North Carolina Stream Quantification Tool

Data Collection and Analysis Manual

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NC SQT v3.0

September 2017

Acknowledgements

The NC Stream Quantification Tool (SQT) is the collaborative result of many scientists, engineers, and resource managers. The Data Collection and Analysis Manual was funded by the Environmental Defense Fund with project management support from Will McDow and Paxton Ramsdell. Special thanks to Dave Penrose for writing the section on organic matter processing and Tom Barrett for reviewing and contributing to the section on riparian vegetation. Periann Russell, Greg Melia, Laura Burckhardt, and Amy James improved the quality and readability of the document with their valuable review comments and edits.

Citation:

Harman, W.A. and C.J. Jones. 2017. North Carolina Stream Quantification Tool: Data Collection and Analysis Manual, NC SQT v3.0. Environmental Defense Fund, Raleigh, NC.

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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

ER – Entrenchment Ratio

F – Functioning

FAR – Functioning-At-Risk

FFS – Functional Foot Score

JFSLAT – Jordan/Falls Lake Stormwater Nutrient Load Accounting Tool

LWD – Large Woody Debris

NC – North Carolina

NCAC – North Carolina Administrative Code

NC DEQ – North Carolina Department of Environmental Quality

NCIBI – North Carolina Index of Biotic Integrity

NF – Not Functioning

NPDES – National Pollutant Discharge Elimination System

PCS – Proposed Condition Score

SFPF – Stream Function Pyramid Framework

SQT –Stream functional lift Quantification Tool

TMDL – Total Maximum Daily Load

TN – Total Nitrogen

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) – Defined by state administrative code rule 02 NCAC 60C.0102 (4) as "a practice, or combination of practices, that is determined to be an effective and practicable means of preventing or reducing the amount of pollution generated by nonpoint sources to a level compatible with water quality goals."

Catchment – Land area draining to the downstream end of 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

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)

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.

Performance Standard – Determines functional capacity of a measurement method using a 0.00 to 1.00 scale. Performance standards are stratified by functioning, functioning-at-risk, and not functioning. Measurement method performance standards are then averaged to create parameter performance standards.

Rapid Method – Collection of office and field techniques specific to the 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 Appendix B. 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.

Restoration Potential – Restoration potential is defined as the highest level (on the stream functions pyramid) of restoration that can be achieved based on the health of the catchment, the condition of the reach, and constraints caused by human activities.

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 performance standards.

1. Purpose and Background

The purpose of this document is to provide instruction on how to collect and analyze data needed by the Stream Quantification Tool (SQT). This manual covers how to determine reach breaks within a project, collect data for the Catchment Assessment, and collect and calculate field values for each measurement method in the reach condition assessments. Few measurements are unique to the 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 SQT.

The Stream Functions Pyramid Framework (SFPF) provides the scientific basis of the SQT. The SFPF is described in detail in *A Function-Based Framework for Stream Assessment and Restoration Projects*, published by the US Environmental Protection Agency and the US Fish and Wildlife Service (Harman et al., 2012). This manual assumes the reader has a basic knowledge of stream processes; therefore, it does not provide extensive definitions of terms such as bankfull, thalweg, riffle, etc.

This Data Collection and Analysis Manual supports and compliments the *North Carolina Stream Quantification Tool Spreadsheet User Manual* (Spreadsheet User Manual) and does not provide guidance on using the SQT or the supporting science for the performance standards. For background, purpose and uses of the quantification tool, see the Spreadsheet User Manual.

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

> SQT Manual Guide
>
> 1. Spreadsheet User Manual – *Rules and procedures for entering data into the Microsoft Excel Workbook.* (published December 2016)
>
> 2. Data Collection and Analysis Manual – *Provides instruction on how to collect and analyze data needed to run the SQT.* (This document)
>
> **Both manuals are available at stream-mechanics.com**

This version of the SQT and this Data Collection and Analysis Manual have been tailored for North Carolina. Additional versions of the SQT are being developed for other regions.

1.1. Downloading the Stream Quantification Tool and Supporting Information

The SQT and supporting documents can be downloaded from the Stream Mechanics web page (stream-mechanics.com). Select the Stream Functions Pyramid Framework tab.

NC Stream Quantification Tool – Includes the NC SQT spreadsheet, NC SQT Example, List of Metrics, Data Collection and Analysis Manual, Spreadsheet User Manual, Debit Tool White Paper, and SQT FAQ. The List of Metrics is a spreadsheet file that provides a comprehensive list of the function-based parameters with their measurement methods, performance standards, stratification methods, and references. The SQT and List of Metrics will be updated frequently, so users should check the web page before starting a new project to make sure they are using the latest version.

This page includes other resources like the Stream Functions Pyramid diagram, *A Function-Based Framework for Stream Assessment and Restoration Projects* (includes the science behind the SQT; Harman et al., 2012), a rapid assessment method, new function-based parameters with measurement methods and performance standards (not included in the Framework book), and Frequently Asked Questions. Additional versions of the SQT are being developed for other regions. The Wyoming SQT and its accompanying documents are available from this page as well. Other states will be posted as they are completed.

In addition, the Workshops tab provides a list of courses providing further education on the Stream Functions Pyramid Framework, the SQT, and other courses related to stream assessment and restoration.

2. Reach Segmentation and Catchment Assessment

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 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 SQT workbook), as stream condition or character can vary widely from the upstream end of a project to the downstream end.

While stream restoration is often performed on a reach scale, the restoration of a reach is affected by the upstream and sometimes downstream catchment condition. The SQT includes a Catchment Assessment worksheet that is used to determine the potential functional lift that restoration can achieve. It is determined primarily by assessing the catchment draining to the restoration site. The data collected in the Catchment Assessment will be similar or identical for separate reaches that are on the same stream. Restoration potential and the Catchment Assessment process are described after the Reach Segmentation section.

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 stream physical 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 project reaches 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 physical-based segmentation, a reach is first defined as a stream segment with similar 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 culvert removal reach may be short and a channelized stream 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 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 a lot of lift is generated from converting a pipe into a natural channel—probably much more lift than restoration efforts elsewhere along the stream. So, a culvert removal project would include three reach segments: upstream, through, and downstream of the culvert.

The following is an example showing how project reaches are identified based on physical observations. A large project site was selected and work was proposed on five streams (Figure 1). Reach breaks are described below, with the main-stem channel 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 SQT Excel Workbooks are required.

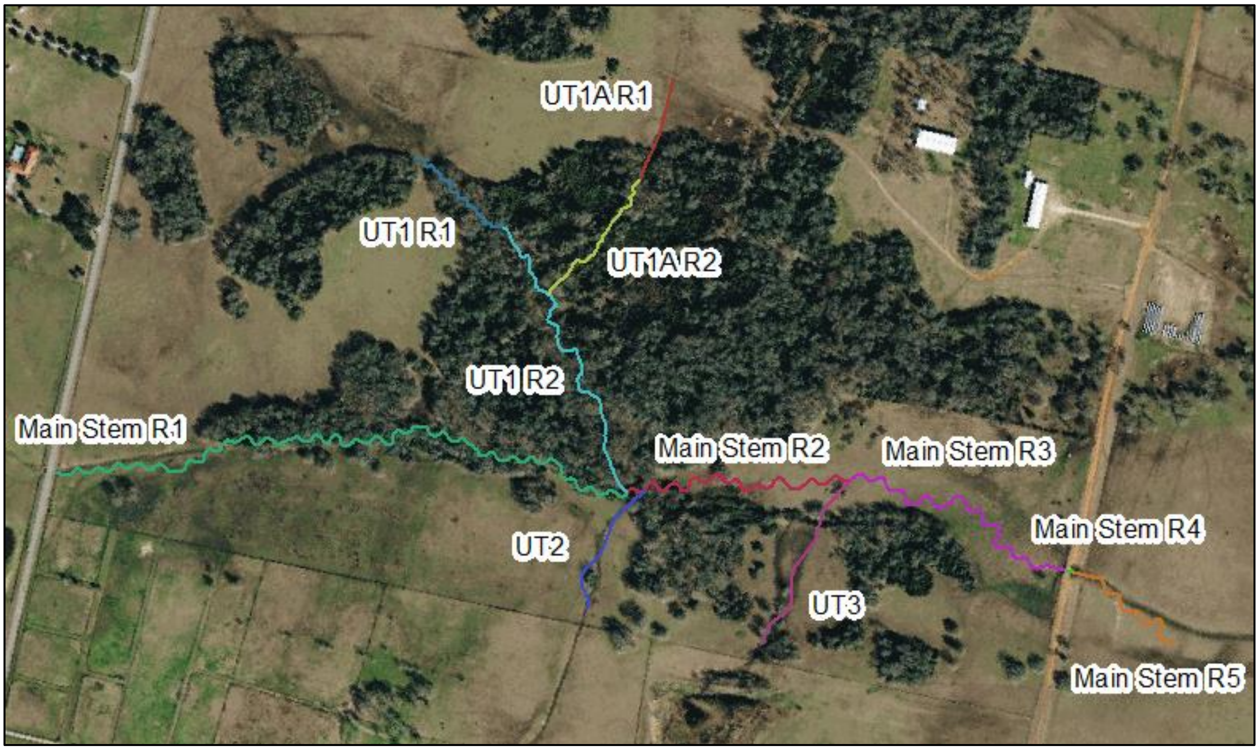
1. Main Stem:
    a. Reach 1 – Spans from the beginning of restoration work to just downstream of the UT1 confluence. This reach break is due to a 25% increase in drainage area at the confluence of UT1.
    b. Reach 2 – Spans from the UT1 confluence downstream to the UT3 confluence where there is a change in slope and substrate (see Reach 3 below). Even though UT2 enters the main stem within this reach, UT2 and UT3 are both small tributaries and increase the drainage area of the main stem by only 5%.

Therefore, the similarity of reach conditions above and below the UT2 confluence do not justify a reach break.

   c. Reach 3 – Spans from downstream of the UT3 confluence to a culvert that conveys the stream under an unimproved road. Flow within Reach 3 is very flat, backwatered by the culvert. As a result, this reach has finer bed material and less bed form diversity as compared to other reaches along the main stem.
   d. Reach 4 – Spans the 40 feet of stream through the culvert. The culvert is planned to be removed as part of the restoration. While short in length, the restoration potential of returning this piped section of channel to a natural state is expected to be high.
   e. Reach 5 – Spans from the downstream end of the culvert to the end of the restoration reach at the property boundary. Channel conditions throughout this reach are similar and no reach breaks are required.

2. UT1 – Tributary to Main Stem
   a. Reach 1 – Spans from the property boundary to downstream of the last in a series of headcuts. This reach consists of multiple headcuts formed by diffuse drainage off the surrounding agricultural fields and is slated for restoration as part of the project.
   b. Reach 2 – Spans from the end of UT1 R1 to the confluence of UT1 and the main stem channel. This reach will be enhanced as part of the project and is in better condition than UT1 R1; the riparian forest will be preserved and a lighter touch is planned. Even though UTA1 enters the stream within this reach, the reach conditions are consistent above and below the confluence and the drainage area of UT1 did not increase significantly.
3. UT1A – Tributary to UT1
   a. Reach 1 – Spans from the property boundary, where there is no riparian vegetation, to the point where bed form diversity improves and the channel has an established riparian forest. This reach consists of the degraded headwaters of a channel formed from concentrated flow off the agricultural fields upstream.
   b. Reach 2 – Spans from the end of UT1A R1 to the confluence of UT1A and UT1. This reach will be enhanced as part of the project and is in better condition than UT1A R1; the riparian forest will be preserved and a lighter touch is planned.
4. UT2 – Tributary to Main Stem
   a. Spans from the beginning of restoration work near the property boundary to the confluence with the main stem. This reach is actively downcutting and supplying sediment to the main stem.
5. UT3 – Tributary to Main Stem
   a. Spans from the beginning of restoration work near the property boundary to the confluence with the main stem. This reach is actively downcutting and supplying sediment to the main stem.

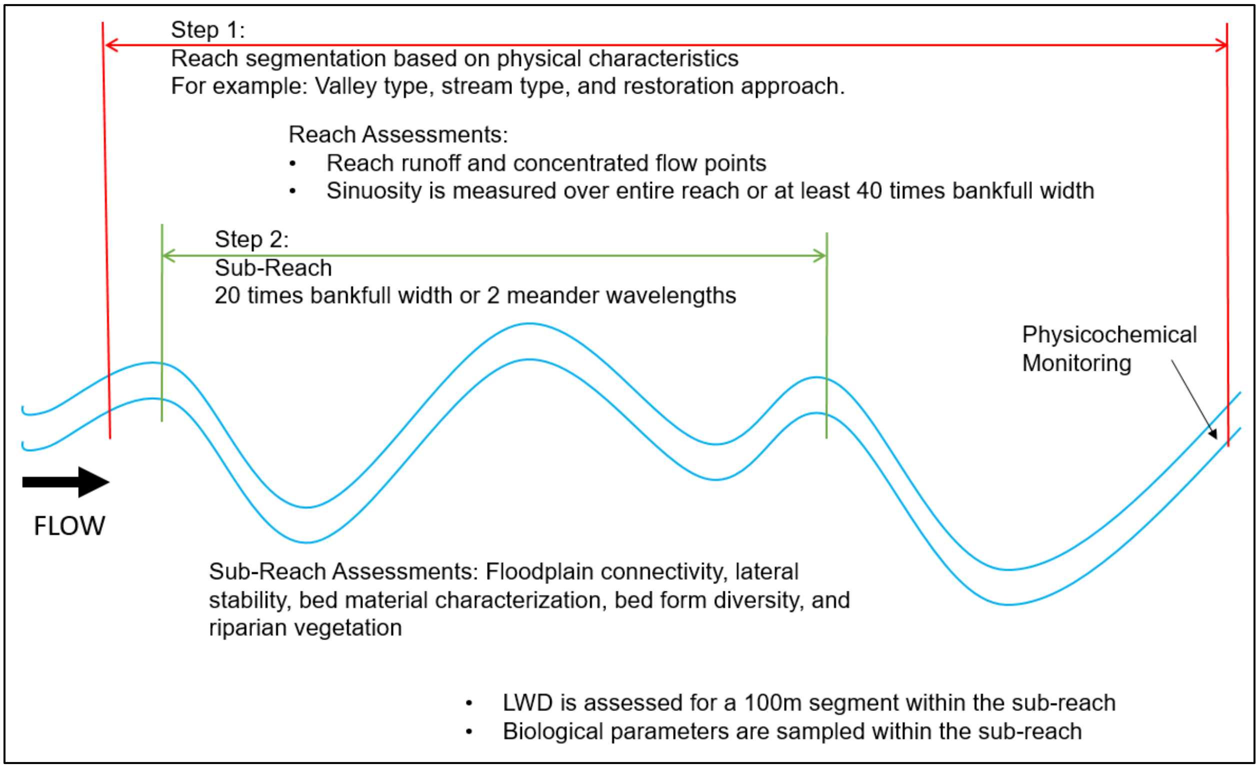
Figure 1: Reach Identification Example



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



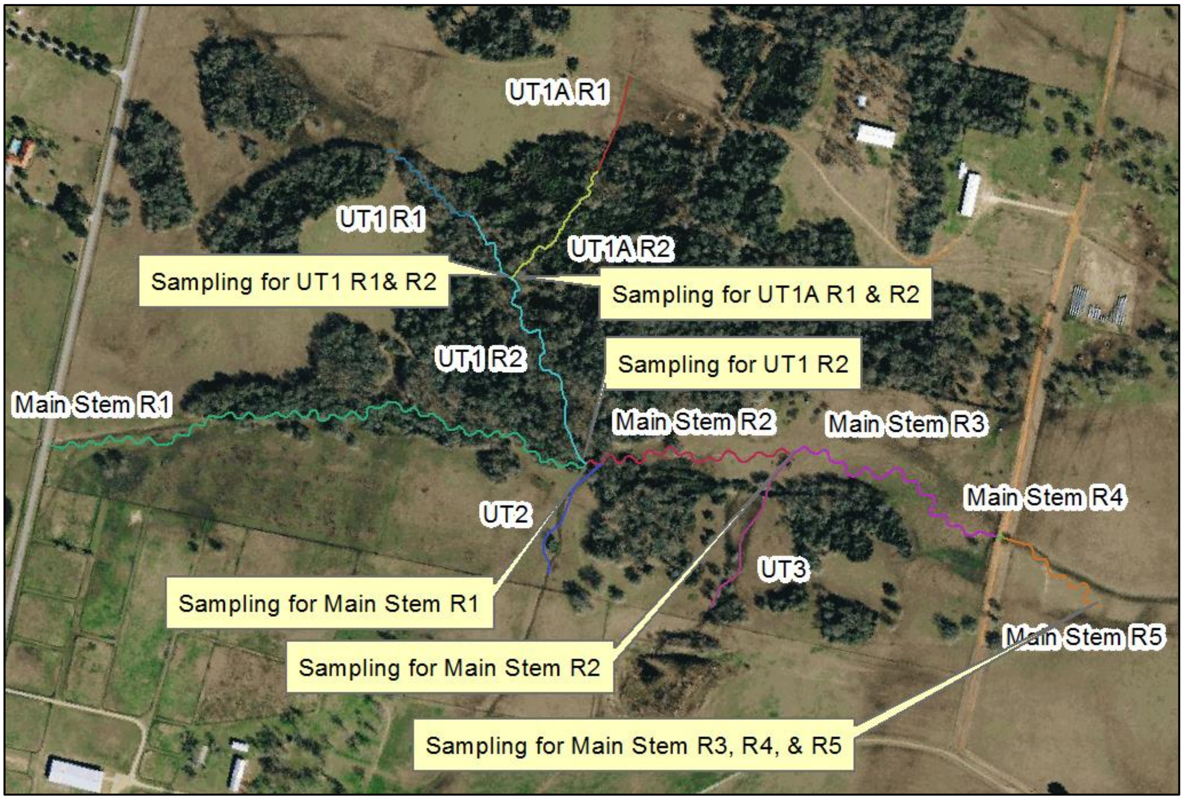
1. *Hydrology Functional Category*:
    a. The catchment hydrology parameter is assessed at the catchment or sub-catchment scale rather than the reach scale.
    b. Reach runoff parameters are evaluated for the entire length of each reach.
2. *Hydraulic and Geomorphology Functional Categories*:
    a. Riparian vegetation, floodplain connectivity, lateral stability, bed material characterization, and bed form diversity are assessed for a length that is 20 times the bankfull width or two meander wavelengths (Leopold, 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 SQT input in that it provides supporting information about functional lift or loss. However, the 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 SQT could show scoring differences in a downstream direction.

Figure 3: Physicochemical and Biological Sampling Points Example



2.2. Catchment Assessment

The Catchment Assessment worksheet is a tab within the SQT. It is also provided in Appendix A. This form is included to assist in determining the restoration potential for the project reach. Restoration potential is a key concept from the SFPF and is described in detail in the following section. The Catchment Assessment worksheet includes descriptions of catchment processes and stressors that exist outside of the project reach and may limit functional lift. Instructions for collecting data and describing each catchment process and stressor are also provided in this section.

Catchment Assessment Highlights

- The purpose of the catchment assessment is to assist in determining restoration potential.
- The catchment assessment does not pertain to stressors within the project reach that will be treated as part of a restoration activity.
- The catchment assessment evaluates conditions upstream and sometimes downstream of the project reach.

2.2.a. Restoration Potential

Restoration potential is defined as the highest level (on the pyramid) of restoration that can be achieved based on the health of the catchment, the condition of the reach, and constraints caused by human activities. A restoration potential of Level 5 means that the project has the potential to restore biological functions to a reference condition. This level can only occur if catchment health supports that level of biology and the reach constraints do not prevent the practitioner from implementing the required activities. Examples of constraints include adjacent infrastructure, easement width, and adjacent land uses. Natural landscape features are not constraints; they are simply catchment features that must be considered. For example, the presence of bedrock is not a constraint in this method.

If the catchment health is impaired and/or the constraints limit restoration activities, then the restoration potential will be less than Level 5. Typical stability focused projects in impaired catchments equate to a Level 3 (Geomorphology) restoration potential. Level 3 projects can improve floodplain connectivity, lateral stability, bedform diversity, and riparian vegetation (function-based parameters describing geomorphology functions) to a reference condition, but could not restore physicochemical or biological functions to a reference condition. Biological or physicochemical improvement can be obtained but the improved condition will remain in the functioning-at-risk or not functioning category. This does not mean that Level 3 projects should not be pursued; however, the design goals and objectives should focus on lower-level functions rather than biology.

Level 4 projects are less common and would typically include a stormwater BMP (e.g., bioretention) or an agricultural BMP (e.g., level spreader or grass water way). The most common example would be a headwater urban project where the stream reach is restored and BMPs are installed to reduce runoff and nutrients from lateral sources, e.g. parking lots. Level 4 projects can improve physicochemical functions in an ephemeral or intermittent tributary to the project reach; however, it won’t return the project reach to a reference condition for biological function. Biological improvement can be obtained but the improved biological condition will remain in the functioning-at-risk or not functioning category.

The SQT requires the user to determine the restoration potential for each reach. The restoration potential is then used to create function-based goals and objectives which are entered into the Project Assessment worksheet of the SQT.

2.2.b. Catchment Assessment Worksheet Categories

The Catchment Assessment worksheet is provided to assist in determining the restoration potential of the project reach. The form is provided in Appendix A. The Catchment Assessment Form includes descriptions of catchment processes and stressors that exist outside of the project reach and may limit functional lift. There are 15 defined categories with space for an additional user-defined category. For each category, there are three choices to describe the catchment condition: Good, Fair and Poor. Data necessary to assess each category is provided below. Data to support each selection should be documented. The catchment assessment requires digital data available from various online or local resources and some site data that can be obtained through windshield surveys and/or site walks. Footnotes provide links to online data resources.

Once the catchment assessment is complete, the user can determine the overall catchment condition based on the identified conditions and constraints. The overall catchment condition is left as a subjective determination so that the user can assess and interpret the information gathered about the catchment. It is possible that one or more of the categories is a "deal breaker," meaning that the result of that category overrides all other answers. Conversely, it is also possible for a good category score to overcome catchment stressors. 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 showed a good condition. This would be a deal breaker. Conversely, if the percent of a catchment being treated is high, i.e. 80-100%, then the project could be large enough to overcome catchment stressors. A description of each item to be assessed is provided below.

1. **Concentrated Flow**

Concentrated flow points upstream of the project reach contribute sediment and pollutants that may limit the project's restoration potential. Ephemeral gulleys are the most obvious example of a concentrated flow source. Smaller concentrations of flow may be more subtle but can still limit the restoration potential of stream restoration projects.

Concentrated flow points entering the main stem or an intermittent tributary can be identified through aerial photo analysis, windshield surveys, or field reconnaissance. Evidence of concentrated flow includes eroded gulleys and stormwater outfalls (see Figures 4 and 5). The potential for concentrated flow can also be identified using topography data, such as a digital elevation model (DEM), and/or a review of adjacent land uses. However, this assessment should be field verified as the topographic data may be outdated or too coarse to delineate concentrated flow points and stormwater drainage networks may have treatments in place to mitigate pollution.

A good quality catchment has no untreated concentrated flow to the channel immediately upstream the reach. A poor quality catchment has concentrated flow immediately upstream of the project reach . A fair condition has potential for concentrated flow but existing measures are in place to address it.

Figure 4: Eroded gulley transporting water and pollutants directly to a stream channel.

Figure 5: Stormwater Outfall

2. Impervious Cover

Runoff from impervious surfaces arrives at a stream channel faster and with lower 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 catchment has been found to be indicative of stream health (Schueler et al., 2009). Therefore, this category can provide insight into the quality of water entering a restoration reach.

An estimate of percent impervious cover is available in the basin characteristics of Stream Stats as derived from the National Land Cover Dataset (NLCD 2011).[1] For smaller catchments, 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 25% of the drainage area, the catchment condition is considered poor. Where impervious cover makes up less than 10% of the drainage area, the catchment condition is considered good (Schueler et al., 2009). A poor or fair catchment 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 catchment is being restored (i.e. good condition rating is achieved for Category 14 of the Catchment Assessment).

3. Land Use Change

Land use is temporally variable and catchments that are currently in good or fair condition can degrade quickly with development. Active construction within a catchment 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 catchment in good condition based on land use change consists of rural, or otherwise slow growth potential, communities. Catchments evaluated as poor in this category, such as urban or urbanizing communities, have ongoing development or imminent large-scale development.

Trends in land use can be determined through examining orthoimagery from the last 20 years or by examining the NLCD data available online or provided in Stream Stats. The North Carolina Stream Stats page will provide percent impervious cover, developed, and forested land from the NLCD 1992, 2001, 2006, and 2011 datasets. Zoning designations and development plans can also be obtained from local governments and assessed for the project catchment.

4. Distance to Roads

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 catchment that are not directly connected to the project reach would indicate a fair catchment condition in this category.

[1] http://water.usgs.gov/osw/streamstats/north_carolina.html

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 NCDOT and county government websites. The State Transportation Improvement Program (STIP)[2] is available from NCDOT 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 catchment assessment rating (See Figure 4-6 in the WARSSS book).

5. Percent Forested

Forested land has a lower runoff potential than developed land. The processes that prevent or lower runoff include: interception, surface retention, plant uptake, and flow resistance caused by vegetation. Forested ecosystems also provide more groundwater contributions to stream channels than their urban counterparts. The lack of forested land cover can limit level 4 and 5 restoration potential as less forest cover indicates lower water quality draining to the project reach. Catchment areas that are 70% or more forested are in good condition. Catchments that consist of 20% or less forested land are in poor condition. These numeric criteria are based on best professional judgment of the SQT development team and select reviewers.

The forested percent of the catchment can be derived from the National Land Cover Dataset (NLCD 2011), available in the North Carolina application of USGS Stream Stats as a selection under the basin characteristics category.[3] For smaller catchments, it is possible to delineate forested areas using recent orthoimagery.

6. Riparian Vegetation

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 to the stream channel. Catchments 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. Catchments 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 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 driving around the catchment and performing a windshield survey.

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[2] http://www.ncdot.gov/strategictransportationinvestments/2016-2025.html
[3] http://water.usgs.gov/osw/streamstats/north_carolina.html

7. Sediment Supply

Figure 6: Alternating point bars indicate sediment storage in the channel that can be mobilized during high flows. Sediment is also being supplied to the channel from bank erosion.

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. If the design does not adequately address the sediment load, the restoration project could aggrade.

Users should review recent orthoimagery of the catchment and walk as much of the upstream channel as possible looking for bank erosion, mid-channel bars, lateral bars and other sources of sediment that can be mobilized (See Figure 6). If there are multiple, large sources of sediment that can be mobilized then there is a high sediment supply and the catchment condition is poor. If there are only a few small sources of sediment then the catchment condition is good.

There are also simple tools available to estimate the sediment load that may come from surrounding land use such as the Spreadsheet Tool for Estimating Pollutant Loads (STEPL v4.1) (Tetra Tech, Inc., 2011). The potential sediment supply could also be determined using the WARSSS if this data will be required elsewhere in the project. WARSSS is an intensive level of effort that is not necessary for this catchment assessment.

8. Location in relation to 303(d) or TMDL listed waters

The North Carolina Department of Environmental Quality (NC DEQ) Division of Water Resources (DWR) maintains a list of 303(d) Impaired Waterbodies.[4] Impaired waters have exceeded water quality standards for their designated use and require a Total Maximum Daily Load (TMDL) allocation to bring the water body into compliance. Once a TMDL is created, the impaired waterbody is removed from the 303(d) list even though the water quality standards may not be met. It is therefore important to check for both 303(d) listed waters and active TMDLs in the catchment. TMDLs[5] and basinwide water quality plans[6] are also available from NC DEQ. Most stream restoration projects do not restore a sufficient portion of the stream or

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[4] The current and past 303(d) lists are available at http://deq.nc.gov/about/divisions/water-resources/planning/classification-standards/303d/303d-files. NCDEQ also hosts an interactive map to locate 303(d) listed waters: http://ncdenr.maps.arcgis.com/apps/webappviewer/index.html?id=dcb44280272e4ac49d9a86b999939fec

[5] http://deq.nc.gov/about/divisions/water-resources/planning/modeling-assessment/tmdls

[6] http://deq.nc.gov/about/divisions/water-resources/planning/basin-planning

catchment to overcome poor water quality. A poor or fair catchment 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 catchment is being restored (i.e. good condition rating is achieved for Category 14 of the Catchment Assessment).

There are many impaired waters that do not make the 303(d) list. The rest of the categories in this catchment assessment will assist in identifying impairments and possible impairments for waters that are not listed. Additionally, if recent water quality data have been collected for the project reach then it can be used to justify a poor condition rating in this category even if the water is not listed as impaired by NCDEQ.

9. Agricultural Land Use

Figure 7: 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.

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 7). A catchment 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 catchment 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 stream restoration is performed in a reach where there is cattle access and/or cropland immediately upstream of the project reach, the catchment condition is poor and the restoration potential is limited.

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 catchment can be determined using recent orthoimagery, the 2011 NLCD, or through windshield surveys.

10. NPDES Permits

The NC DEQ hosts maps of the minor and major National Pollutant Discharge Elimination System (NPDES) permitted facilities.[7] 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 limit levels 4 and 5 restoration potential. A catchment in good condition would have no NPDES facilities in the catchment or near the project reach while

[7] https://ncdenr.maps.arcgis.com/apps/webappviewer/index.html?id=9626aac34f08404680d5cd5f8ede39c

a poor catchment in this category would have multiple NPDES facilities in the catchment and/or one near the project reach.

11. Specific Conductance

Specific conductance measures the amount of dissolved ions in water. Freshwater aquatic species have tolerance limits for overall ion concentrations and dissolved oxygen before their vigor and survival are affected. High specific conductance can impact macroinvertebrate populations (NC DENR, 2013) and therefore limit levels 4 and 5 restoration potential. Stream restoration practices are unlikely to reduce specific conductance; therefore, this category could be a deal breaker if the project goal requires a Level 5 restoration potential. Again, this does not mean that the project should be abandoned. If the project owner (funding entity) will accept a lower restoration potential (Level 3) and there are reach-scale problems at Levels 2 and 3, then the project could still be justified.

This category requires a meter/probe to measure the conductance at the upstream extent of the restoration site. Specific conductance should be measured *in situ* following the procedure outlined by the *Intensive Survey Branch Standard Operating Procedures Manuals: Physical and Chemical Monitoring* (NC DENR, 2013) or by following any calibration, sample collection and measurement methodology recommended by the manufacturer for the device being used. Note that instrument calibration is required before any trip into the field.

12. Watershed impoundments

Watershed impoundments are 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. Catchments 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 catchment is in good condition. A catchment that contains an impoundment that has a negative effect on the project area and fish passage 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.

13. Organism Recruitment

Aquatic organisms rely on a variety of channel substrate sizes and characteristics to survive and reproduce. Impaired channel substrates, or other factors that limit the presence of aquatic organisms, surrounding the project reach can negatively impact macroinvertebrate community recruitment and the ability of fish to spawn. Recruitment and colonization of aquatic organisms within stream reaches is affected by the presence of desired communities in proximity to the project site (Blakely et al., 2006; Hughes, 2007; Lake et al., 2007; Sundermann et al., 2011; Tonkin et al., 2014). Impairments to the channel, such as hardened substrates, excessive sedimentation, culverts or piping, may prevent macroinvertebrate communities from inhabiting a stream reach and extended length of channel impairments may reduce the possibility of organism recruitment. If there are substantial channel impairments preventing desirable taxa immediately upstream or downstream of the project reach (e.g., within 1 km) this should be scored as in poor condition. If the channel substrate immediately upstream or downstream of the project reach is impaired, but some proximate stream reaches support desirable aquatic communities, then the catchment is in fair condition. Impairment can include excessive deposition of fine sediments, hardened or armored channels (e.g., concrete channels or grouted riffles), culverts or piped channels or other similar modifications to the channel substrate.

The most important source of recolonization of benthic insects is drift from upstream. If upstream reaches or unimpacted tributaries are hardened, recolonization of restored reaches will take much longer. Emphasis needs to be given to the quality of upstream reaches for organism recruitment. This category may not limit the future restoration potential, since benthic insects can recolonize via adult egg deposition from nearby catchments if drift from upstream reaches is unlikely. However, this kind of recruitment process may take much longer. 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.

14. Percent of Catchment Being Enhanced or Restored

As outlined in the categories above, there are many catchment stressors that can limit the restoration potential of the project reach. In most cases, a single stream restoration project reach will not be long enough to overcome the effects of these impairments. However, in the case where a significant proportion of the catchment and/or a significant proportion of the drainage network is included in the project area, a restoration potential of level 4 or level 5 may be possible.

The proportion of the catchment being restored can be determined by dividing the area within the project reach catchment area by the total catchment area. A catchment rated as good condition in this category is one where more than 60% of the total catchment area is being restored or enhanced. Where the project area is less than 40% of the total catchment area the condition is poor. If this category is scored as good condition, then an argument can be made that the restoration potential is high, regardless of the other scores. This is more likely to occur in small headwater catchments.

15. Other

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

3. Getting Started with the Stream Quantification Tool

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. The process of parameter selection is described in detail in the following section.

- 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 *4. Measurement Method Field Values*.
    - 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-based. While the SQT is **not** a qualitative rapid assessment, there are methods provided for quickly collecting quantitative data. Rapid-based methods are recommended during the site selection or prospectus stage of a project. Detailed assessments are recommended once the project location has been approved or during the mitigation plan stage.
- Some of the measurement methods use bankfull dimensions. It is important to verify the bankfull stage when these measurement methods are used. There are rapid and detailed methods to verify bankfull provided in this chapter.

Rapid and Detailed Assessments

The SQT supports rapid and detailed assessment methods—both are more quantitative than qualitative. Rapid assessments are used during the early stages of a project, like site selection or the prospectus stage. Detailed assessments are used once the project is approved, e.g., for mitigation plans.

3.1. Parameter Selection

This manual describes each measurement method included in the SQT. However, a project would rarely, if ever, enter field values for all measurement methods. Within the SQT workbook, a Parameter Selection Guide worksheet can help the user select the parameters appropriate for a given project scenario. A summary of the Parameter Selection Guide is provided here as well.

Practitioners should not be allowed to “cherry pick” parameters to create lift at minimal cost. For example, a practitioner should not be allowed to only plant a buffer, creating lift in riparian vegetation, when the channel is incised and actively eroding the bed and/or banks.

The following parameters should be included for all assessments throughout North Carolina:

- Reach Runoff
- Floodplain Connectivity
- Lateral Stability
- Riparian Vegetation
- Bed Form Diversity
- Large Woody Debris
- Plan Form

Important Note about Parameter Selection for Credit Determination

The guidelines provided in this manual are for projects that simply want to show functional lift. If the SQT is going to be used for credit (or debit) determination, the regulatory agencies should select a suite of function-based parameters and measurement methods that will not change from one project to another.

In order to provide a minimum condition achieved by restoration, it is recommended that **ALL** projects bring floodplain connectivity, lateral stability, and bed form diversity to a functioning condition at the end of the project. Since the riparian vegetation parameter is based on a functioning forest, restoration sites with newly-planted trees will not achieve a functioning score within the typical five- to seven-year monitoring period. Regardless, it should be included in minimum quality requirements by achieving a score well within the functioning-at-risk category, e.g., 0.60.

The SQT can be applied to stream restoration projects installed in combination with BMPs but should not be applied to stand-alone BMPs or BMPs installed independently of/not adjacent to a stream restoration reach. Add any of the following parameters to the list above based on what the BMP will treat:

- BMP Runoff
- Temperature
- Specific Conductivity
- Nitrogen
- Phosphorus

Some of the parameters listed above occur in both the BMP Routine and the reach condition assessments. There are tools available to model the impact of BMPs on runoff, nitrogen and phosphorus and these modeled values can be entered into the BMP Routine for these parameters. However, if the practitioner or regulator believes that the BMPs and/or the restoration practices could have a measurable effect on the receiving stream (i.e. the stream restoration project reach), these parameters could be monitored in the stream and values entered into the existing and proposed condition assessments.

The following parameters should be required for projects with a level 4 – physicochemical restoration potential:

- Organic Carbon
- Temperature

The following parameters should be required for projects with a level 5 – biology restoration potential:

- Macros for regions with macroinvertebrate performance standards
- Fish for regions with fish data

Not all regions in North Carolina have performance standards for macroinvertebrates and fish. If a project lies outside of these areas, monitoring is still encouraged to document change but scoring will not be available in the SQT. If the user monitors the project reach and a reference reach, site-specific performance standards could be developed.

The rest of the parameters and their measurement methods can be selected based on their applicability to the project reach.

- Catchment Hydrology is recommended for projects with easements that include a large portion of the catchment upstream of the stream restoration reaches.
- Bed Material Characterization is recommended for streams with gravel beds and sandy banks, where there is potential to coarsen the bed.

- Temperature is recommended for streams with sport fishing, e.g. trout.
- Bacteria is recommended where livestock have access to the stream.

For example, consider a typical level 3 restoration potential project in a pastureland setting. The catchment is small and consists mostly of rural and agricultural land uses. The overall catchment assessment is fair and stressors would not prevent at least some biological lift (but not back to reference condition). The project goals are habitat improvement for native fish and reducing sediment supply from eroding banks. The work will include: 1) fencing to keep cattle out of the channel; 2) grading to provide floodplain connectivity and greater bedform diversity; 3) adding woody debris to the channel to provide channel complexity and fish habitat; and 4) planting woody riparian vegetation along the streambank and across the floodplain. The parameter list would likely consist of:

- Reach Runoff
- Floodplain Connectivity (Must be brought to a functioning condition)
- Lateral Stability (Must be brought to a functioning condition)
- Riparian Vegetation (Must be brought to well within functioning-at-risk category, e.g. 0.6.)
- Bed Form Diversity (Must be brought to a functioning condition)
- Large Woody Debris
- Plan Form
- Bacteria
- Macros
- Fish

While the project only has level 3 restoration potential, there is monitoring at levels 4 and 5. The bacteria parameter is included because cows have access to the stream channel. Keeping the cattle out of this reach is likely to provide functional lift at level 4. The macros and fish are being monitored because the practitioner expects that one or both parameters will improve (at least some). This would contribute more functional lift to the restoration project; however, the project is not expected to return macros and fish biomass back to a forested reference condition.

The Parameter Selection Guide worksheet and this section provide guidance on which parameters in the SQT to assess for a project. It is recommended that practitioners and regulators work together to determine a list of parameters suitable for each project that will determine whether project goals and objectives are being met.

3.2. Rapid Versus Detailed Assessment Methods

The SQT can be used with rapid-based assessments and detailed-based 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, survey tapes and rods are used to simply take the measurements in the field. Keep in mind that cross sections and profiles cannot be plotted using this method. Instructions for carrying out the rapid method are provided in section 4 of this manual and collected in Appendix B. A field form for collecting rapid-based measurements is also provided in Appendix B.

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 SQT is being used as part of a mitigation plan or monitoring report. These applications require the detailed method.

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. The advantage to the detailed method is that the calculations can be used to create plots/graphs by hand or in computer programs. 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.

3.3. Bankfull Verification

Multiple parameters in the 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.

3.3.a. Verifying Bankfull Stage and Dimension with Detailed Assessments

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. From the longitudinal profile, a best-fit-line is plotted through the bankfull stage points. Rosgen (2014) provides step-by-step instructions on how to survey a longitudinal profile and compare best-fit-lines through the water surface and bankfull points. 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 correlation coefficient (R^2 value) of less than 0.80.

In addition to the longitudinal profile, a representative riffle cross section must be selected within the study reach. The data surveyed from this cross section is used to calculate bankfull cross-sectional area, width, mean depth, and discharge (if channel slope and bed material samples have been collected as well). Rosgen (2014) and Harrelson et al. (1994) provide detailed methods on how to survey a cross section. The bankfull width and mean depth values are used to calculate several of the dimensionless ratios included as measurement methods in the SQT. Selection of the representative riffle is critical; the criteria below can aid in the selection of a suitable riffle:

- Stable width and depth, no signs of bank erosion or headcutting. The bank height ratio is near 1.0.
- Cross-sectional area plots within the range of scatter used to create the regional curve. More information is provided in the following paragraphs.
- The bankfull width/depth ratio is on the lower end of the range for the reach.

- Note: In a highly degraded reach, a stable riffle cross section may be used from an adjacent upstream or downstream reach. If a stable riffle is still not identified, the bankfull width and mean depth from the regional curve should be used.

The bankfull dimensions of cross-sectional area, width, and mean depth should be calculated for at least one surveyed representative riffle cross section, as described above. Additional cross sections may be necessary to quantify the effects of aggradation and the weighted entrenchment ratio. These methods are discussed later. The 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 catchment. If catchment-specific regional curves are not available, the user can overlay the field data with established curves. NC State University's Stream Restoration Program provides published papers, data and equations for North Carolina regional curves. [8]

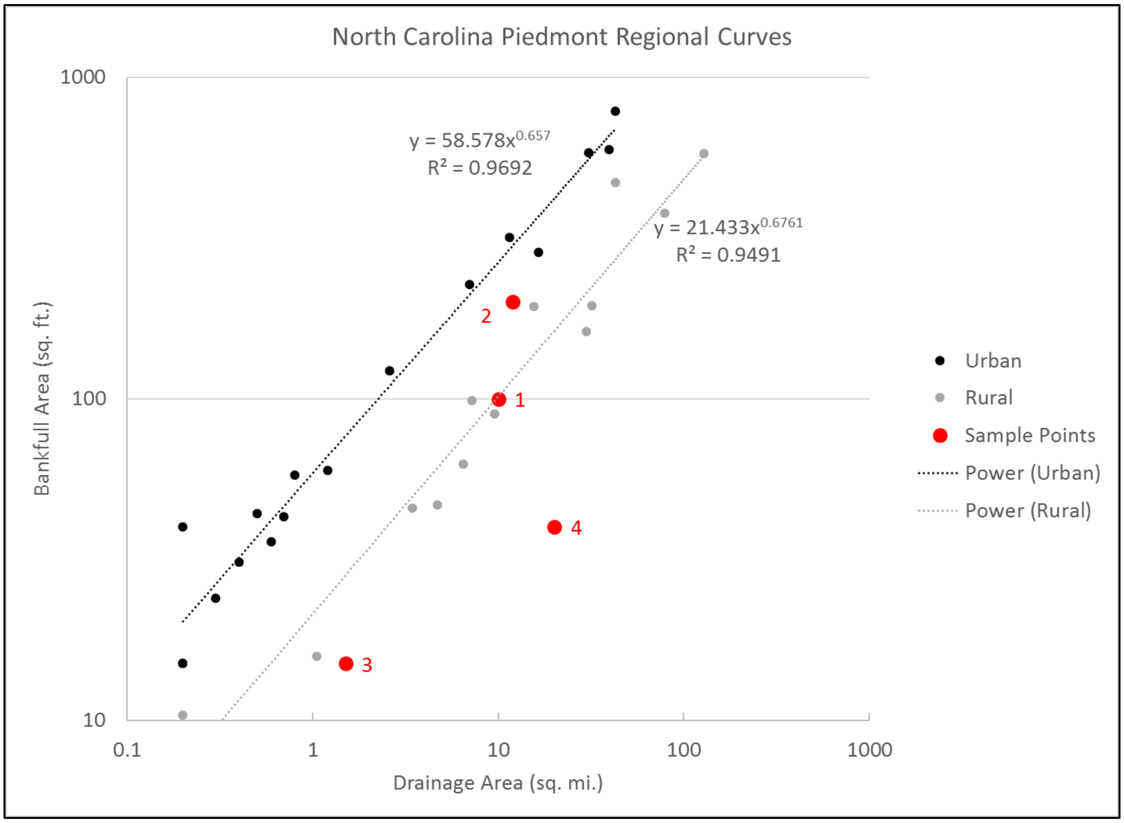
For North Carolina, established curves are available for Coastal Plain streams, rural Piedmont streams, urban Piedmont streams, and rural Mountain streams. Urban streams have a high percent impervious cover (the stream channels used to develop the urban Piedmont regional curve had drainages that consisted of 17 – 80% impervious cover). Flood control channels are common examples of projects that may fall on the urban curve. Choose the curve that matches the hydro-physiographic region of the project and plot the bankfull dimensions against regional curve data.

Figure 8 shows the urban and rural regional curves for the Piedmont Region of NC along with four sample points, numbered and shown in red, for streams that were considered rural.

- Sample point 1 plots on the rural regional curve and can be considered verified.
- Sample point 2, however, falls slightly above the scatter for the rural curve. As the point is between the urban and rural curves, 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 between the urban and rural curves. 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 rural 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.

[8] http://www.bae.ncsu.edu/programs/extension/wqg/srp/techresources.html

Figure 8: Verifying Bankfull with Regional Curves Example



3.3.b. Verifying Bankfull Stage and Dimension with the Rapid Method

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.

3.4. Reference Reach Identification

The bed material characterization parameter and leaf litter processing rate measurement method (for organic matter parameter) require a comparison between the project reach and a reference reach. These parameters and measurement methods are optional depending on project goals and funding. The SQT defines reference condition as a stream that is considered fully functioning for the function-based parameter being assessed. A reference condition does not simply represent the best condition that can be *achieved* at a given site. This definition is in accordance with the definition laid out by Stoddard, et al. (2006) for a reference condition for biological integrity. Any parameter that scores an index of 1.00 should be functioning like a very healthy aquatic ecosystem.

Finding good reference conditions for these parameters and measurement methods can be challenging. When possible, pick reference reaches that are upstream of the project reach. For example, a stable C stream type with a forested catchment upstream of an unstable C4 or G4c or F4 stream type is ideal for this analysis. If a reference reach cannot be located, then the bed material characterization and leaf litter processing rate measurement methods cannot be used. Be sure to document the location of reference and project reaches on a map.

4. Measurement Method Field Values

The Quantification Tool worksheet is the main sheet in the Stream Functional Lift Quantification Tool (SQT) 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 SQT worksheet requires data entry in three areas: Site information and Performance Standard Stratification, Existing Condition Field Values, and Proposed Condition Field Values. For projects with BMPs within the project boundary, either adjacent or immediately upstream, the BMP routine can also be completed. For detailed information on the Site Information and Performance Standard Stratification section of the SQT, refer to the Spreadsheet User Manual. This manual provides instruction for collecting and analyzing field data that is required for the Existing and Proposed Condition Assessments (Table 1) and the BMP Routine (Table 2). Note that the Monitoring Data worksheet contains condition assessment tables identical to the existing and proposed condition assessment tables. Data collection and analysis procedures for monitoring events need to follow the procedures outlined in this chapter.

A project would rarely, if ever, enter field values for all measurement methods included in the SQT. The Parameter Selection Guide worksheet and Section 3.1. of this manual provides 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.

Table 1: Condition Assessment from the SQT

Functional Category	Function-Based Parameters	Measurement Method	Field Value
Hydrology	Catchment Hydrology	Curve Number	
	Reach Runoff	Curve Number Concentrated Flow Points Soil Compaction	
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	
	Plan Form	Sinuosity	
Physicochemical	Temperature	Temperature (°F)	
	Bacteria	Fecal Coliform (Cfu/100 ml)	
	Organic Carbon	Leaf Litter Processing Rate Percent Shredders	
	Nitrogen	Monitoring (mg/L)	
	Phosphorus	Monitoring (mg/L)	
Biology	Macros	Biotic Index EPT Taxa Present	
	Fish	North Carolina Index of Biotic Integrity	

Table 2: BMP Routine from the SQT

Site Information			BMP 1	
BMP ID				
Basin Area treated by BMP (Ac)				
Effective Stream Length (ft)				
Existing Condition Assessment				
Function-Based Parameters	**Measurement Method**		**Field Value**	**Index Value**
BMP Runoff	Impervious Cover (%)			
Temperature	Temperature (°F)			
Specific Conductivity	Specific Conductivity (uS/cm at 25°C)			
Nitrogen	Falls Lake Nutrient Tool (mg/L)			
Phosphorus	Falls Lake Nutrient Tool (mg/L)			
Proposed Condition Assessment				
Function-Based Parameters	**Measurement Method**		**Field Value**	**Index Value**
BMP Runoff	Impervious Cover (%)			
Temperature	Temperature (°F)			
Specific Conductivity	Specific Conductivity (uS/cm at 25°C)			
Nitrogen	Falls Lake Nutrient Tool (mg/L)			
Phosphorus	Falls Lake Nutrient Tool (mg/L)			
Results				
BMP Existing Score				
BMP Proposed Score				
Existing BMP Functional Foot Score				
Proposed BMP Functional Foot Score				
Proposed FFS - Existing FFS				

4.1. Hydrology

The SQT contains two function-based parameters to describe the transport of water from the watershed to the channel: Catchment Hydrology and Reach Runoff. The BMP Routine also includes a Runoff parameter that is different than the Reach Runoff parameter.

4.1.a. Catchment Hydrology

Catchment hydrology assesses the hydrologic health of the catchment *upstream* of the 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 not change the catchment hydrology score between the existing and proposed condition. In this scenario, the catchment hydrology score simply affects the overall hydrology category score. For example, catchments with better upstream hydrology conditions will yield a higher hydrology category score.

There is one measurement method for catchment hydrology: an area-weight curve number used to characterize the catchment land use *upstream* of the project reach. The portion of the reach catchment that drains laterally to the project reach is assessed using the reach runoff parameter and should not be included in this calculation. 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 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 3 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 3: 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 SQT as field values. Performance standards in the SQT are based on the curve number values from TR-55 for woods in good condition (NRCS, 1986).

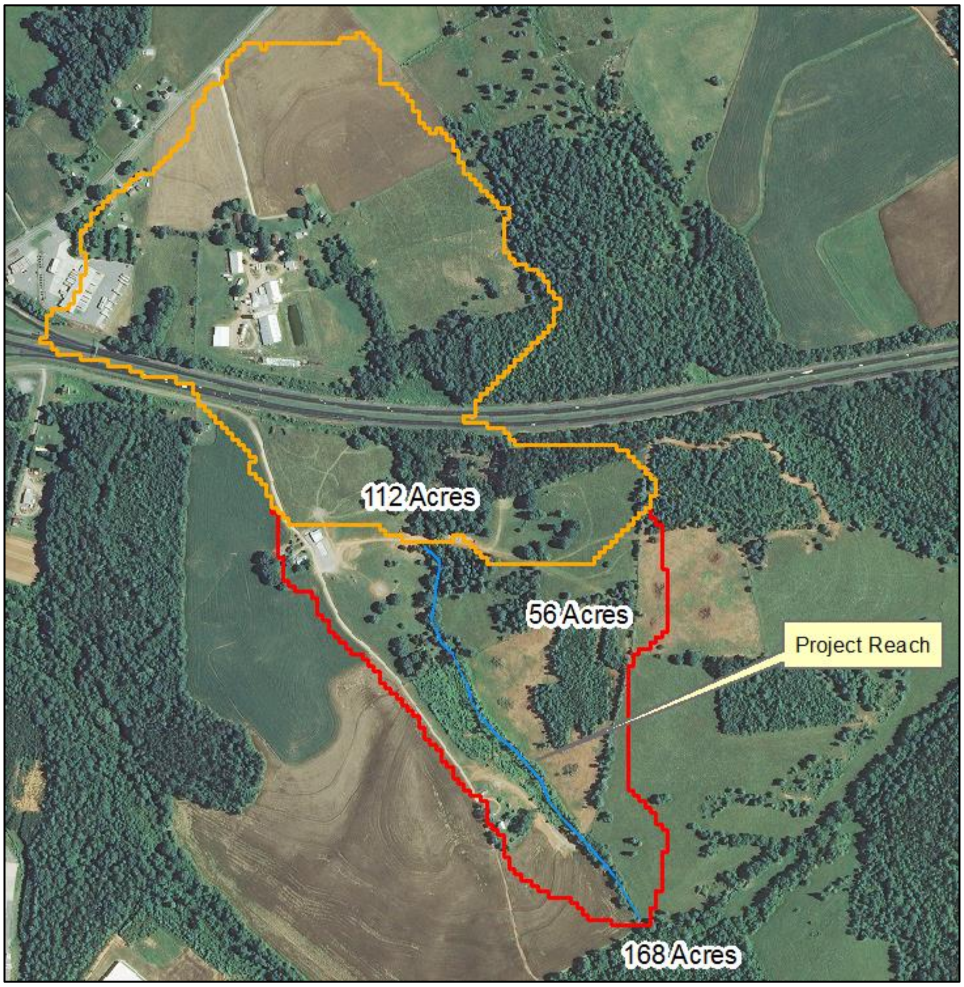
4.1.b. Reach Runoff

The runoff parameter is included in both the hydrology category and BMP Routine of the SQT; however, the measurement methods and performance standards are different. Section 4.1.c. will address the Runoff parameter in the BMP Routine, this section describes the measurement methods within the reach condition assessments.

It is recommended that reach runoff be assessed for all projects. The reach runoff parameter consists of three measurement methods: curve number, concentrated flow points, and soil compaction. Curve number and concentrated flow points should be assessed for all projects where reach runoff is measured. Soil compaction should be added once a project site has been approved as a restoration or mitigation site, e.g. at the mitigation plan stage. This level of effort is only needed for approved project sites.

The reach runoff parameter evaluates the hydrologic functioning of the land that drains laterally into the stream reach. The catchment above the stream reach is assessed by the catchment hydrology parameter. The purpose of the reach parameter is to assess the catchment that drains directly to the reach. An example is shown in Figure 9. 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 land draining laterally to the project reach is represented by the difference between the two measurements, or 56 acres (delineated in red in the figure). This area is the catchment assessed by the reach runoff parameter.

Figure 9: Catchment Delineation Example for Reach Runoff.



1. **Curve Number (CN)**

The curve number measurement method characterizes the land use of the portion of the catchment that is assessed by the reach runoff parameter, i.e. the land that drains directly to the project reach. This measurement method is also used to assess the catchment hydrology parameter and instructions for calculating an area-weighted curve number are included in that section of this manual.

For the 56-acre catchment shown in Figure 9, Table 5 shows the breakdown in land use and the resulting weighted curve numbers entered into the SQT. The land shown is on hydrologic soil group A, the woods are in good condition, and the crops are in straight rows. For the proposed condition, the riparian area would be planted, thus converting some of the pasture to woods. As shown in Table 4, this change in land use would alter the existing condition field value from 59 to the proposed condition field value of 51.

Table 4: Example Curve Number Calculations

Land Use	Area (acres)	Area (%)	CN	% Area * CN
Existing Condition				
Woods	13	13/56 = 23.2	30	7
Pasture, grassland or range	37	66.1	68	45
Row Crops	3	5.4	72	4
Farmsteads[9]	3	5.4	59	3
TOTAL	56	100.0	-	**59**
Proposed Condition				
Woods	24	42.9	30	13
Pasture, grassland or range	26	46.4	68	32
Row Crops	3	5.4	72	4
Farmsteads	3	5.4	59	3
TOTAL	56	100.0	-	**51**

Performance standards in the SQT are based on the curve number values from TR-55 for woods in good condition (NRCS, 1986).

2. Concentrated Flow Points

Figure 10: Agricultural ditch draining water from field into stream channel.

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 10 is an example of an agricultural ditch (ephemeral channel) used to drain water from the adjacent cropland into the project reach.

The three primary drivers that cause sheet flow to transition to concentrated flow were found to be discharge, bare soil fraction, and slope angle (Al-Hamdan, et al., 2013). Stream restoration projects can reduce concentrated flow entering the channel by dispersing flow in the floodplain

[9] Curve numbers for Farmsteads are provided in Table 2-2c of TR-55 (NRCS, 1986)

and increasing ground cover near the channel. Performance standards are based on best professional judgement and are provided in Table 5.

Table 5: Concentrated Flow Points Performance Standards

Field Value (#/1,000 ft)	Index Value	Condition
0	1	Functioning
1	0.6	Functioning-At-Risk
2	0.4	
3	0.3	
>3	0	Not Functioning

3. 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 11.

Figure 11: Restoration activities to reduce soil compaction can include disking in a cross-disk pattern.

Soil compaction is measured as an average depth to a compacted layer (inches) using a penetrometer. For the SQT, the compacted layer is defined as the condition where soil resistance is 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 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.

Performance standards are based on best professional judgement and design criteria for stormwater infiltration practices.

4.1.c. Runoff – BMP Routine

The runoff parameter in the BMP Routine is assessed for projects that include stormwater BMPs adjacent to the stream restoration project. The runoff parameter for a BMP is assessed using the percent of impervious cover in the BMP catchment, or Basin Area. Performance standards are readily available since the percent impervious cover has been found to be indicative of stream health (Schueler et al., 2009). Runoff volume reductions associated with BMP practices are related to reductions in impervious cover in the BMP catchment for this measurement method.

The existing condition impervious cover can be determined by delineating impervious surfaces (rooftops, streets, sidewalks, parking lots, etc.) within the BMP drainage using recent orthoimagery. The total area of impervious surfaces can then be summed and divided by the total drainage area for the BMP. For larger catchments, the percent impervious area can also be derived from the 2011 NLCD, which is available from the North Carolina application of USGS Stream Stats as a selection under the basin characteristics category.

For the proposed condition in the BMP Routine, the user must implement the Jordan/Falls Lake Stormwater Nutrient Load Accounting Tool (JFSLAT)[10] to calculate the proposed condition runoff with the BMP installed and use this value to calculate the effective percent impervious cover. The User Manual for JFSLAT (NC DENR & NC State Bio & Ag Engineering, 2011) provides instruction on using the spreadsheet tool to obtain the proposed condition runoff. Equations (1) and (2) from the model documentation section show how the tool implements the Simple Method for estimating the volume of stormwater runoff. These equations, provided below, are used to back calculate an effective percent impervious from the Annual Runoff Volume (ft^3) of the Post-Development with BMP(s) condition found in the Development Summary sheet.

Equation (1):
$$R_v = 0.05 + (0.009 * I)$$

Where, R_v is the Simple Method runoff coefficient and I is the percent impervious cover of the catchment (%). Note that the JFSLAT counts the area of land taken up by the BMP as impervious cover.

Equation (2):
$$V = R_v * A * \left({}^{P}/_{12}\right)$$

Where V is the volume of runoff (ft^3), A is the catchment area (ft^2), and P is the average annual rainfall (in). The average annual precipitation is selected based on the Precipitation Location input provided on the Watershed Characteristics tab. The value used is not visible or provided in the User's Manual and would need to be calculated using equations (1) and (2) and the Post-Development Condition percent impervious and annual runoff volume. Alternatively, equation

[10] Current version is v2.0 from May 2013, available through NCDEQ DWR: http://portal.ncdenr.org/web/fallslake/rules-implementation-information

(3) is derived using equations (1) and (2) and can be used to determine the effective percent impervious for the Post-Development with BMPs condition (a.k.a. the proposed condition).

Equation (3): $$I_{effective} = \left(\frac{V_{Post-Development\ with\ BMP}}{V_{Post-Development}}\right)(5.56 + I) - 5.56$$

If the stream restoration project did not include a BMP but did include the removal of impervious surfaces from the reach catchment, then the field value for the Proposed Condition Assessment is determined by recalculating the percent impervious using the Existing Condition value and the impervious area to be removed as shown in equation (4).

Equation (4): $$I_{proposed} = \frac{(I*A - A_{impervious\ removed})}{A} = I - \left(\frac{A_{impervious\ removed}}{A}\right)$$

Where I is the percent impervious cover of the catchment (%) for the existing condition, A is the catchment area (ft^2, Acres or mi^2), $A_{impervious\ removed}$ is the area of impervious surface that will be removed with the project (units need to match the catchment area units), and $I_{proposed}$ is the field value for percent impervious in the Proposed Condition Assessment (%).

Performance standards for percent impervious cover were derived from a meta-analysis of impervious cover model research studies (Schueler et al., 2009).

4.2. Hydraulic

The 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). Both are described below.

4.2.a. Floodplain Connectivity

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

The two measurement methods include the Bank Height Ratio (BHR) and the Entrenchment Ratio (ER). Rapid and detailed assessments are available for each. 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 (Leopold, 1994).

1. Bank Height Ratio (BHR)

The BHR is a measure of channel incision and therefore 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 (Dmax). The low bank height is the lower of the left and right streambanks, indicating the minimum water depth necessary to inundate the floodplain.

Equation (5) $$BHR = \frac{Low\ Bank\ Height}{Dmax}$$

To improve consistency and to reduce the potential for "cherry picking" riffles that create artificially high existing conditions or artificially low proposed conditions, the 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 data set, a weighted BHR is calculated as follows.

Equation (6)

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

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

Table 6 below provides an example of the weighted bank height ratio calculation in an assessment segment with four riffles.

Table 6: 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 performance standard for the BHR measurement method follows 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 SQT, BHR can be calculated for each riffle within the reach using detailed or rapid field methods.

<u>Detailed Method</u>

For the SQT, the BHR is measured at riffle features from the longitudinal profile. Field instructions for measuring a longitudinal profile are provided on pages 2-19 through 2-25 of Rosgen (2014). Figure 3-2 in 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.

<u>Rapid Method</u>

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. There are two options for rapidly measuring the BHR:

Option 1 measures the BHR using low bank and bankfull depths measured from the *thalweg*, which are the same measurements as the detailed method, but not measured as part of a profile.

Option 2 measures the BHR using depths measured to the *edge of the channel* and a regional curve. It is more rapid and less accurate than Option 1.

For both options, the length of each riffle must also be measured using a tape and the weighted BHR calculated using Equation (6). Field methods for both options are described below.

Option 1 – BHR Measured from Thalweg

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 (5).
3. Measure the difference in stadia rod readings from the thalweg to the bankfull indicator, and enter this value in the denominator of Equation (5).
4. Measure the length of the riffle.
5. Repeat these measurements for every riffle to enter values into Equation (6).

Again, this is the same measurement as the detailed method, just measured in the field using a hand level and stadia rod rather than a longitudinal profile.

Option 2 – BHR Measured from Edge of Channel and Regional Curve

As long as a regional curve is available, this rapid method does not require bankfulll verification. It is more rapid and less accurate than Option 1. Using a regional curve, 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 edge of channel to the top of the low streambank. This result is the Low Bank Height in Equation (5). The edge of channel is the location of the break in slope between the bottom of the channel and the streambank.
3. Use the regional curve to calculate mean riffle depth and enter this value in the denominator of Equation (5).
4. Measure the length of the riffle.
5. Repeat these measurements for every riffle to enter values into Equation (6).

Note that in the detailed method and rapid method option 1, the low bank height was measured from the thalweg. In step 2 of the procedure for the rapid method option 2 the low bank height is measured from the edge of channel. This is because in option 2 the denominator of Equation (5) is the bankfull mean depth calculated from a regional curve rather than the maximum riffle bankfull depth.

2. Entrenchment Ratio (ER)

The ER is used to classify stream types and 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 (7) below). The flood prone width is measured as the cross section width at an elevation two times the bankfull max depth. Procedures for measuring and calculating the ER are provided on pages 5-15 through 5-21 of Rosgen (1996 second edition).

Equation (7)

$$ER = \frac{Flood\ Prone\ Width}{Bankfull\ Width}$$

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 data set, a weighted ER is calculated as follows:

Equation (8)

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

Where, RL_i is the length of the riffle where ER_i was measured. Refer to Table 7 for an example of the weighted entrenchment ratio calculation.

Table 7: 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 performance 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. The performance standards for this measurement method are based on the classification criteria for stream type with modifications based on best professional judgement. Note, the performance 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 performance standards for a C-type channel.

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

<u>Detailed Method</u>

Measure ER at riffle features from surveyed cross sections. Field instructions for measuring a cross section are provided on pages 2-13 through 2-18 of Rosgen (2014). 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.

<u>Rapid Method</u>

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, 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 (7).
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 (7).
7. Measure the length of the riffle and repeat these measurements for every riffle to enter values into Equation (8) if needed.

4.3. Geomorphology

The SQT contains six function-based parameters to describe the transport of wood an sediment to create diverse bed forms and 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. Refer to section 3.1. of this manual for guidance on selecting parameters for a stream restoration project.

4.3.a. 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 SQT.

For both measurement methods in the 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 performance standards are based on data collected throughout the Piedmont and Mountain regions of North Carolina. A limited data set is available for the Coastal region. As more data are collected, additional performance standard curves will be developed.

1. 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).

The Forest Service manual 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).

2. Piece Count

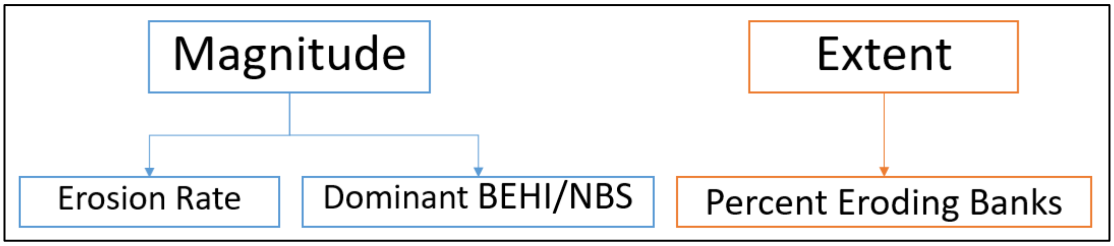
For this measurement method, the pieces of LWD within or touching the active channel of a stream are simply counted. For debris dams, each piece within the dam that qualifies as LWD is counted as a piece. This procedure and the rapid method data form are included in Appendix B.

4.3.b. 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 (Leopold, 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 to use two of these measurement methods 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 12). Percent eroding bank should not be used alone to describe lateral stability.

Figure 12: 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.

1. 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. Since mitigation projects require five to seven years of post-restoration data, a good estimate of the lateral erosion rate is likely. However, if there are only two years of pre-restoration data (two years or less between site identification and construction is common), it is unlikely that a reasonable estimate of bank erosion can be determined for the pre-restoration condition. Therefore, this measurement method will be more common for research-oriented projects than mitigation projects.

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, 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 SQT, calculate the weighted average of the erosion rates using the lengths of each bank segment.

Equation (9)

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

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

The performance standards for erosion rate are based on data collected in North Carolina streams and compared to national datasets.

2. Dominant BEHI/NBS

The dominant BEHI/NBS are 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 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 dominate BEHI/NBS category is included below.

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 8.

Table 8: 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

Total Percent by Category:

Low/Low = 32
High/High = 8+20+20 = 48
Mod/High = 14
Low/Mod = 6

The dominant BEHI/NBS is determined by summing the percent of total (4th column of Table 10) of eroding bank in each BEHI/NBS category (2nd column). For the example in Table 9, there are four BEHI/NBS categories present, as shown in the box to the left. 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 performance 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 9 shows the scoring associated with BEHI/NBS categories.

Table 9: BEHI/NBS Category Performance 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

3. 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 10) should be considered as an eroding bank.

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

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 9 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 9). Therefore, 96/1100 = 9% streambank erosion.

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

4.3.c. Riparian Vegetation

Riparian vegetation is a critical component of a healthy stream ecosystem and is defined as plant communities contiguous to and affected by surface and subsurface hydrologic features of perennial or intermittent water bodies. 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). In addition, riparian vegetation is supported by hydrology and hydraulic functions. For example, the amount of water transported to the channel from surface and subsurface flow paths effects the composition and growth of riparian vegetation. And the flow regime in the channel (velocity and shear stress) also effects the health and stability of streamside vegetation. Therefore, riparian vegetation is placed within the geomorphology functional category.

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

1. Basal Area

Figure 13. Measuring tree basal area.

Basal area is the cross-sectional area (ft^2) 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. For detailed instruction on setting up sampling plots refer to *Monitoring Requirements and Performance Standards for Compensatory Mitigation in North Carolina* (USACE Wilmington District, 2013). Measure the diameter at breast height (DBH) for all trees in each sampling plot (Figure 13). 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 mature forests and not pastureland, cropland, or other land uses without mature trees. Compute the cross-sectional area (square feet) of the tree at DBH (measured in inches) using the following equation:

Equation (10): $$BA = 0.005454 * DBH^2$$

The measurement method for basal area is reported as the ratio of basal area per acre of riparian area (ft^2/ac). This value should be calculated for each plot and then averaged to obtain a field value for the 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 ft^2) wedge prism is recommended. Instructions for using a wedge prism are described in Avery & Burkhart (2002).

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

2. 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. The guidance for setting up and monitoring vegetation plots is detailed in *Monitoring Requirements and Performance Standards for Compensatory Mitigation in North Carolina* (USACE Wilmington District, 2013) and the *Wilmington District Stream and Wetland Compensatory Mitigation Update* (2016).

Performance standards are based on the compensatory mitigation performance standards at the end of a typical 5-year monitoring period for stream mitigation (USACE Wilmington District, 2013). Note that the maximum index score for this measurement method is 0.5 (functioning-at-risk). It is expected that if riparian vegetation can reach tree size (>3 inch DBH) within the monitoring period, the basal area measurement method will be used instead of stem density.

3. Buffer Width

The riparian buffer width is measured horizontally from the top of the stream bank to the edge of the riparian vegetation community or the edge of the valley if the riparian buffer is not disrupted by utility easements, roads, or other gaps in riparian vegetation cover. Procedures for measuring buffer width are provided below (taken from NC IRT, 2009):

> "Buffer width calculations will be made separately for each side of the stream and then totaled for the entire stream reach. The reach will first be broken into 100-foot segments along the thalweg length of the mitigation site starting at the uppermost end of the mitigation reach. The average width of the segment is then calculated for each segment of the stream by averaging the sum of the buffer widths measured at each of the segment boundaries and the mid-point of the segment. The buffer width is measured horizontally from the bankfull elevation to the conservation easement boundary line. The stream channel between the left and right side bankfull elevations are not included in the measurements."

Buffer width measurements will be perpendicular to the fall-line of the valley. Performance standards are based on the regulatory guidance for stream mitigation in North Carolina and meta-analysis findings published by Mayer, et al. (2005).

4. Canopy Coverage

Canopy coverage is measured using a densiometer. For detail on how to use the densiometer refer to the device instructions or Using Forest Densiometers (Forestry Suppliers. Inc., 2008). The percent canopy coverage is estimated by counting how much of the densiometer grid is (or is not) occupied by canopy cover. This is done at four locations, facing each of the cardinal directions. This measurement method is an assessment of riparian vegetation health rather than stream shading. Measurements should not be taken from the stream channel or on the stream banks.

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

4.3.d. 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).[11]

The following steps are required for the assessment reach and the reference reach. A reference reach 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 catchment upstream of an unstable 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, performance standards for p-values associated with bed material characterization are provided in Table 10.

[11] www.fs.fed.us/biology/nsaec/assets/size-classpebblecountanalyzer2007.xls

Table 10: Bed Material Characterization Performance 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

4.3.e. 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 (Leopold, 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.

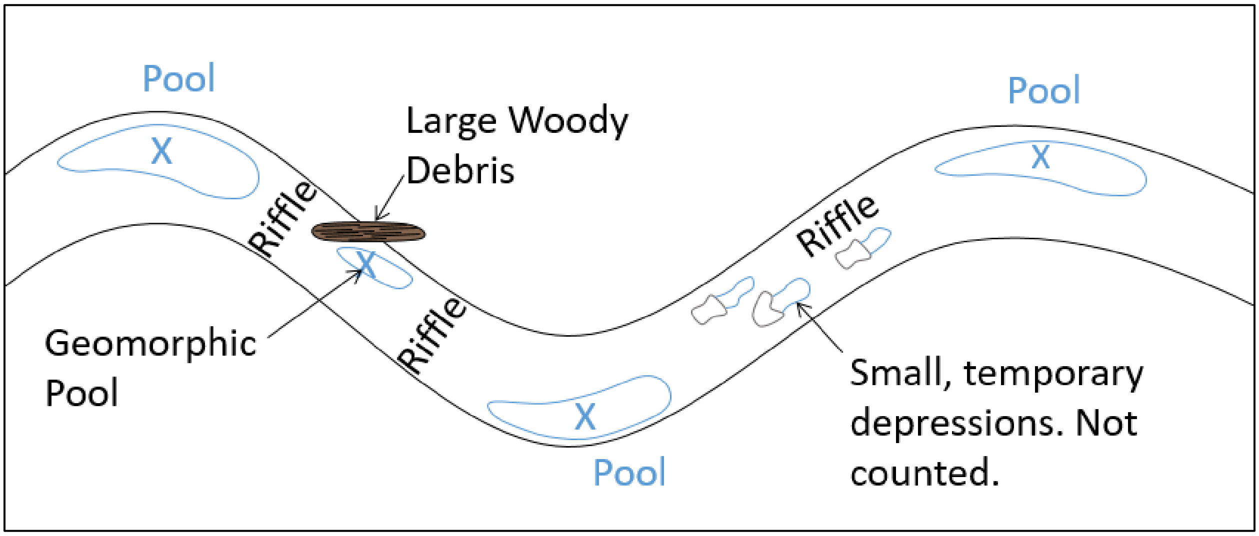
<u>Identifying Pools in Alluvial-Valley Streams</u>

For use with the 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 two 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 14 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.

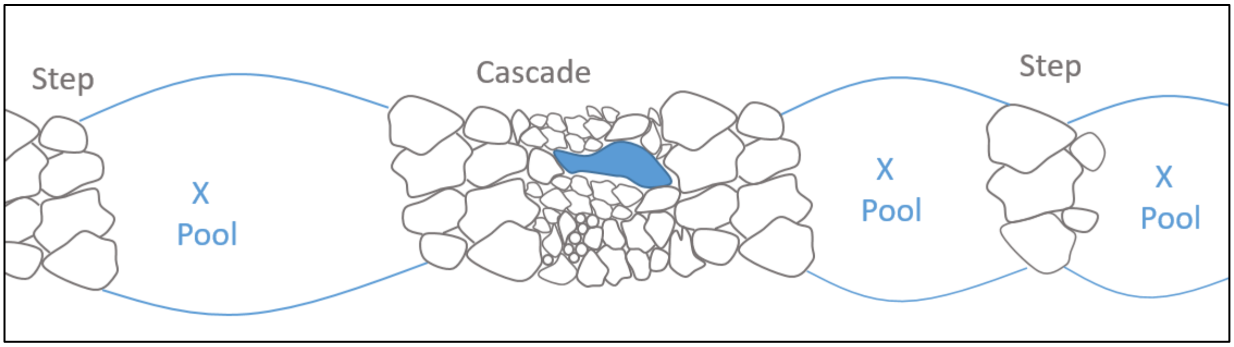
Figure 14: Pool Spacing in Alluvial Valley Streams (X marks the Dmax location of pools counted for pool spacing)



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 15. For these bed forms, pools are only counted at the downstream end of the cascade. Micro-pools within the cascade are not included.

Figure 15: Pool Spacing in Colluvial and V-Shaped Valleys (X marks the Dmax location of pools counted for pool spacing)



2. Pool Spacing Ratio

The pool spacing ratio is the calculation of the pool spacing divided by the bankfull riffle width. The bankfull riffle width is from one representative riffle cross section rather than measured at each riffle. Pool-to-pool spacing is essentially a measure of how many pools are present within the given reach. A low ratio means more pools and fewer riffles; a high ratio means fewer pools and more riffles. 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.

Equation (11)

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

The pool spacing ratio is calculated for each pair of sequential pools in the assessment reach. Since the performance standard curve is bell-shaped for meandering channels, low and high field values (both non-functioning) could average to a functioning score. Therefore, an averaged pool spacing ratio is not the recommended field value. Instead, the field value entered in the SQT should be a representative value based on best professional judgement and consideration of the complete ratio dataset.

Performance standards are stratified by stream slope and drainage area. Performance standards were developed based on a review of published studies (Lowther, 2008; Rosgen, 2014; Zink et al., 2012) and data collected by the authors throughout North Carolina and the Appalachian Mountains.

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. Instructions for measuring a longitudinal profile are provided on page 2-20 of Rosgen (2014). Procedures for surveying a representative riffle cross section and determining bankfull are also provided in Rosgen (2014).

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 representative riffle is selected from within the sampling reach and the bankfull width of this representative riffle is measured with a tape and recorded to calculate the pool-to-pool spacing ratio for each pair of pools using Equation (11).

3. 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 representative riffle cross section rather than measured at each riffle. 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 (12)

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

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 SQT. The detailed and rapid methods of field data collection are provided below.

Performance standards are stratified by stream type and bed material. Performance standards were developed based on data collected in NC streams (Lowther, 2008; Rosgen, 2014; and Zink, 2012).

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 are provided on page 2-20 of Rosgen (2014). Mean riffle depth is calculated from a surveyed riffle cross section. Procedures for surveying a representative riffle cross section and determining bankfull are also provided in Rosgen (2014).

Rapid Method

The rapid-based assessment requires that the maximum bankfull depth of each pool in the reach be recorded. A representative 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 (12) 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.

4. 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 performance standards are not provided. However, if practitioners choose to calculate percent pool, the glide features should be included in the percent pool calculation.

Performance standards are stratified by stream slope and were developed based on data collected in NC streams (Lowther, 2008; and best professional judgement).

Detailed Method

For the detailed assessment method, the percent riffle is measured from a longitudinal profile of the stream thalweg. Instructions for measuring a longitudinal profile are provided on page 2-20 of Rosgen (2014).

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.

5. 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 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 13; Table 11). This measurement method will l be used mainly for C and E stream types, but could also apply to some Bc and B stream types.

Equation (13)

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

Table 11: Reference Bankfull WDR Values by Stream Type

Stream Type	Reference WDR
B	16
C	13
E	9

Performance 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 12.

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 12.

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.

4.3.f. 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 orthoimagery [12] in the office. Sinuosity calculations are described in more detail on page 2-32 of Rosgen (2014). 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 ceenterline 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 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.

[12] Recent orthoimagery for NC is available for download from http://fris.nc.gov

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

4.4. Physicochemical

The 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. Specific conductivity is also included in the BMP Routine of the SQT. Few projects will enter values for all physicochemical parameters; refer to section 3.1. of this manual for guidance on selecting parameters for a stream restoration project.

4.4.a. Temperature

Temperature plays a key role in both physicochemical and biological functions. For example, each species of fish have an optimal growth temperature but can survive a wider range of thermal conditions. Water temperature also influences conductivity, dissolved oxygen concentration, rates of aqueous chemical reactions, and toxicity of some pollutants. These factors directly impact the water quality and ability of living organisms to survive in the stream.

There is one measurement method for this parameter: daily maximum temperature. The field value for the daily maximum temperature (measured in degrees Fahrenheit) is the maximum temperature in the period of record that is sustained for at least 2 hours. Placement and use of in-water temperature sensors should follow the *Best Practices for Continuous Monitoring of Temperature and Flow in Wadeable Streams* (USEPA, 2014).

Note that this procedure requires the deployment of an air temperature sensor as well. The procedure covers sensor selection, calibration, sensor placement, and data QAQC. For the NC SQT, the monitoring period is the summer season of the sampling year. The sensors should be set to record point temperature measurements at intervals that do not exceed 30 minutes.

The performance standards for this parameter are based on the lethal and optimum temperatures for coldwater and cool water fish habitats (Morrow & Fischenich, 2000).

4.4.b. Specific Conductivity – BMP Routine

Specific conductance measures the amount of dissolved ions in water. Freshwater aquatic species have tolerance limits for overall ion concentrations and dissolved oxygen before their vigor and survival are affected. Specific conductivity is optional and is only used in the BMP Routine. This parameter requires a specific conductance meter to measure the conductance at the BMP outlet. Specific conductance should be measured *in situ* following the procedure outlined by the *Intensive Survey Branch Standard Operating Procedures Manuals: Physical and Chemical Monitoring* (NC DENR, 2013). Samples should not be collected during or immediately after a rain event.

Performance standards are based on the findings from research performed by the NC Division of Water Quality (Gale, 2011).

4.4.c. Bacteria

Fecal coliforms are associated with pathogens that are a serious risk to human and animal health. This parameter is recommended for projects where cattle have access to the stream within the project reach. When cattle have free access to streams or pastureland with limited riparian buffer, cow manure can be deposited in the channel or washed in during a runoff event.

Fecal coliform will be measured by a laboratory. Sample collection procedures are outlined in section 2.3 of the *Intensive Survey Branch Standard Operating Procedures Manuals: Physical and Chemical Monitoring* (NC DENR, 2013). Samples should be collected at or near the downstream extent of the reach. The field value entered in the 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.

The performance standard for this measurement method is based on NC water quality standards for freshwater aquatic life of 200 cfu/100ml. The fully functioning condition is considered to be 0 cfu/100mL and a linear relationship was derived from these two points.

4.4.d. Organic Carbon

There are two measurement method options for quantifying organic carbon: leaf litter processing rate and percent shredders.

1. Leaf Litter Processing Rate

The leaf litter processing rate is a functional, rather than structural, measure of organic matter. The procedure for placing and monitoring leaf litter packs is outlined below with more detail available in Young, et al. (2008). Note that this study should be performed during peak-leaf fall if possible.

1. Acquire 2 coarse-mesh bags (0.1 cm aperture)
2. Identify a reference site (see section 3.4. Reference Reach Identification)
3. Pick leaves from trees in a single location and air dry. It is important that the leaves in both bags have the same leaf type and treatment. Do not fill the reference reach bag with leaves from the reference site and the project reach bag with leaves from the project reach. Fill both bags with leaves from one site: either the reference, project, or another site with sufficient leaf litter.
4. Place leaves in the bags and weigh them, placing roughly the same weight of leaves in each bag.
5. Securely fasten leaf bags to metal pegs (≥15-20 cm in length) and drive the pegs into a riffle section of each reach. The metal pegs are to be anchored to the stream bottom and driven beneath the bed surface. Bags should not be allowed to float.
6. Retrieve both leaf bags after 1 month. Note, if study is performed in the winter or fall a longer retention time may be needed.
7. Remove the leaf packs from the bags and allow them to dry. Weigh the leaf packs, take care to remove inorganic sediment from the sample as much as possible.
8. Using Microsoft Excel, or any mathematic software package such as MatLab, enter the data for the project site in two columns: time (days) and sample weight (g) (See Table

12, columns 1 and 2). Plot the data points as shown in Figure 16 and use the fit curve or plot trendline tool to fit an exponential trendline through the data points. The equation will be in the form of $y = ae^{k}$. Record the exponential decay coefficient as $k_{Project}$.

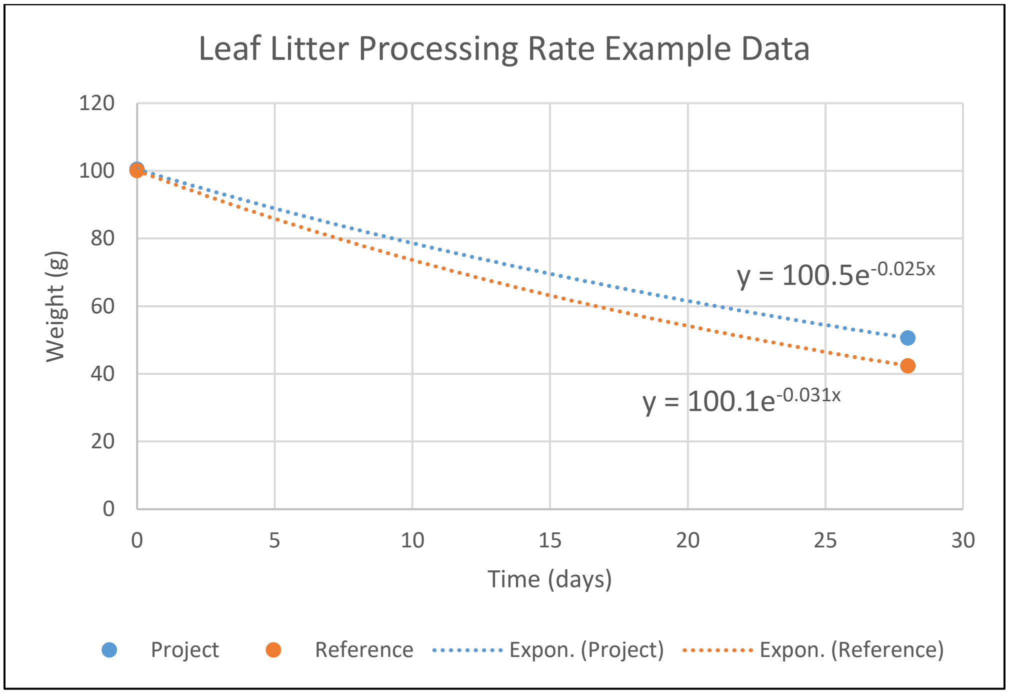
9. Repeat step 8 for the reference site. Record the exponential decay coefficient as $k_{Reference}$.
10. Calculate the ratio of $k_{Project}/k_{Reference}$, this is t
11. he field value entered into the SQT.

The performance standard for this measurement method follows the criterion laid out in Young, et al. (2008).

Table 12: Example Leaf Pack Decay Data

Time (days)	Weight (g)		Exponential Decay Coefficient		Field Value = $k_{Project}/k_{Reference}$
	Project	Reference	$k_{Project}$	$k_{Reference}$	
0	100.5	100.1	-0.025	-0.031	0.81
28	50.6	42.4			

Figure 16: Determining the Exponential Decay Coefficients



2. Percent Shredders

The diversity and taxa richness of aquatic macroinvertebrates are commonly used by regulatory agencies to determine water quality and sources of perturbations. The feeding ecologies of these insects are also very helpful to ecologists to determine stream function. This measurement method uses the presence of shredder organisms as a surrogate metric to determine the retention of organic material in newly restored streams. Shredder organisms are those benthic insects that pulverize primarily large pieces of decomposing vascular plant tissue (>1mm diameter) along with associated microflora and fauna, or feed directly on living vascular macrophytes or gouge decomposing wood (Wallace and Webster, 1996). Wallace and Webster note that upland streams receive a large portion of their energy as coarse particulate organic material from terrestrial inputs. Therefore, to function properly streams must retain and process this material.

Collection methods for macroinvertebrate samples should follow *Standard Operating Procedures (SOP) for the Collection and Analysis of Benthic Macroinvertebrates* (2016) from NCDEQ DWR. These protocols are semi-qualitative and use kick nets, sweep nets, leaf pack samples and visual inspections of the habitat for cryptic organisms. Specimens are collected, preserved in the field and identified in the laboratory. Care must be taken to note the ecoregion, stream size and data collection season when collecting benthic insect data and calculating shredder percentages. The same samples collected for macroinvertebrates (section 4.8.a. of this document) can and should be used for the shredder metric both before and after construction.

Once a macroinvertebrate sample is collected according to the SOPs, calculate the percent of organisms collected that are shredders. Table 13 lists some of the common shredder benthic insects found in North Carolina.

Table 13: List of Common Shredders in North Carolina

Mayflies • *Eurylophella spp*	Coleoptera • *Ancytarsus biocolor*
Stoneflies • *Amphineumura spp* • *Allocapnia spp* • *Leuctra spp* • *Paracapnia spp* • *Prostoia spp* • *Pteronarcys spp* • *Tallaperla spp* • *Viehoperla spp*	Diptera • *Brillia spp* • *Tipula spp* Caddisflies • *Anisocentropus spp* • *Ironoquia spp* • *Heteroplectron spp* • *Hydatophylax spp* • *Lepidostoma spp* • *Pycnopsyche spp* • *Triaenodes spp*

A rapid evaluation of the benthic community and presence of shredder organisms should be conducted to note pre-monitoring descriptive conditions. This may entail a collection of leaf packs in the project area or visual inspections of microhabitats prior to permitting.

Performance standards are stratified by ecoregion, stream size and data collection season and are based on data collected throughout North Carolina by NCDEQ DWR and analyzed by Dave Penrose with Penrose Environmental.

4.4.e. Nitrogen

The nitrogen parameter is included in both the BMP Routine and the reach condition assessments. Total Nitrogen (TN) is assessed as a concentration in mg/L for projects that will include stormwater BMPs adjacent to the stream restoration project or in-stream if nitrogen is expected to be improved by restoration activities. For urban BMP projects, nitrogen can be modeled using the Jordan/Falls Lake Stormwater Nutrient Load Accounting Tool (JFSLAT)[13] to estimate the TN concentration. Field values will be entered in the BMP Routine. However, if the practitioner or regulator believes that the BMPs and/or the restoration practices could affect the receiving stream (i.e. the stream restoration project reach), TN could be monitored in the stream and values entered into the SQT reach assessments as well.

[13] Current version is v2.0 from May 2013, available through NCDEQ DWR: http://portal.ncdenr.org/web/fallslake/rules-implementation-information

If a BMP is being installed, then the JFSLAT should be used. The JFSLAT estimates the amount of TN typical in runoff from various land uses and has built in typical removal rates for a variety of BMPs. The User Manual for JFSLAT (NC DENR & NC State Bio & Ag Engineering, 2011) provides instruction for using the spreadsheet tool and describes the existing catchment and BMPs installed. The Development Summary Tab of this spreadsheet provides the Total Nitrogen (mg/L) for post-development conditions (to be entered as the existing condition field value) and post-development w/ BMPs (to be entered as the proposed condition field value).

If reach monitoring is being performed, Total Kjeldahl Nitrogen (TKN) and Nitrite/Nitrate will be measured by a laboratory. TN is the total of TKN and nitrite/nitrate. Sample collection procedures are outlined in section 2.22 of the *Intensive Survey Branch Standard Operating Procedures Manuals: Physical and Chemical Monitoring* (NC DEQ, 2013). 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]

Performance standards for this measurement method are based on Schueler (2000) and Harden, *et al.* (2013).

4.4.f. Phosphorus

Phosphorus is assessed for projects that include stormwater BMPs adjacent to the stream restoration project or stream reaches where phosphorus is expected to be improved by restoration activities. The measurement method for phosphorous is the Total Phosphorous (TP) concentration in mg/L. Phosphorus occurs in both the BMP Routine and the reach condition assessments. For most projects, phosphorus can be modeled using the Jordan/Falls Lake Stormwater Nutrient Load Accounting Tool (JFSLAT) to estimate the TP and field values will be entered in the BMP Routine. However, if the practitioner or regulator believes that the BMPs and/or the restoration practices could affect the receiving stream (i.e. the stream restoration project reach), TP could be monitored in the stream and values entered into the SQT reach assessments as well.

If a BMP is being installed, then the JFSLAT should be used. The JFSLAT estimates the amount of TP typical in runoff from various land uses and has built in typical removal rates for a variety of BMPs. The User Manual for JFSLAT (NC DENR & NC State Bio & Ag Engineering, 2011) provides instruction for using the spreadsheet tool the describe the existing catchment and BMPs installed. The Development Summary Tab of this spreadsheet provides the TP (mg/L) for post-development conditions (to be entered as the existing condition field value) and post-development w/ BMPs (to be entered as the proposed condition field value).

If reach monitoring is being performed, the user can collect water samples and have them analyzed to obtain actual values for TP pre- and post-construction. TP will be measured by a laboratory; sample collection procedures are outlined in section 2.22 of the *Intensive Survey Branch Standard Operating Procedures Manuals: Physical and Chemical Monitoring* (NC DEQ, 2013). For any project quantifying lift, the existing condition will need to be measured. For a

14 https://ncdenr.maps.arcgis.com/apps/webappviewer/index.html?id=5965f22e762143a3bdea66ea8bcf1f38

rapid assessment during site selection, the existing condition could be characterized using recent sampling data if available.[15]

Performance standards for this measurement method are based on Schueler (2000) and Harden, et al. (2013).

4.5. Biology

The SQT contains two function-based parameters to describe the biodiversity and life histories of aquatic life: macroinvertebrates and fish community structure. These parameters are included because they have documented performance standards in North Carolina. The macroinvertebrate bioclassification and fish index of biotic integrity (NCIBI) are common metrics applied throughout the state for determining the biological health of a stream. This is not a comprehensive collection of parameters to describe biologic function. Future versions of the SQT will include other parameters (e.g. amphibians, mussels, etc.) if data are available to determine performance standards. If possible, both macroinvertebrates and fish should be assessed. There have been restoration projects where the Biology functional category scored functioning while Geomorphology was functioning-at-risk, which seems to be counter to the logic of the SFPF (i.e., lower levels must be functioning to support higher levels). For a stream reach that is riffle dominated, scoring poorly in bed form diversity, the macroinvertebrates could score well since their habitat is present while the habitat for fish is missing. In this case, if macroinvertebrates are the only parameter assessed in the biology functional category then the SQT would indicate the biology is functioning. If fish communities were also assessed, the biology functional category would score functioning-at-risk.

4.5.a. Macroinvertebrates

Macroinvertebrates are an integral part of the food chain that supports healthy river ecosystems. There are two measurement methods for macroinvertebrates included in the SQT, both are from the *Standard Operating Procedures (SOP) for the Collection and Analysis of Benthic Macroinvertebrates* (2016) from NCDEQ DWR. These protocols are semi-qualitative and use kick nets, sweep nets, leaf pack samples and visual inspections of the habitat for cryptic organisms. Specimens are collected, preserved in the field and identified in the laboratory. Care must be taken to note the ecoregion, stream size and data collection season when collecting benthic insect data

The two measurement methods in the SQT correspond to the bioclassification criteria for the sampling procedures most likely to be used in stream restoration project sites. For example, NC DENR DWR has classification criteria for rivers that were not included in the SQT as they are unlikely to apply to restoration projects.

The Biotic Index measurement method is appropriate when (list taken from section 4.6.4 of the SOPs):

- Drainage area is less than or equal to 3 square miles;
- Site is located within either the mountain or piedmont ecoregion;

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15 https://ncdenr.maps.arcgis.com/apps/webappviewer/index.html?id=5965f22e762143a3bdea66ea8bcf1f38

- Site is not within the Triassic Basin Level IV ecoregion;
- Sample was collected between April 1 and June 30; and
- Qual-4 sample method was used.

The EPT Taxa measurement method is appropriate when (list taken from section 4.6.1 of the SOPs):

- EPT or Qual-4 sample method was used;
- Sample was collected from a coastal stream that normally flows throughout the year, or from a mountain or piedmont stream;
- Drainage area above the site is greater than 3 square miles; and
- The sample was not collected from the Triassic Basin Level IV ecoregion.

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]

The performance standards for this measurement method are based on the criteria established by NCDEQ to determine bioclassifications. Excellent and good bioclassifications correspond to a functioning score while poor and fair bioclassifications indicate that the macroinvertebrates parameter is not functioning.

4.5.b. Fish

Fish are an integral part of the food chain that supports healthy perennial river ecosystems. The measurement method for fish included in the SQT is from the *SOP for the Stream Fish Community Assessment Program* (2013b) from NCDENR. The procedures for sample collection, calculating the NCIBI, and the limitations of applying the NCIBI are provided in that document. 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]

The performance standards for this measurement method are based on the criteria established by NCDENR to determine the integrity class of a stream. An integrity classification of excellent or good indicates that the fish parameter is functioning while an integrity classification of poor or fair indicates that the fish parameter is not functioning.

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16 https://ncdenr.maps.arcgis.com/apps/webappviewer/index.html?id=62b93004f5a64fc0ae86a6b7cf51ff2a

17 http://ncdenr.maps.arcgis.com/apps/webappviewer/index.html?id=43100b4143af4834a9dfaaf32ca6bd44

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Appendix A

Catchment Assessment

Catchment Assessment Form

Rater(s):

Date:

Overall Catchment Condition	
Restoration Potential	

Purpose: This form is used to determine the project's restoration potential.

CATCHMENT ASSESSMENT

	Categories	Description of Catchment Condition			Rating (P/F/G)
		Poor	Fair	Good	
1	Concentrated Flow (Hydrology)	Potential for concentrated flow/impairments immediately upstream of the project and no treatments are in place	Some potential for concentrated flow/impairments to reach restoration site, however, measures are in place to protect resources	No potential for concentrated flow/impairments from adjacent land use	
2	Impervious cover (Hydrology)	Greater than 25%	Between 10% and 25%	Less than 10%	
3	Land Use Change (Hydrology)	Rapidly urbanizing/urban	Single family homes/suburban	Rural communities/slow growth or primarily forested	
4	Distance to Roads (Hydrology)	Roads located in or adjacent to project reach and/or major roads proposed in 10 year DOT plans	No roads in or adjacent to project reach. No more than one major road proposed in 10 year DOT plans.	No roads in or adjacent to project reach. No proposed roads in 10 year DOT plans.	
5	Percent Forested (Hydrology)	<= 20%	>20% and <70%	>=70%	
6	Riparian Vegetation (Geomorphology)	<50% of contributing stream length has > 25 ft corridor width	50-80% of contributing stream length has > 25 ft corridor width	>80% of contributing stream length has > 25 ft corridor width	
7	Sediment Supply (Geomorphology)	High sediment supply from upstream bank erosion and surface runoff	Moderate sediment supply from upstream bank erosion and surface runoff	Low sediment supply. Upstream bank erosion and surface runoff is minimal	
8	Located on or downstream of a 303(d) listed stream TMDL list (Physicochemical)	On, upstream, or downstream of 303(d) and no TMDL/WS Mgmt plan to address deficiencies	On, upstream, or downstream of 303(d) and TMDL/WS Mgmt plan addressing deficiencies	Not on 303(d) list	
9	Agricultural Land Use (Physicochemical)	Livestock access to stream and/or intensive cropland immediately upstream of project reach.	Livestock access to stream and/or intensive cropland upstream of project reach. A sufficient reach of stream is between Ag. land use and project reach.	There is little to no agricultural land uses or the livestock or cropland is far enough away from project reach to cause no impact to water quality or biology.	
10	NPDES Permits (Physicochemical)	Many NPDES permits within catchment or some within one mile of project reach	A few NPDES permits within catchment and none within one mile of project reach	No NPDES permits within catchment and none within one mile of project reach	
11	Specific Conductance (uS/cm at 25oC) (Physicochemical)	Piedmont = >229; Blue Ridge = >66	Piedmont = 78-229; Blue Ridge = 41-66	Piedmont = <78; Blue Ridge = <41	
12	Watershed impoundments (Biology)	Impoundment(s) located within 1 mile upstream or downstream of project area and/or has a negative effect on project area and fish passage	No impoundment within 1 mile upstream or downstream of project area OR impoundment does not adversely affect project area but a blockage could exist outside of 1 mile and impact fish passage	No impoundment upstream or downstream of project area OR impoundment provides beneficial effect on project area and allows for fish passage	
13	Organism Recruitment (Biology)	Channel immediately upstream or downstream of project reach is concrete, piped, or hardened.	Channel immediately upstream or downstream of project reach has native bed and bank material, but is impaired.	Channel immediately upstream or downstream of project reach has native bed and bank material.	
14	Percent of Catchment being Enhanced or Restored	Less than 40% of the total catchment area is draining to the project reach.	40 to 60% of the total catchment area is draining to the project reach.	Greater than 60% of the total catchment area is draining to the project reach.	
15	Other				

Appendix B

Rapid Data Collection Methods

for the North Carolina Stream Quantification Tool

Table of Contents

I. Introduction and Purpose

The purpose of this document is to provide instruction on how to collect and analyze data needed to run the Stream Quantification Tool (SQT) using the rapid method. The rapid method is a suite of office and field techniques specific to the SQT for collecting quantitative data. While the SQT is **not** a rapid assessment method, there are methods provided for quickly collecting quantitative data to input into the spreadsheet.

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 SQT is being used as part of a mitigation plan or monitoring report. These applications require detailed assessment methods.

A rapid assessment will typically take one to three hours to complete per project reach. Required pyramid-level 2 and 3 parameters are quantitatively measured; however, standard surveying equipment like laser levels or a total station are not used. Instead, survey tapes and stadia rods are used to simply take the measurements in the field. Keep in mind that cross sections and profiles cannot be plotted using this method.

This appendix compiles instructions from the *North Carolina Stream Quantification Tool Data Collection and Analysis Manual* (data collection manual) so that all rapid measures can be read in one place. Few measurements are unique to the 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 SQT.

A Stream Quantification Tool Rapid Assessment Form (field form) is included in Section VI of this appendix and can be used with these instructions to collect field data. This field form is also available as a Microsoft Excel Workbook where data can be entered upon returning from the field. [1]

II. Rapid Method Parameter List

Not all function-based parameters included in the SQT can be assessed using the rapid methodology and while an effort is made to minimize the amount of time required to implement the rapid method, some parameters require the same level of effort as the detailed analysis. A list of function-based parameters and measurement methods that are included in the rapid method is provided below. The rapid method is divided into two efforts: an office / desktop component and a fieldwork component. Items in the list below are noted as being part of the (1) desktop component or (2) fieldwork component.

- Catchment Hydrology
    - Curve number (1, optional)
- Reach Runoff
    - Concentrated flow points (2)

[1] Microsoft Excel version of the field form is available from the Stream Mechanics website: https://stream-mechanics.com/stream-functions-pyramid-framework/

  - Curve number (1)
- Floodplain Connectivity
  - Bank Height Ratio (2)
  - Entrenchment Ratio (2)
- Large Woody Debris
  - Piece Count (2)
- Lateral Stability
  - Dominant BEHI / NBS (2)
  - Percent Stream Erosion (2)
- Bedform Diversity
  - Pool Spacing Ratio (2)
  - Pool Depth Ratio (2)
  - Percent Riffle (2)
  - Aggradation (2)
- Sinuosity (1)
- Riparian Vegetation
  - Buffer width (2)
  - Basal Area (2)
  - Canopy density (2, optional)
- Temperature (1)
- Nitrogen (1)
- Phosphorus (1)
- Bacteria (1)
- Macros (1)
- Fish (1)

The next two chapters outline the rapid data collection methods for the SQT. The desktop component is described first, followed by the field component.

III. Desktop Component

Certain desktop tasks must be completed prior to collecting field data while a second portion of the desktop tasks can be completed after the fieldwork.

<u>Before Fieldwork</u>:

1. Determine reach breaks. Save a copy of the SQT and the field form for each reach within the project and begin entering data.

The SQT is a reach based tool and requires one Excel Workbook for each reach contained within the project. For long homogenous reaches, a sub-reach can be assessed to represent the overall reach. Refer to Section 2.1 of the data collection manual for detailed guidance on reach delineation.

Enter the stream reach length (measured in feet) into the Site Information and Stratification section of the SQT and the rapid method form. Many of the desktop components below can be entered in to the SQT for each stream reach.

2. Determine the region, river basin, and local geology of the project.

This background data will help in understanding and interpreting the field data. Enter values for the region and river basin into the Site Information and Stratification section of the SQT and on the field form for each reach.

3. Delineate the catchment for each reach.

The catchment is the land area draining to the downstream end of the reach; its delineation is necessary to complete the catchment assessment form and the reach runoff assessment. Additionally, the drainage area of the reach is used calculate bankfull dimensions from the regional curve. Enter the drainage area for the reach (measured in square miles) into the Site Information and Stratification section of the SQT and the field form.

4. Complete the catchment assessment worksheet in the SQT.

Methods and links to relevant online data sources for each category in the catchment assessment are provided in Section 2.2 of the data collection manual. The catchment assessment is used to identify possible constraints and conditions that limit the restoration potential of the reach. This background data will also help in understanding and interpreting field data. A catchment assessment should be completed for every reach within a project although values may be similar for reaches located on the same stream.

5. Obtain bankfull regional curves.

Ideally the regional curve has been developed specifically for the study catchment. NC State University's Stream Restoration Program provides published papers, data and equations for North Carolina regional curves. [2]

6. Calculate regional curve dimensions.

This data is used to verify the bankfull indicators observed in the field. The regional curve dimensions should be entered into Section III of the rapid method form (Lines E, F, and G). The user should enter the name or description of the bankfull regional curve applied in Line H (e.g. project specific or rural Piedmont). Bankfull verification is discussed in more detail in Section 3.3 of the data collection manual.

7. Review recent orthoimagery and elevation data to measure or estimate valley widths, sinuosity, and riparian buffer widths.

Determine the valley type (unconfined alluvial, confined alluvial, or colluvial) for each reach in the SQT and the field form. The entrenchment ratio measurement method varies with valley width. On maps that will be taken into the field, mark locations where valley width changes and valley measurements will need to be taken.

[2] http://www.bae.ncsu.edu/programs/extension/wqg/srp/techresources.html

Instructions for measuring the sinuosity of a reach are provided in both the desktop and fieldwork components. Given the prevalence and quality of aerial imagery, sinuosity can most often be measured from the office. For small streams and/or streams with significant canopy cover it may be difficult to determine sinuosity in the office and it should be noted to measure or confirm sinuosity in the field. Procedures for measuring the sinuosity of a reach using recent orthoimagery are provided below.

The extent of riparian vegetation can also be estimated from the recent orthoimagery but should be verified in the field.

Desktop components that can be completed after fieldwork:

8. Characterize land uses in the lateral drainage area delineated for each reach.

Curve number is a measurement method for the catchment hydrology and reach runoff parameters that requires characterizing the land use of the reach catchment and the area that drains laterally to each reach, respectively.

9. Collect and interpret available data for physicochemical and biology parameters.

It is important to score the physicochemical and biological functional categories in the SQT but difficult to assess these categories rapidly. In NC, data may be publicly available near the project reach to assess these functional levels. Available state and local data should be collected and assessed as to whether the data can be applied to the project reaches.

Specific measurement methods in the SQT that are assessed in the desktop component are described in the following sections.

III.a. Curve Number (CN) – Catchment Hydrology

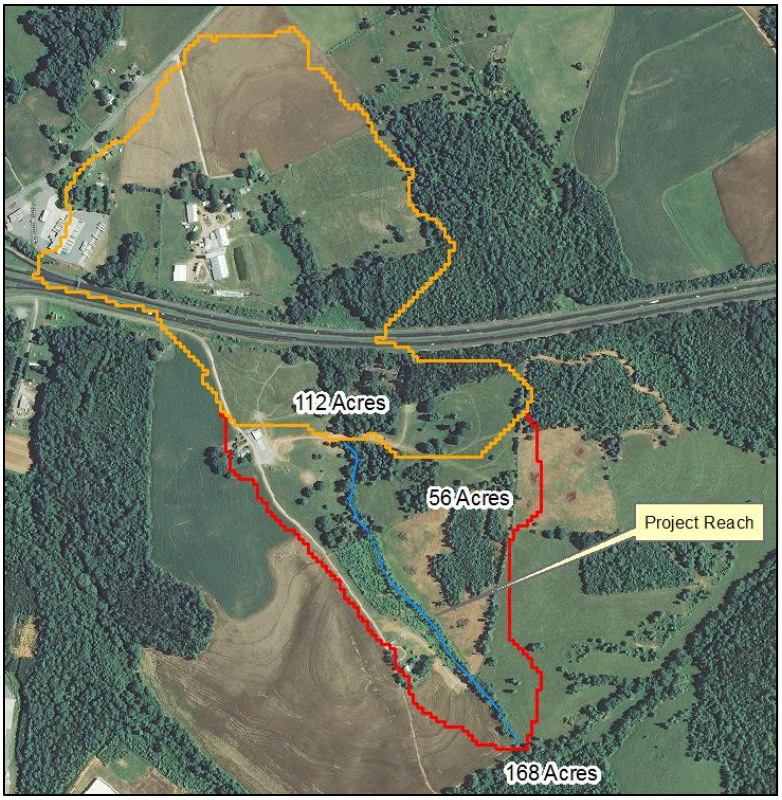
The curve number measurement method characterizes the land use of the catchment upstream of the stream reach. This parameter and measurement method are optional for the rapid method. To determine the field value:

1. Delineate the different land use types using the best matching description from TR-55 (NRCS, 1986). This can be accomplished using recent orthoimagery of the site or, less accurately, using land use data from the National Land Cover Dataset (NLCD). [3]
2. Calculate the percent of the total lateral drainage area that is occupied by each land use.
3. Match each land use to the best fitting description from Tables 2-2a, 2-2b, and 2-2c in TR-55 (NRCS, 1986).
4. For each land use, multiply the percent of the total lateral drainage area (step 2) by the CN that corresponds to the land use from step 3.
5. Calculate an area-weighted curve number for the lateral drainage area of the reach by summing the results from step 4. This is the field value for the CN measurement method in the Quantification Tool worksheet of the SQT.

[3] https://gapanalysis.usgs.gov/gaplandcover/data/download/

This calculation will yield and existing condition curve number, an example is provided in Table 5 of the Data Collection and Analysis Manual. Most stream restoration projects will not change the catchment hydrology score between the existing and proposed condition. In this scenario, the catchment hydrology score simply effects the overall hydrology category score. If the expected planting area or easement boundary includes a large portion of the catchment upstream of the stream restoration reaches, then a new area-weighted curve number for the catchment upstream the stream reach can be calculated for the proposed condition.

Figure B.1: Upstream Catchment (Orange) and Lateral Drainage Area (Red) Delineation Example



III.b. Curve Number (CN) – Reach Runoff

This measurement method is identical to the curve number measurement method for catchment hydrology but applied to the land that drains directly to the project reach (for example, the 56-acre area delineated in Figure B.1). To determine the field value:

1. Delineate the different land use types using the best matching description from TR-55 (NRCS, 1986). This can be accomplished using recent orthoimagery of the site or, less accurately, using land use data from the National Land Cover Dataset (NLCD). [4]
2. Calculate the percent of the total lateral drainage area that is occupied by each land use.

[4] https://gapanalysis.usgs.gov/gaplandcover/data/download/

3. Match each land use to the best fitting description from Tables 2-2a, 2-2b, and 2-2c in TR-55 (NRCS, 1986).
4. For each land use, multiply the percent of the total lateral drainage area (step 2) by the CN that corresponds to the land use from step 3.
5. Calculate an area-weighted curve number for the lateral drainage area of the reach by summing the results from step 4. This is the field value for the CN measurement method in the Quantification Tool worksheet of the SQT.

This calculation will yield and existing condition curve number, an example is provided in Table 5 of the Data Collection and Analysis Manual. For the proposed condition, use the expected planting area or easement boundary to determine the land use change and calculate a new area-weighted curve number for the catchment that drains laterally into the stream reach.

III.c. Sinuosity

Sinuosity is measured from the plan form of the stream reach. The sinuosity of a stream is calculated by dividing the thalweg distance by the straight-line valley length between two common points. Sinuosity calculations are described in more detail on page 2-32 of Rosgen (2014). 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. [5]

1. Download recent orthoimagery available for the site.
2. Determine the minimum length required using the bankfull width from the regional curve.
3. Trace out the path on the recent orthoimagery for at least the distance determined in Step 2.
4. Measure the straight line valley distance between the beginning and the end of the traced stream path.
5. Calculate sinuosity by dividing the stream length by the valley length.

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 instructions are provided in Section IV.k of this appendix.

III.d. Temperature, Nitrogen, Phosphorus, Bacteria

Data for measurement methods within the physicochemical functional category may be available through water quality monitoring databases. Integrated Reports are published every two years by NCDENR for surface water bodies in the state with Surface Water Classifications. These reports and the data are available from the NCDENR [6] and EPA STORET [7].

[5] Recent orthoimagery for NC is available for download from http://fris.nc.gov
[6] Integrated Reports are available from: https://deq.nc.gov/about/divisions/water-resources/planning/modeling-assessment/water-quality-data-assessment/integrated-report-files
[7] https://www.epa.gov/waterdata/storage-and-retrieval-and-water-quality-exchange

These data should be reviewed for the project reaches or surrounding water bodies to determine whether physicochemical parameters are likely 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.

III.e. Macros and Fish

Data for measurement methods within the biology functional category may be available through state monitoring databases as well. Macroinvertebrates and fish communities are assessed as part of the Surface Water Classifications assessment in addition to water quality. This data is available from NCDENR in the Integrated Report published every two years. The NCDENR Biologic Assessment Branch stores data on EPA STORET in addition to their web site. [8]

These data should be reviewed for the project reaches or surrounding water bodies to determine whether macroinvertebrate and 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.

IV. Fieldwork Component

This section follows the Stream Quantification Tool Rapid Assessment Form (field form) provided in Section VI of this appendix. This section provides instructions for completing each section of the field form and entering the field data into the SQT. The field form is also available for download as a Microsoft Excel Workbook. There is a shading key for the field form indicating which cells of the workbook are intended to be filled out in the office versus the field, and which cells in the workbook perform calculations. The calculation cells are blank and can be filled out on a printed field form but in the workbook version, these cells will automatically calculate values from provided field data.

A basic outline of the fieldwork component of the rapid assessment is provided below while detailed instructions are provided in the subsequent sections.

1. Fill out any desktop values on the field forms for all reaches and print. This includes data in Sections I and III of the field form.
2. Walk the reach. (Section II of the field form)
    a. Determine assessment segment (segment roughly 20 times the bankfull width or two meander wavelengths).
    b. Identify representative riffle cross section locations.
    c. Measure difference between bankfull stage and water surface elevation at bankfull features throughout the reach.
    d. Count concentrated flow points.
3. Survey representative riffle.

[8] https://deq.nc.gov/about/divisions/water-resources/water-resources-data/water-sciences-home-page/biological-assessment-branch/dwr-benthos-data

   a. Collect bankfull dimensions for bankfull verification. (Section III of field form)
   b. Determine stream type. (Section IV of the field form)
4. Stretch a tape along the thalweg of the assessment segment. Start and end the assessment segment at the head of a riffle. (Sections V through VIII of the field form)
   a. Record assessment segment length.
   b. Estimate the slope of the reach.
   c. Working from upstream to downstream, take measurements at every riffle and pool within the assessment segment.
   d. Identify 100 meters within assessment segment with highest number of pieces of large wood and count the number of pieces.
   e. Perform a BEHI/NBS assessment for all eroding banks and banks with the potential to erode within the assessment segment.
5. Assess riparian vegetation for the entire stream reach. (Section IX of the field form)
   a. Measure canopy density (optional) and basal area at representative points throughout the project reach.
   b. Measure riparian buffer width using valley transects throughout reach.

At a minimum, the following gear will be needed to perform the field portion of a rapid assessment:

- Field forms and maps
- Waders
- Stadia rod
- Hand level (line level can be used for small streams)
- Ruler
- 100’ Tape
- Enough 300’ tapes for the assessment reach length
- Basal area wedge prism
- Canopy Densiometer*
- GPS unit* (helpful with lateral stability and sinuosity field measurements)

*Denotes item is optional.

IV.a. Site information and Stratification

The Site Information and Performance Standard Stratification section consists of general site information and information necessary to determine what performance standards are applied in the SQT for calculating index values of some measurement methods. Some of the data in this section of the SQT will be determined in the field. The list below includes site information and stratifying information listed on the field form. Items in the list below are noted as being determined (1) in the office (2) in the field.

- Project name (1)
- Reach ID (1)
- Drainage Area (1)
- Stream Reach Length (aka Existing stream length) (1)
- Flow Type (1)
- River Basin (1)

- Existing stream type (2)
- Bed Material (2)
- Stream Slope (2)

Values shaded as a desktop value on the field form should be filled in prior to printing the form to complete the fieldwork component. Values determined in the field can be filled in later.

IV.b. Reach Walk

It is recommended to walk the entire reach, if practicable, or as much of a long reach as possible to begin the field work component. During the reach walk, the following tasks should be completed.

1. Determine the location of the assessment segment and representative riffle cross section.

The assessment segment for floodplain connectivity, bed form diversity, and lateral stability parameters is roughly 20 times the bankfull width or two meander wavelengths. The assessment segment should capture the bed form diversity that is typical of the stream reach and contains the stretch of channel with the greatest amount of large woody debris.

Selection of the representative riffle is critical. Select a suitable riffle that has stable width and depth, no signs of bank erosion or headcutting, bank height ratio is near 1.0, and bankfull width/depth ratio that is on the lower end of the range for the reach.

Note: In a highly degraded reach, a stable riffle cross section may be used from an adjacent upstream or downstream reach.

2. Measure difference between bankfull stage and water surface elevation.

It is important to assess bankfull at more than one location in the stream reach. Throughout the site walk, be on the lookout for bankfull indicators and measure the difference between water surface elevation and the suspected bankfull elevation using a stadia rod and a hand or eye level. This data can be recorded in Section II.A of the rapid method form. Use this data to come to a consensus on the difference between the bankfull (BKF) elevation and water surface (WS) elevation and record the value in Section III.A of the rapid method form.

3. Count concentrated flow points.

The number of concentrated flow points is a measurement method for the reach runoff parameter. The measurement method assesses the number of concentrated flow points 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.

The number of concentrated flow points along the entire stream reach should be tallied during a reach walk on Line II.B of the field form. The number of concentrated flow points is normalized to a count per 1,000 LF of stream. Space is provided for this calculation on Line II.C of the field form and the workbook version of the field form will automatically divide the count by the reach length.

IV.c. Bankfull Verification

Multiple parameters in the SQT require bankfull dimensions. These include: floodplain connectivity, large woody debris, lateral stability, and bed form diversity. Prior to making field measurements for these parameters, 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 Rosgen (2014). Lines E, F, and G of Section III of the field form should be populated with the bankfull area, width, and mean depth as calculated from regional curves before going out in the field.

Using the difference between BKF and WS elevation found earlier, stretch a level tape across the bankfull elevation and survey a riffle cross section with a level, tape, and stadia rod or just with a tape and stadia rod. There is space in Section III of the rapid method form to enter station and depth readings for this riffle cross section. Use the cross section data to calculate the bankfull dimensions of area, width, and mean depth and populate lines B., C., and D. of the field form.

These dimensions are compared to the bankfull regional curve data to verify the bankfull indicators. The field data for the site should fall within the range of scatter of the regional curve in order for the site to be verified. If the field data are drastically different than the regional curve, the practitioner will need to determine if the wrong indicator was selected or if the regional curve represents a different hydro-physiographic region than the field site. More detail on bankfull verification is provided in Section 3.3 of the data collection manual.

IV.d. Stream Classification

The SQT requires stream type according to the Rosgen classification system (Rosgen, 1996). Stream classification is based on entrenchment ratio (ER), width depth ratio (WDR), sinuosity, slope and channel material. Section IV of the field form provides space to collect these data based on the representative riffle cross section for the reach.

Width Depth Ratio (WDR)

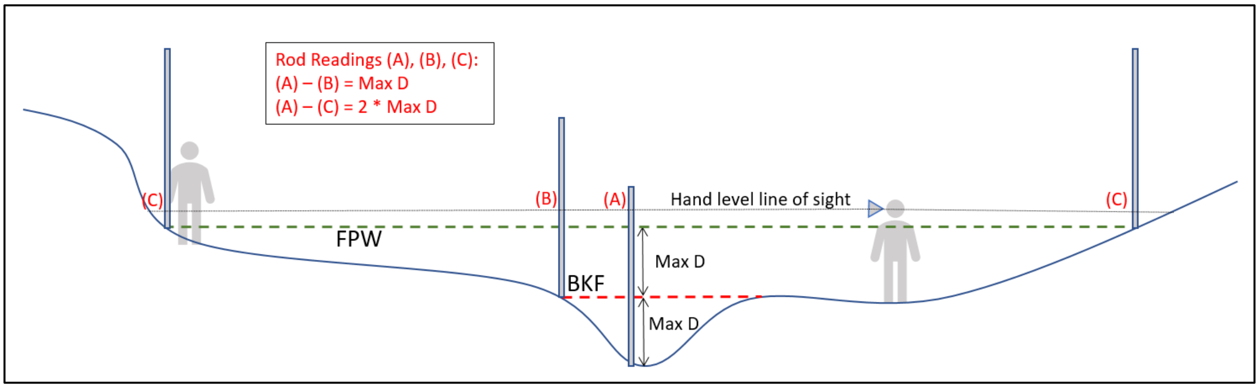
The WDR is calculated by dividing the bankfull width by the bankfull mean depth. Both these values were collected or calculated in Section III of the field form.

Entrenchment Ratio (ER)

ER is the flood prone width divided by the bankfull width of a channel, measured at a riffle cross section. The flood prone width (FPW) is measured as the width of the cross section at an elevation two times the bankfull (BKF) max depth.

At the representative riffle cross section location, 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 (refer to Figure B.2). Procedures for measuring and calculating the ER are provided on pages 5-15 through 5-21 of Rosgen (1996 second edition).

Figure B.2: Surveying Entrenchment Ratio



Reach Slope

Reach slope is a key measurement for the energy present in a stream reach and part of stream classification. Ideally, the average reach slope would be calculated for the entire stream reach as the difference between the water surface elevation at the head of the first riffle and at the head of the last riffle in the reach, divided by the centerline distance between these two points. For the rapid-based assessment, the distance will be limited by the line of sight and magnification of the hand level being used. Estimate the slope of the channel by:

1. Taking a stadia rod reading at the head of similar features (i.e. riffle to riffle, pool to pool, etc.).
2. Calculate the difference in stadia rod readings.
3. Measure the centerline distance between the two shots.
4. Divide the difference in stadia rod readings by the centerline distance between these two points and enter the value in Section IV.E of the field form.

Note that this measurement may be quicker to collect in the assessment segment where a tape has been stretched along the centerline of the channel.

Channel Material

Visually estimate the channel material for the reach. Measurements can be taken of representative particles if necessary. Table B.1 below provides the size class descriptions and particle size ranges for different channel materials.

Table B.1: Channel Material Size Classification Data

Channel Material	Size Class	Particle Size Range (mm)
Bedrock	1	-
Boulders	2	≥ 257
Cobble	3	65 – 256
Gravel	4	2 – 64
Sand	5	< 2
Silt/Clay	6	-

Use the data collected to determine the Rosgen stream type of the existing channel and enter the stream type into Section IV.G of the field form. This data is also required in the Site Information and Stratification section of the SQT, therefore there is space to record the stream type in section I of the field form as well.

IV.e. Riffle Data (Floodplain Connectivity and Bed Form Diversity)

Sections V through VIII of the field form are performed for the assessment segment of the stream reach. The assessment segment for floodplain connectivity, bed form diversity, and lateral stability parameters is roughly 20 times the bankfull width or two meander wavelengths (Leopold, 1994). The assessment segment should capture the bed form diversity that is typical of the stream reach and contain the stretch of channel with the most large woody debris within the reach.

Stretch a tape or multiple tapes along the edge of the channel or top of streambank. Begin and end this assessment segment at the head of a riffle feature. Enter the assessment reach length in Section V.A of the field form.

Measure the following at riffles within the assessment segment and record values in Section V.B of the field form:

- Low bank height – Measure at every riffle
- Bankfull max depth – Measure at every riffle
- Bankfull mean depth – Measure at any riffle with aggradation features and/or the widest riffle in the assessment segment.
- Bankfull width – Measure at every riffle
- Floodprone area width – Measure only if the valley width changes or if the BHR is greater than 1.8.
- Length of riffle (including the length of the run if present) – Measure at every riffle

These data are used to calculate the BHR, ER, aggradation ratio, and percent riffle measurement method field values. BHR and ER assess the floodplain connectivity parameter in the hydraulic functional category while aggradation ratio and percent riffle assess the bed form diversity parameter in the geomorphology functional category. Each measurement method is described in more detail below.

Bank Height Ratio (BHR)

The BHR is the Low Bank Height divided by the maximum bankfull riffle depth (Dmax). The low bank height is the lower of the left and right streambanks, indicating the minimum water depth necessary to inundate the floodplain.

To improve consistency and to reduce the potential for "cherry picking" riffles that create artificially high existing conditions or artificially low proposed conditions, the SQT requires BHR to be measured at every riffle within the assessment segment. 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 data set, a weighted BHR is calculated as follows.

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

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

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

1. Measure the length of the riffle (including the run feature if present) and record the length in the table of Section V.B of the field form.
2. Identify the middle of the riffle feature and the lower of the two streambanks.
3. Measure the difference in stadia rod readings from the thalweg to the top of the low streambank. Record this value as the Low Bank Height in Section V.B of the field form.
4. Measure the difference in stadia rod readings from the thalweg to the bankfull indicator, and record this value as the bankfull max depth in Section V.B of the field form.
    - Alternatively, measure the difference in stadia rod readings from the thalweg to the water surface then add the value recorded for the difference between bankfull stage and water surface (Section III.A on the field form).
5. Repeat these measurements for every riffle.
6. Calculate the weighted BHR per the equation above.

Section V.B of the field form provides space to multiply the BHR by the riffle length at each riffle (numerator of the equation above), sum the riffle lengths for the assessment segment (denominator), and enter the final weighted BHR. These values are automatically calculated in the workbook version of the field form and can be used to check field calculations.

Entrenchment Ratio (ER)

Field methods for measuring the ER are covered in the Stream Classification section of this appendix. 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 all riffles and to calculate the weighted ER. Locations where valley width changes in the reach were noted during the desktop component of the rapid method.

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 data set, a weighted ER is calculated as follows:

Equation (2) $$ER_{weighted} = \frac{\sum_{i=1}^{n}(ER_i * RL_i)}{\sum_{i=1}^{n} RL_i}$$

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

Space is provided in Section V.B. of the field form to record the floodprone area width, bankfull width and entrenchment ratio at each riffle. Section V.B of the field form also provides space to multiply the ER by the riffle length at each riffle (numerator of the equation above), sum the riffle lengths for the assessment segment (denominator), and enter the final weighted ER. These values are automatically calculated in the workbook version of the field form and can be used to check field calculations.

Aggradation Ratio

The aggradation ratio is the bankfull width at the widest riffle within the assessment reach divided by the mean bankfull riffle depth at that riffle. It is recommended to survey multiple riffle cross sections with aggradation features to ensure that the widest value for the assessment segment is obtained and to document the extent of aggradation throughout the project reach. Visual indicators of aggradation include mid-channel bars and bank erosion within riffle sections.

At candidate riffle features:

1. Measure the bankfull riffle width.
2. Estimate the mean depth as the difference between the edge of channel and the bankfull stage.
3. Use these values to calculate the WDR at that riffle.

Space is provided in Section V.B of the field form to record the bankfull mean depth, bankfull width and WDR at each riffle. The maximum WDR is automatically calculated in the workbook version of the field form but the user will need to divide this value by the appropriate reference WDR (provided in Table B.2 and on the field form).

Note that the field value that gets entered into the SQT Existing Condition Assessment is the maximum WDR ratio observed within the assessment segment divided by a reference WDR based on stream type (Table B.2). This step is not included in the field form.

Table B.2: Reference Bankfull WDR Values by Stream Type

Stream Type	Reference WDR
B	16
C	13
E	9

Percent Riffle

The percent riffle is the total length of riffles and runs within the assessment segment divided by the total assessment segment 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.

Individual riffle lengths are recorded in Section V.B of the field form (these data were also collected for the weighted BHR and ER calculations). Line V.C of the field form provides space to sum the riffle lengths for the assessment segment while Section V.G provides space to divide the total riffle length by the length of the assessment segment (recorded in Line V.A). The total riffle length and percent riffle are automatically calculated in the workbook version of the field form and can be used to check field calculations.

IV.f. Pool Data (Bed Form Diversity)

This section uses the same tape(s) stretched along the centerline of the assessment segment as the Riffle Data section. Data to calculate the pool spacing ratio and pool depth ratio measurement methods are collected in Section VI of the field form. Both of these measurement methods assess the bed form diversity parameter in the geomorphology functional category.

Working from upstream to downstream, record the following at every pool within the assessment segment:

- Maximum pool depth (measured from bankfull)
- Station of max pool depth

Pool Spacing Ratio

The pool spacing ratio is the distance between sequential pools divided by the bankfull riffle width. The bankfull riffle width is from the representative riffle cross section (Section III of the field form) rather than measured at each riffle.

The pool spacing ratio is calculated for each pair of pools in the assessment reach, working from upstream to downstream:

1. Record the station for the deepest point of each pool in Section VI.A of the field form.
2. Calculate the pool-to-pool spacing in Section VI.A of the field form (This is automated in the workbook version of the field form to check field calculations.)
3. Divide each spacing measurement by the bankfull riffle width from Section III of the field form. (This is automated in the workbook version of the field form to check field calculations.)

Since the performance standard curve is bell-shaped for meandering channels, low and high field values (both non-functioning) could average to a functioning score. Therefore, the field value entered in the SQT is the median value based on at least three pool spacing measurements.

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 representative riffle cross section (Section III of the field form) rather than measured at each riffle.

The pool depth ratio is calculated for each pool in the assessment segment, working from upstream to downstream:

1. Measure and record the maximum bankfull depth in Section VI.A of the field form.
    a. Alternatively, measure the difference in stadia rod readings from the thalweg to the water surface then add the value recorded for the difference between bankfull stage and water surface recorded in Section III.A on the field form.
2. Divide each bankfull pool depth measurement by the mean bankfull riffle depth from Section III of the field form. (This is automated in the workbook version of the field form to check field calculations.)

The field value for the pool depth measurement method is the average of the pool depth ratios for pools within the assessment segment. Section VI.B provides space to average the pool depth ratios calculated in Section VI.A, this is also automatically calculated in the workbook version of the field form and can be used to check field calculations.

IV.g. Large Woody Debris

For the rapid method, all pieces of LWD within a 100-meter (328 ft) are counted. In this methodology, large woody debris is defined as dead wood over 1-meter in length and at least 10cm in diameter at the largest end. The wood must be within the stream channel or touching the top of the streambank. In a debris jam, the number of pieces of large wood within than dam should be counted. The 100-meter assessment reach should be within the same reach limits as the other geomorphology assessments and should represent the length that will yield the highest score. Record the number of pieces on line VII.A of the field form.

Optionally, the large woody debris index can be completed for the same 100m segment, instructions are provided Section IV.6.a of the data collection manual.

IV.h. Lateral Stability

Section VIII of the field form allows space to assess the lateral stability of the assessment segment. This section uses the same tape(s) stretched along the thalweg of the assessment segment as the Riffle Data section. Two measurement methods for the lateral stability parameter are included in the rapid assessment: dominant bank erosion hazard index (BEHI)/near bank stress (NBS), and percent streambank erosion. Dominant BEHI/NBS characterizes the magnitude of bank erosion while percent eroding bank characterizes the extent of bank erosion within a reach.

Dominant BEHI/NBS

The dominant BEHI/NBS assessment determines the predominant score of banks that are eroding or have a strong potential to erode. The assessment will focus on the outside bank of meander bends and areas of active erosion to determine the dominant BEHI/NBS. Depositional zones and riffle sections that are not eroding and have a low potential to erode are not included. However, if a riffle is eroding, it is assessed.

For banks throughout the assessment segment:

1. Determine whether the bank has the potential to erode or is actively eroding.
2. Determine the BEHI/NBS rating for each bank identified as actively eroding or that has a strong potential to erode. Record the rating in Section VIII.A of the field form.
3. Measure and record the length of each bank assessed in Section VIII.A of the field form. Bank lengths can be paced in the field or measured back in the office if a GPS unit is used to map assessed banks.

Using the data recorded in Section VIII.A of the field form, the dominant BEHI/NBS rating can be determined and entered in to the SQT for the field value of this measurement method. The dominant BEHI/NBS single category that describes the largest length of the banks assessed. For example, if an assessment segment evaluated 3 banks with scores and lengths shown in Table B.3 the dominant BEHI/NBS rating would be High/High (H/H).

Table B.3: Example BEHI/NBS Data

BEHI/NBS Score	Bank Length (Feet)
Low/Low	50
High/High	12
Mod/High	22
High/High	31
Low/Mod	9
High/High	31

Enter the dominant BEHI/NBS value in Section VIII.B of the field form. If there is a tie between BEHI/NBS categories, the category representing the highest level of bank erosion should be selected.

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. 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 thalweg stream length. The total assessment segment bank length can be paced, delineated with a GPS or estimated as twice the bank length.

Banks with a BEHI rating of Extreme, Very High or High are considered an eroding bank regardless of their NBS rating. Additionally, banks with the following BEHI/NBS scores are considered an eroding bank:

- M/Ex, M/VH, M/H, M/M, M/L,
- L/Ex, L/VH, L/H

Using the data collected in Section VIII.A of the field form, determine the length of eroding bank and enter it in Section VIII.C of the field form. Enter the total bank length for the assessment segment in Section VIII.D of the field form. The percent of bank erosion is calculated by dividing these two numbers, space is provided in Section VIII.E of the field form and is automatically calculated in the workbook version of the field form.

IV.i. Riparian Vegetation

Riparian vegetation is defined as plant communities contiguous to and affected by surface and subsurface hydrologic features of perennial or intermittent water bodies. Due to variations in riparian vegetation it is recommended to assess the riparian vegetation for as much of the stream reach as possible rather than for the assessment segment used to assess other geomorphic measures. Three measurement methods for the riparian vegetation parameter are included in the rapid assessment: basal area, canopy coverage, and buffer width. Basal area and buffer width are required while canopy coverage is optional.

Basal Area

A wedge prism is used to estimate basal area in the rapid-based method. Instructions for using a wedge prism are described in Avery & Burkhart (2002). [9] A 10 BAF (basal area factor of 10 ft^2) wedge prism is recommended. The BAF of the wedge prism used is recorded in Section IX.A of the field form.

1. Use aerial imagery and the reach walk to select multiple locations along the entire reach within the left and right riparian communities that will provide a representative sampling of the riparian vegetation community for the reach.
2. Record the tree count obtained with the wedge prism for each sample point along the reach in Section IX.A of the field form.
3. The average basal area from all sampling locations is calculated for the left and right banks separately and entered as field values.

Space is provided to record individual tree counts and calculate an average tree count for the left and right sides of the channel in Section IX.A of the field form. The average tree count will automatically calculate from data entered into this section in the workbook version of the field form. The basal area is calculated by multiplying average tree count by the BAF, these values will automatically calculate in the workbook version of the field form.

Buffer Width

The riparian buffer width is measured horizontally from the top of the stream bank to the edge of the riparian vegetation community or the edge of the valley if the riparian buffer is not disrupted by utility easements, roads, or other gaps in riparian vegetation cover. Buffer width measurements will be perpendicular to the fall-line of the valley. Buffer width is measured separately on the left and right sides of the channel and the width does not include the channel width. Measurements should be taken every 50 feet along the thalweg length, these measurements can be performed using recent orthoimagery but sufficient measurements need

[9] Guidance on using wedge prisms is also readily available online from multiple sites including: https://gabrielhemery.com/2011/12/05/how-to-use-a-wedge-prism-relascope-to-measure-basal-area/

to be taken in the field to verify the desktop measurements. An average buffer width is calculated for the right and left side of the channel separately.

Space is provided to record individual buffer width measurements and calculate an average buffer width for the left and right sides of the channel in Section IX.B of the field form. The average buffer width will automatically calculate from data entered into this section in the workbook version of the field form.

Canopy Coverage

The canopy coverage measurement method is optional for the rapid method. If the user is not measuring canopy coverage then there is no need to print page 5 of the field form.

This measurement method is an assessment of riparian vegetation health rather than stream shading. Measurements should not be taken from the stream channel or on the stream banks. Canopy coverage is measured using a densitometer. For detail on how to use the densiometer refer to the device instructions or Using Forest Densiometers (Forestry Suppliers. Inc., 2008).

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 either shaded or not shaded by canopy cover, whichever is easier to count.

- If the user is counting the number of dots ***occupied*** by canopy cover (i.e. shaded), enter "Canopy" as the method under the measurements. The canopy method will be easier where canopy cover is sparse.
- If the user is counting the number of dots ***not occupied*** by canopy cover (i.e. in the sun or not shaded), enter "No Canopy" as the method under the measurements. This method will be easier where canopy cover is prevalent and most of the densitometer is shaded.

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 entered as field values.

Space is provided to record canopy cover measurements in Section IX.C of the field form. The workbook version of the field form will automatically calculate the average count for each sampling location and, if the method is entered, calculate the percent canopy coverage for each sampling location and the average canopy coverage for each bank.

IV.j. Sinuosity

Sinuosity is also covered in the desktop component, Section III.c of this appendix, as the rapid-based method 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 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.

V. References

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VI. Rapid Assessment Field Form

Date:
Investigators:

Stream Quantification Tool
Rapid Assessment Form

I. Site Information and Stratification

Project Name:		
Reach ID:		
Drainage Area (sq. mi.):		
Stream Reach Length (ft):		
Flow Type:		
River Basin:		
Stream Type:		Section IV.
Bed Material:		Section IV.
Stream Slope (%):		Section IV.

Shading Key
Desktop Value
Field Value
Calculation

II. Reach Walk

A.	Difference between bankfull (BKF) stage and water surface (WS) (ft)							

B.	Number Concentrated Flow Points	
C.	Concentrated Flow Points/ 1,000 L.F.	

III. Bankfull Verification and Representative Riffle Cross Section

A.	Difference between BKF stage and WS (ft) *Average or consensus value from reach walk.*	
B.	Bankfull Width (ft)	
C.	Bankfull Mean Depth (ft) = Average of depth measurements	
D.	Bankfull Area (sq. ft.) Width * Mean Depth	
E.	Regional Curve Bankfull Width (ft)	
F.	Regional Curve Bankfull Mean Depth (ft)	
G.	Regional Curve Bankfull Area (sq. ft.)	
H.	Curve Used	

Cross Section Measurements Depth measured from bankfull			
Station	Depth	Station	Depth

Date:
Investigators:

Stream Quantification Tool
Rapid Assessment Form

IV. Stream Classification

A.	Width Depth Ratio (ft/ft) Bankfull Width / Bankfull Mean Depth	
B.	Bankfull Max Riffle Depth	
C.	Floodprone Area Width (ft)	
D.	Entrenchment Ratio (ft/ft) Floodprone Area Width /Bankfull Width	
E.	Slope Estimate (%)	
F.	Channel Material Estimate	
G.	Stream Type	

V. Riffle Data (Floodplain Connectivity & Bed Form Diversity)

A.	Assessment Reach Length At least 20 x the Bankfull Width		20*Bankfull Width	

B. Bank Height & Riffle Data

	R1	R2	R3	R4	R5	R6	R7	R8
Low Bank Height (ft)								
Bankfull Max Depth (ft)								
Bankfull Mean Depth (ft)								
Bankfull Width (ft)								
Floodprone Area Width (ft)								
Riffle Length (ft) *Including Runs*								
Bank Height Ratio (BHR) Low Bank H / Bankfull Max D								
BHR * Riffle Length (ft)								
Entrenchment Ratio (ER)								
ER * Riffle Length (ft)								
WDR BKF Width / BKF Mean Depth								
WDR_Riffle / WDR_Reach								

C.	Total Riffle Length (ft)	
D.	**Weighted BHR** $\frac{\Sigma(Bank\ Height\ Ratio_i \times \text{Riffle Length}_i)}{\Sigma Riffle\ Length}$	
E.	**Weighted ER**	
F.	**Maximum WDR**	
G.	**Percent Riffle (%)**	

VI. Pool Data (Bed Form Diversity)

A. Pool Data

	P1	P2	P3	P4	P5	P6	P7	P8
Station								
P-P Spacing (ft)	X							
Pool Spacing Ratio Pool Spacing / BKF Width	X							
Pool Depth (ft) Measured from Bankfull								
Pool Depth Ratio Pool depth/BKF mean depth								

B.	Average Pool Depth Ratio		C.	Median Pool Spacing Ratio	

Date:
Investigators:

Stream Quantification Tool
Rapid Assessment Form

VII. Large Woody Debris

A.	Number of Pieces per 100m	
B.	LWDI (optional)	

VIII. Lateral Stability

A. Bank Data

BEHI/NBS Score	Bank Length (ft)	BEHI/NBS Score	Bank Length (ft)

B.	Dominant BEHI/NBS Score	
C.	Total Eroding Bank Length (ft)	
D.	Total Bank Length (ft)	
E.	Percent of Bank Erosion (%) Total Eroding Bank Length/ Total Bank Length	

IX. Riparian Vegetation

A. Basal Area

Prism Factor (BAF)	

	Basal Area Plots - Tree Counts with Prism					Average	Basal Area (sq.ft./ac)
Riparian Buffer	1	2	3	4	5		
Left (looking downstream)							
Right (looking downstream)							

B. Buffer Width

	Buffer Width Measurements (ft)							Average
Riparian Buffer	1	2	3	4	5	6	7	
Left (looking downstream)								
Right (looking downstream)								

Stream Quantification Tool
Rapid Assessment Form

C. Canopy Coverage

Densiometer Factor	

	Canopy Coverage Plots							
Riparian Buffer	1		2		3		4	
Left (looking downstream)								
Method (No Canopy/ Canopy)								
Average Count								
Canopy Coverage (%)								
Right (looking downstream)								
Method (No Canopy/ Canopy)								
Average Count								
Canopy Coverage (%)								

Riparian Buffer	Average Canopy Cover
Left (%)	
Right (%)	