karr, 1986. Applying an Index of Biotic Integrity Based on Stream-Fish Communities: Considerations in Sampling and Interpretation. North American Journal of Fisheries Management 6: 418-429.
- Avery, T. and H. Burkhart, 2002. *Forest Measurements Fifth Edition*, Waveland Press, Inc., Long Grove, Illinois.
- Bevenger, G.S. and R.M. King, 1995. A Pebble Count Procedure for Assessing Watershed Cumulative Effects. Research Paper RM-RP-319. US Department of Agriculture Forest Service Research Paper RM-RP-319. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.
- Blakely, T.J., Harding, J. S., McIntosh, A.R. and Winterbourn, M.J. (2006), Barriers to the recovery of aquatic insect communities in urban streams. *Freshwater Biology*, 51: 1634–1645. doi:10.1111/j.1365-2427.2006.01601.x
- Davis, J.C., G.W. Minshall, C.T. Robinson, and P. Landres, 2001. Monitoring Wilderness Stream Ecosystems. General Technical Report RMRS-GTR-70. US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, Colorado.
- Denton, G.M., D.H. Arnwine and S.H. Wang. 2001. *Development of Regionally-Based Interpretations of Tennessee's Narrative Nutrient Criterion*. Tennessee Department of Environment and Conservation, Division of Water Pollution Control. Nashville, TN.
- Duiker, S.W. 2002. Diagnosing Soil Compaction Using a Penetrometer (Soil Compaction Tester). Pennsylvania State University, College of Agricultural Sciences, Agricultural Research and Cooperative Extension. Available from: http://extension.psu.edu/plants/crops/soil-management/soil-compaction/diagnosing-soil-compaction-using-a-penetrometer/extension_publication_file
- Duiker, S.W. 2004. Effects of Soil Compaction. Pennsylvania State University, College of Agricultural Sciences, Agricultural Research and Cooperative Extension. Available from: http://extension.psu.edu/plants/crops/soil-management/soil-compaction/effects-of-soil-compaction/extension_publication_file
- Fischenich, J.C. 2006. Functional Objectives for Stream Restoration. Vicksburg, M.S. U.S. Army Engineer Research and Development Center. EMRRP Technical Notes Collection, ERDC TN-EMRRP-SR-52.
- Forestry Suppliers, Inc., 2008. Using Forest Densimeters. Jackson, Mississippi. http://www.forestry-suppliers.com/Documents/1450_msds.pdf

- Gaines, G., P. Arndt, S. Croy, M. Devall, C. Greenberg, S. Hooks, B. Martin, S. Neal, G. Pierson, and D. Wilson, 1997. Guidance for Conserving and Restoring Old-Growth Forest Communities on National Forests in the Southern Region. US Department of Agriculture Forestry Service. http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5212346.pdf
- Harman, W.A. and C.J. Jones. 2017. North Carolina Stream Quantification Tool: Spreadsheet User Manual, NC SQT v3.0. Environmental Defense Fund, Raleigh, NC.
- Harman, W., R. Starr, M. Carter, K. Tweedy, M. Clemmons, K. Suggs, C. Miller. 2012, A Function-Based Framework for Stream Assessment and Restoration Projects. US Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Washington, DC EPA 843-K-12-006.
- Harrelson, C.C., C.L. Rawlins, and J.P. Potyondy, 1994. Stream Channel Reference Sites: An Illustrated Guide to Field Technique. General Technical Report RMRS-GTR-245. US Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.
- Hughes, J.M., 2007. Constraints on recovery: using molecular methods to study connectivity of aquatic biota in rivers and streams. *Freshwater Biology*, 52: 616–631. doi:10.1111/j.1365-2427.2006.01722.x
- Karr, J. R., 1981. Assessment of Biotic Integrity Using Fish Communities. *Fisheries* (Bethesda) 6(6):21-27.
- Lake, P., N. Bond and P. Reich, 2007. Linking ecological theory with stream restoration. *Freshwater Biology*, 52: 597–615. doi:10.1111/j.1365-2427.2006.01709.x
- Leopold, L.B., 1994. *A View of the River*. Harvard University Press, Harvard University, Cambridge, MA.
- Marcy, L.E., 1988. "Distance Sampling Techniques: Section 6. 2. 2, US Army Corps of Engineers Wildlife Resources Management Manual," Technical Report EL-88- 23, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.
- Mayer, P.M., S.K. Reynolds, M.D. McCutchen, and T.J. Canfield, 2006. Riparian Buffer Width, Vegetative Cover, and Nitrogen Removal Effectiveness: A Review of Current Science and Regulations. US Environmental Protection Agency EPA/600/R-05/118, Washington, DC.
- Natural Resources Conservation Service (NRCS), 1986. Urban Hydrology for Small Watersheds Technical Release No. 55. United States Department of Agriculture Natural Resources Conservation Service, Conservation Engineering Division, Washington, DC. <http://www.wcc.nrcs.usda.gov/water/quality/common/tr55/tr55.pdf>
- NRCS, 1999. Soil Quality Test Kit Guide. U.S. Department of Agriculture, NRCS, Soil Quality Institute. Available from: http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044790.pdf
- NRCS. 2003. Soil Quality – Agronomy Technical Note No. 17. Soil Compaction: Detection, Prevention and Alleviation. U.S. Department of Agriculture, NRCS, Soil Quality Institute,

Auburn, AL. Available from:

https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_053258.pdf

NRCS, 2008. Soil Quality Indicators Bulk Density. U.S. Department of Agriculture NRCS. Washington D.C. http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_053256.pdf

Potyondy, J. and K. Bunte, 2007. Size-Class Pebble Count Analyzer v1 2001, updated September 2007. US Forest Service. <http://www.stream.fs.fed.us/publications/software.html>

Rosgen, D.L., 1996. *Applied River Morphology*, Wildland Hydrology Books, Pagosa Springs, Colorado.

Rosgen, D.L., 2006. *Watershed Assessment of River Stability and Sediment Supply (WARSSS)*, Wildland Hydrology Books, Fort Collins, Colorado.

Rosgen, D.L., 2014. *River Stability Field Guide, Second Edition*. Wildlands Hydrology Books, Fort Collins, Colorado.

Schueler, T., L. Fraley-McNeal and K. Capiella, 2009. Is Impervious Cover Still Important? Review of Recent Research. *Journal Hydrologic Engineering*, 14: 309-315.

Stoddard, J.L., D.P. Larsen, C.P. Hawkins, R.K. Johnson, and R.H. Norris, 2006. Setting Expectation for the Ecological Condition of Streams: The Concept of Reference Condition. *Ecological Applications*, 16(4): 1267-1276.

Sundermann, A., S. Stoll, and P. Haase. 2011. River restoration success depends on the species pool of the immediate surroundings. *Ecological Applications*, 21: 1962–1971. doi:10.1890/10-0607.1

Tennessee Department of Environment and Conservation (TDEC), 2011. Quality System Standard Operating Procedure for Chemical and Bacteriological Sampling of Surface Water. Tennessee Department of Environment and Conservation Division of Water Pollution Control, Nashville, Tennessee.

TDEC, 2017. Quality System Standard Operating Procedure for Macroinvertebrate Stream Surveys. Tennessee Department of Environment and Conservation Division of Water Pollution Control, Nashville, Tennessee.

TDEC, 2016. Final QAPP for 106 Surface Water Monitoring in the Division of Water Resources Volume I, Version 11. Tennessee Department of Environment and Conservation Quality Management Program, Nashville, Tennessee.

Tonkin, J. D., S. Stoll, A. Sundermann and P. Haase, P. 2014. Dispersal distance and the pool of taxa, but not barriers, determine the colonisation of restored river reaches by benthic invertebrates. *Freshwater Biology*, 59: 1843–1855. doi:10.1111/fwb.12387

USACE, 2012. Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Eastern Mountains and Piedmont Region (Version 2.0). ERDC/EL TR-12-9

USEPA, 2017. 2017 Preliminary Healthy Watershed Assessment for Tennessee. U.S. Environmental Protection Agency, Washington DC. Accessed on November 20, 2017: <https://www.epa.gov/hwp/2017-preliminary-healthy-watersheds-assessments-files>

US Fish and Wildlife Service (USFWS) Chesapeake Bay Field Office, 2013. Riparian Buffer Vegetation Evaluation Methods. Available from <http://stream-mechanics.com/wp-content/uploads/2012/01/Riparian-Vegetation.pdf>

Xian, G., C. Homer, J. Dewitz, J. Fry, N. Hossain, and J. Wickham. 2011. Change of Impervious Surface Area Between 2001 and 2006 in the Conterminous United States. *Photogrammetric Engineering and Remote Sensing*. 77(8): 758 – 762.

Young, R.G., C.D. Mattaei, and C.R. Townsend, 2008. Organic matter breakdown and ecosystem metabolism: functional indicators for assessing river ecosystem health. *Journal of the North American Benthological Society*, 27(3): 605-625.
<http://www.bioone.org/doi/abs/10.1899/07-121.1>