Functional Lift Quantification Tool for Stream Restoration Projects in North Carolina

Data Collection and Analysis Manual

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December 2016

Acknowledgements

The NC Stream Functional Lift 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. 2016. Functional Lift Quantification Tool for Stream Restoration Projects in North Carolina: Data Collection and Analysis Manual. Environmental Defense Fund, Raleigh, NC.

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Glossary of Terms

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."

Condition Score – A value between 1 and 0 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

Flow Type – Describes the duration of flow in a channel as either perennial, intermittent or ephemeral.

- Perennial streams carry water all year long during a year of normal rainfall.
- Intermittent streams only carry water for part of the year.
- Ephemeral streams carry stormwater in direct response to a precipitation event.

Functional Category – The levels on the stream functions pyramid: Hydrology, Hydraulics, Geomorphology, Physicochemical, and Biology.

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

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

Function-Based Parameter –Describes and supports the functional statements within each functional category.

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

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

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.

Stream Functions Pyramid Framework (SFPF) – The Stream Functions Pyramid presents the five functional categories based on the premise that lower-level functions support higher-level functions and that all are influenced by local geology and climate. The Stream

Functions Pyramid Framework includes the function-based parameters, measurement methods, and performance standards.

Stream Quantification Tool (SQT) – The Stream Quantification Tool is a spreadsheet that calculates stream condition by function-based parameter, functional category, and overall. The primary purpose of the tool is to quantify the functional lift (improvement) of a stream restoration project or the functional loss of a permitted impact.

I. 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 form, 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 *Functional Lift Quantification Tool for Stream Restoration Projects in North Carolina 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.

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. Check the Stream Mechanics web page for supporting resources and SQT's for other states.

<u>SQT Manual Guide</u>

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)
3. Reference Manual – *Science behind the development of performance standard curves.* (Summer 2017)

All manuals will be available from stream-mechanics.com

I.1. Downloading the Stream Quantification Tool and Supporting Information

The following spreadsheets and documents can be downloaded from the Stream Mechanics web page (http://stream-mechanics.com/), under the Pyramid Framework tab:

- Stream Quantification Tool V2 – The functional lift quantification spreadsheet.
- Stream Quantification Tool V2 Example – The SQT with example data included.
- List of Metrics – Spreadsheet showing the list of all function-based parameters, measurement methods, and performance standards with references.
- Stream Quantification Tool User Manual (Spreadsheet User Manual)

- Stream Quantification Tool, Data Collection and Analysis Manual

This page includes other resources like the Stream Functions Pyramid diagram, *A Function-Based Framework for Stream Assessment and Restoration Projects* (Harman et al., 2012), a rapid assessment method, and new function-based parameters with measurement methods and performance standards (not included in the Framework book).

Workshops – The Workshops tab provides a list of courses providing further education on stream functions and restoration.

II. 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 watershed-scale, which include all stream channels within the watershed.

The SQT is a reach- or segment-based assessment methodology with one Excel Workbook used per stream segment. This is required because stream condition can vary widely from the upstream end of a project to the downstream end. Reach segmentation allows the practitioner to divide the project into homogeneous segments. A detailed description of the segmentation process is described below.

The potential functional lift that restoration can achieve is called restoration potential. It is determined primarily by assessing the catchment draining to the restoration site. The SQT includes a Catchment Assessment that consists primarily of digital data collection, windshield surveys, preliminary site walks and assessment. Restoration potential and the Catchment Assessment process are described after the Reach Segmentation section.

II.1. Reach Segmentation

Segmenting a stream reach is a two-step process. The first step is to identify reaches based on physical characteristics. The second step is to further sub-divide the reach based on certain metric requirements.

<u>Step 1: Physical Segmentation</u>

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 physically-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.

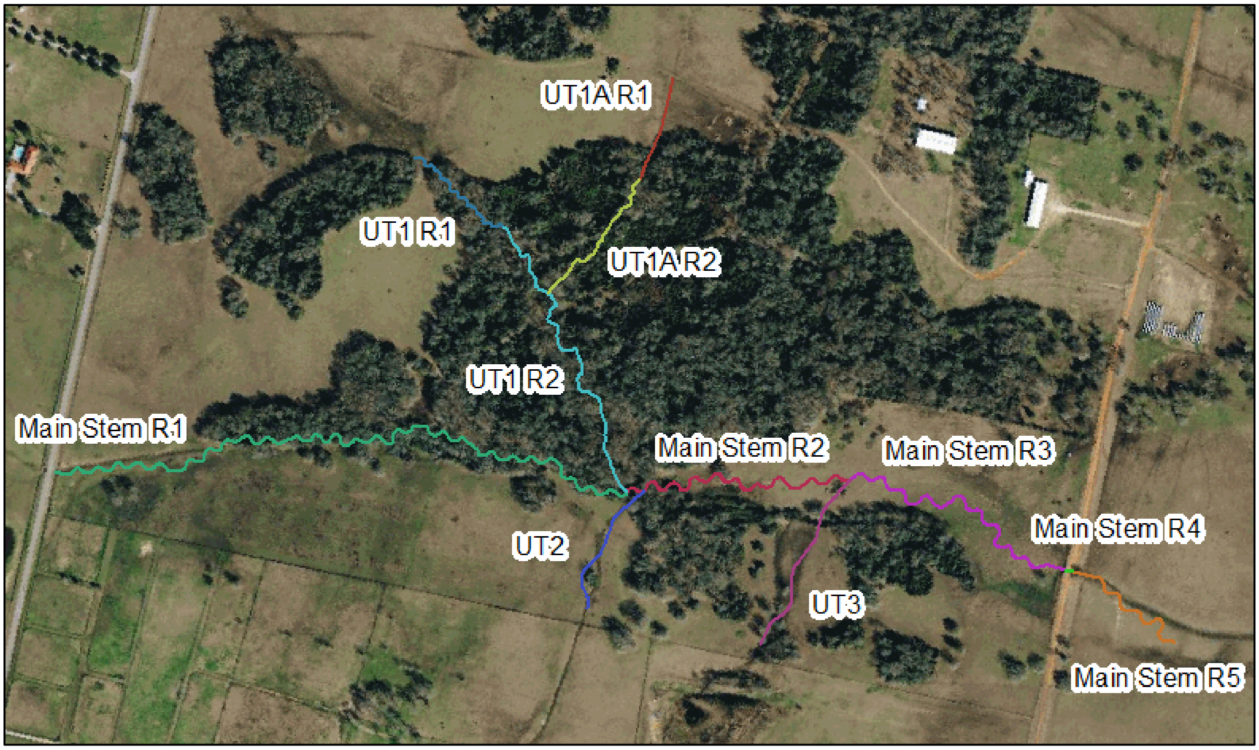
- A significant increase in drainage area should lead to a reach break. When the drainage area for a channel increases significantly, the design criteria will change. Typically, when a large tributary enters the main stem, the main stem would consist of one reach upstream and one reach downstream of 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.

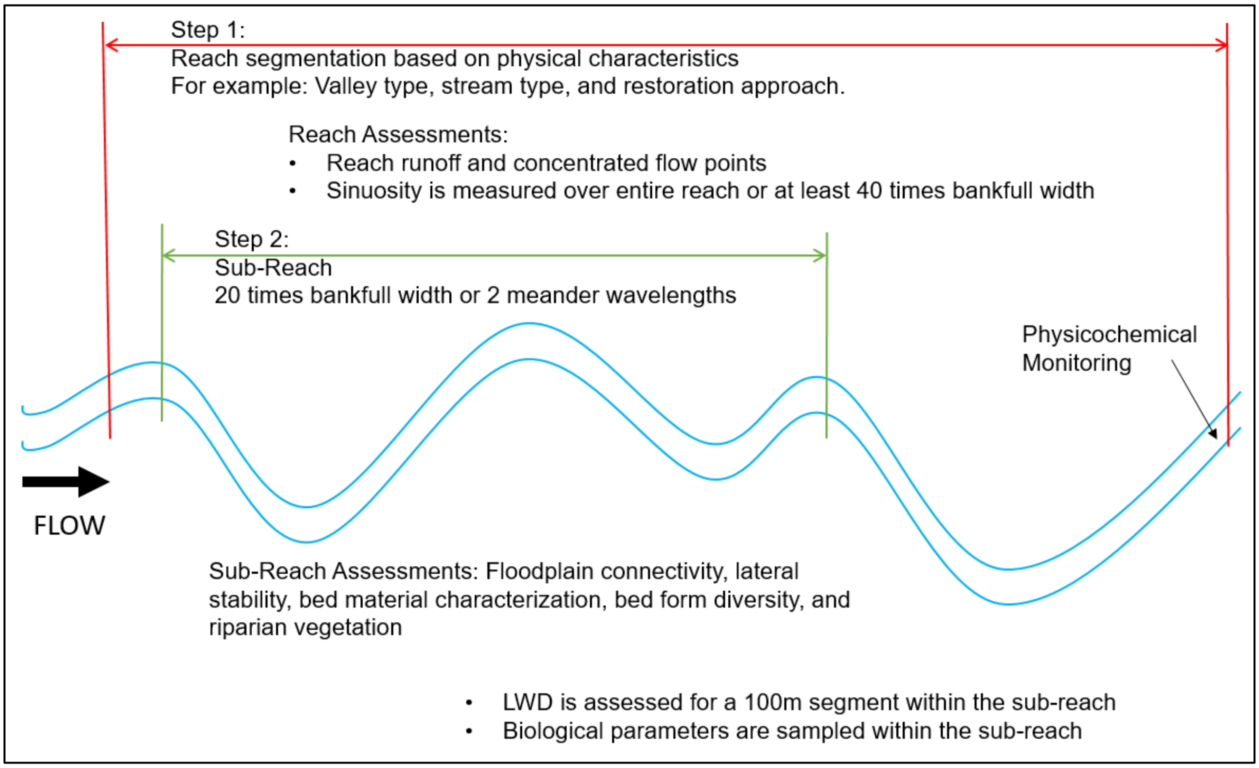
Figure 1: Reach Identification Example



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

The second step in reach determination is to determine how much of each reach will be quantitatively assessed. This is a sub-reach that is contained within the overall reach determined above. Figure 2 below shows the difference between the overall reach (Step 1) and the sub-reach (Step 2) and their associated parameters. This second step is necessary to avoid having to quantitatively assess very long reaches with similar physical conditions. Length is used to delineate an assessment segment and varies by functional category and parameter. Guidelines and examples are provided below for each functional category.

Figure 2: Reach and Sub-Reach Segmentation

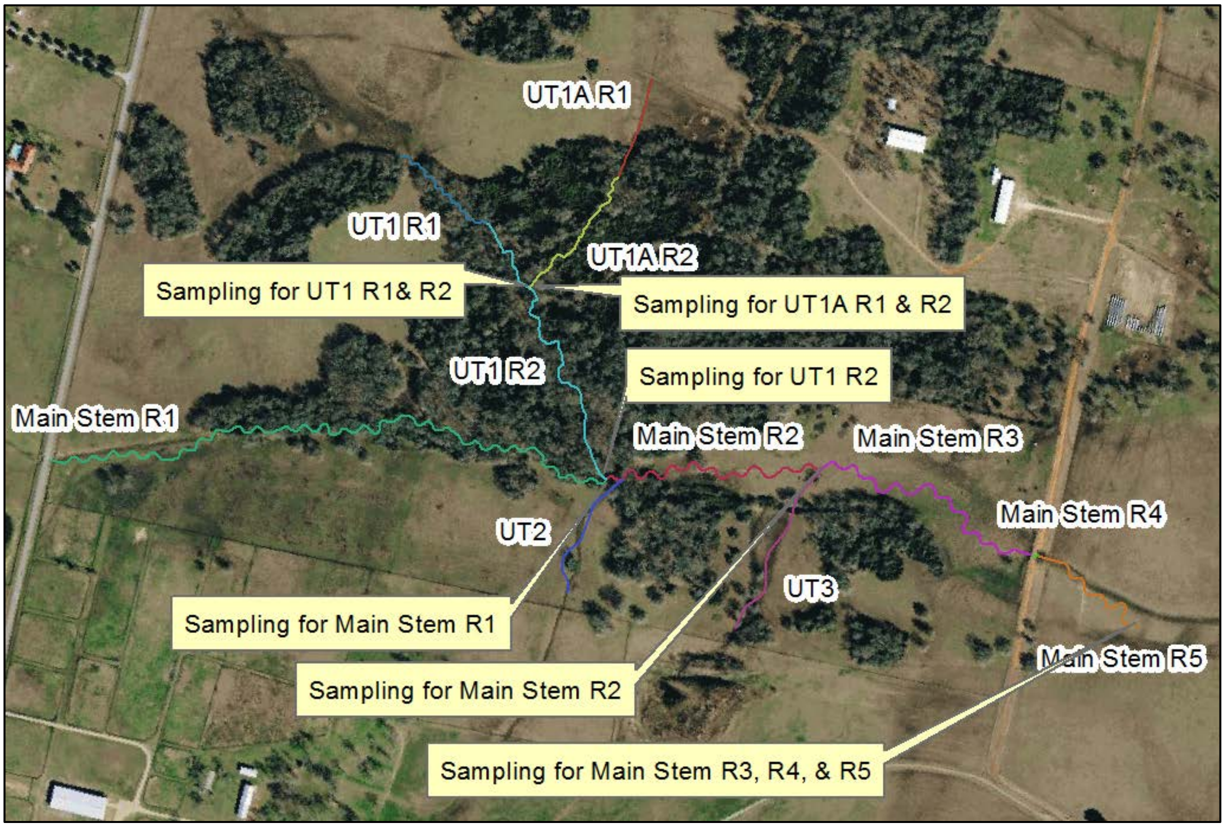


1. *Hydrology Functional Category*: Hydrology parameters are assessed at the catchment or sub-catchment scale rather than the reach scale. The sole exception to this rule is the number of concentrated flow points measurement method for the reach runoff parameter. The number of concentrated flow points should be determined 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 (not just the sub-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*: All physicochemical parameters are assessed at a single location at the downstream end of the reach. Biological parameters may be sampled at the last downstream riffle or within representative habitats throughout the reach. For these parameters, several reaches may be included together since long reaches may be required to determine a change, i.e. lift or loss. However, reach combinations should stop at the confluence with another tributary. Figure 3 illustrates how to identify physicochemical and biological reach limits. In addition to downstream monitoring, 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



II.2. Catchment Assessment

The Catchment Assessment worksheet is a tab within the SQT workbook. It is also provided in Appendix A. This form is included to assist in determining the restoration potential and the catchment hydrology field value for each 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 watershed processes and stressors that exist outside of the project reach and may limit functional lift. Instructions for collecting data and describing each watershed process and stressor are also provided in this section.

Catchment Assessment Highlights

- The primary purposes of the catchment assessment are to: 1) assist in determining restoration potential; and 2) assess catchment hydrology health, a function-based parameter for Hydrology.
- 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.

II.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 watershed, 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 watershed 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 watersheds 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.

II.2.b. Catchment Assessment Worksheet Categories

The Catchment Assessment worksheet is provided to assist in determining the restoration potential of the project reach and to score the catchment hydrology parameter. The form is provided in Appendix A. The Catchment Assessment Form includes descriptions of watershed 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 watershed 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 watershed condition based on the identified conditions and constraints. The overall watershed 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 watershed being treated is high, i.e. 80-100%, then the project could be large enough to overcome watershed 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 watershed has no untreated concentrated flow to the channel above the reach. A poor quality watershed has concentrated flow entering the project reach untreated. A fair condition has potential for concentrated flow but existing measures are in place to address it.

Figure 1: Eroded gulley transporting water and pollutants directly to a stream channel.

Figure 2: 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 watershed 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 watersheds, it is possible to delineate impervious surfaces using recent orthoimagery, which provides a more accurate estimate than the NLCD.

When impervious cover makes up more than 25% of the drainage area, the watershed condition is considered poor. Where impervious cover makes up less than 10% of the drainage area, the watershed condition is considered good (Schueler et al., 2009). A poor or fair watershed 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 watersheds that are currently in good or fair condition can degrade quickly with development. Active construction within a watershed can cause excessive erosion and sediment supply. Urban and residential development can drastically change the hydrology and quality of water coming into the project reach. A 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.

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

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

(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 (Watershed)

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 watershed is 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 watersheds, 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 watershed and performing a “windshield survey”.

7. Sediment Supply

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

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

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.

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.

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 watershed to overcome poor water quality. A poor or fair watershed condition in this category would indicate that a restoration potential of level 4 or 5 would be difficult or impossible unless a

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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

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

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.

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.

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 watershed in good condition would have no NPDES facilities in the catchment or near the project reach while

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

a poor watershed in this category would have multiple NPDES facilities in the watershed 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. Hardened channel reaches or otherwise impaired channel substrate surrounding the project reach can negatively impact macroinvertebrate communities and the ability of fish to spawn. Hardened sections of channel may block macroinvertebrate communities from inhabiting a project reach similar to how impoundments can block fish passage. If there is a concrete, piped or hardened section of channel immediately upstream or downstream of the project reach then the catchment is in poor condition. If the channel substrate immediately upstream or downstream of the project reach is not hardened but is impaired, then the catchment is in fair condition.

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 be a deal breaker 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 barriers 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 downstream 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.

III. Getting Started with the Stream Quantification Tool

Before performing a detailed 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 *IV. 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.

III.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.

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

- Catchment Hydrology (assessed using the Catchment Assessment worksheet)
- Reach Runoff
- Floodplain Connectivity
- Lateral Stability
- Riparian Vegetation
- Bed Form Diversity
- Large Woody Debris
- Sinuosity

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 10-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., 0.6.

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 are suggested for urban projects with BMPs. Add any of the following parameters from the BMP Routine to the list above based on what the BMP will treat:

- BMP Runoff
- Specific Conductivity
- Nitrogen
- Phosphorus

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. Some of the parameters listed above occur in both the BMP Routine and the reach condition assessments. For most projects, these parameters will only be modeled for BMP performance and values entered in the BMP Routine. 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 reach assessments. Notice that values entered in the BMP Routine are modeled and the values entered in the stream condition assessments are monitored.

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.

- 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 watershed 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 fencing to keep cattle out of the channel, grading to provide floodplain connectivity, and increasing bedform diversity. Wood will be added to the channel to provide channel complexity and fish habitat. Riparian vegetation will be planted along the streambank and across the floodplain. The parameter list would likely consist of:

- Catchment Hydrology
- 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
- Sinuosity
- 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 of these 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.

III.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. A field form for collecting rapid-based measurements is 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.

III.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 Rosgen (2014). Detailed and rapid methods to verify bankfull are described below.

III.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 low correlation coefficient (R^2 value).

In addition to the profile, the bankfull dimensions of area, width, and mean depth should be calculated for at least one surveyed riffle cross section. These dimensions are plotted on their corresponding bankfull regional curve, e.g., measured cross sectional area is plotted on the cross-sectional area regional curve. 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 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 than the field site. Ideally the regional curve has been developed specifically for the study watershed. If watershed-specific regional curves are not available, the user can overlay the field data with established curves. NC State University's Stream Restoration Program[8] provides published papers, data and equations for North Carolina regional curves. Watershed-specific regional curves are superior to broad physiographic regional curves, as the practitioner is guaranteed to have the curve and field data within the same hydro-physiographic region.

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

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: Verifying Bankfull with Regional Curves Example

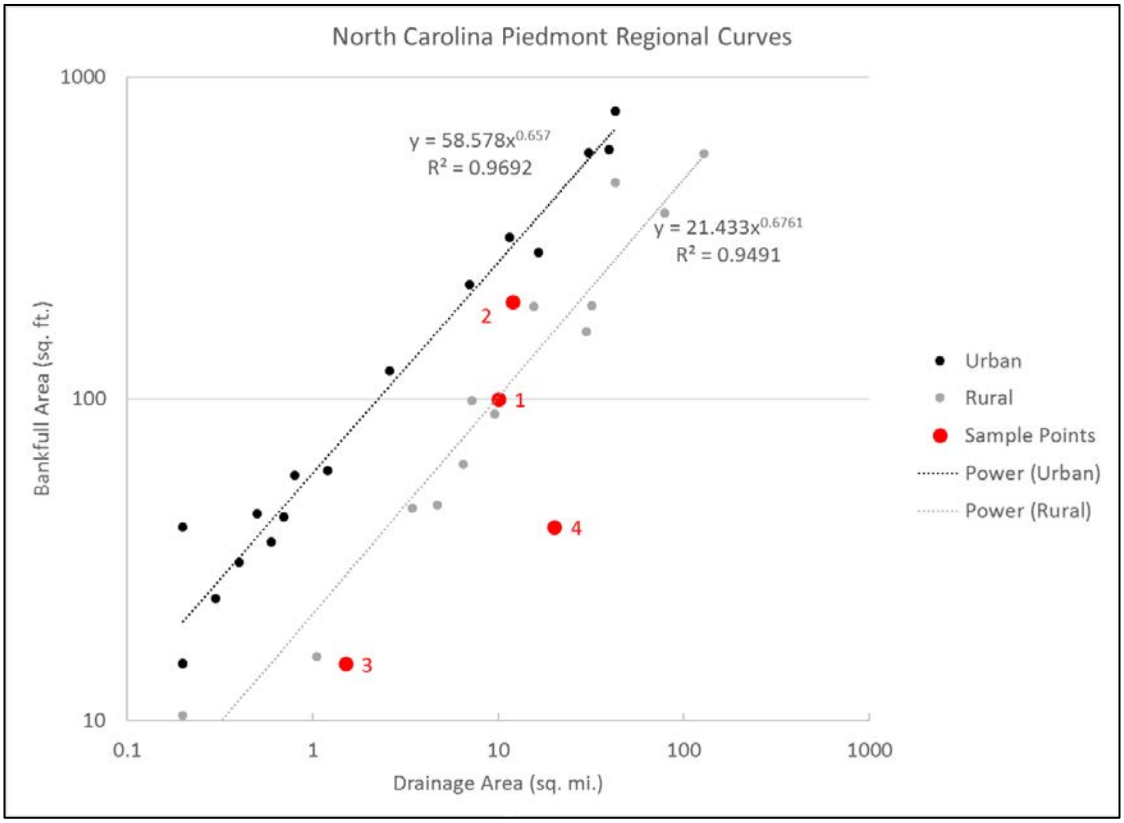


Figure 8 shows the urban and rural regional curves for the Piedmont Region of NC along with four sample points, numbered and shown in red, for streams that were considered rural.

- 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.

III.3.b. Verifying Bankfull Stage and Dimension with Rapid Assessments

Rapid assessments will not include longitudinal profiles and cross sections using a survey level or total station. Instead, the practitioner uses a rod and a hand or line level to record the difference between water surface and bankfull indicators throughout the reach. A riffle cross section should still be surveyed (with a level, tape, and rod or just with a tape and 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. 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 detailed section.

III.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 value and a reference condition. 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 1.0 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 watershed upstream of an unstable C4 or Gc 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.

IV. 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 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.

Table 1: Condition Assessment from the Quantification Tool

Functional Category	Function-Based Parameters	Measurement Method	Field Value
Hydrology	Catchment Hydrology	Catchment Assessment	
	Reach Runoff	Curve Number	
		Concentrated Flow Points	
		Soil Compaction	
Hydraulics	Floodplain Connectivity	Bank Height Ratio	
		Entrenchment Ratio	
Geomorphology	Large Woody Debris	LWD Index	
	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	Pebble Count	
	Bed Form Diversity	Pool Spacing Ratio	
		Pool Depth Ratio	
		Percent Riffle	
	Sinuosity	Plan Form	
Physicochemical	Temperature	Temperature (°F)	
	Bacteria	Fecal Coliform (Cfu/100 ml)	
	Organic Carbon	Leaf Litter Processing Rate	
		Percent Shredders	
	Nitrogen	Falls Lake Nutrient Tool (mg/L)	
	Phosphorus	Falls Lake Nutrient Tool (mg/L)	

Biology	Macros	Biotic Index EPT Taxa Present	
	Fish	North Carolina Index of Biotic Integrity	

A project would rarely, if ever, enter field values for all measurement methods included in the SQT. The Parameter Selection Guide worksheet and Section III.1. of this manual provides guidance on which parameters to assess.

Table 2: BMP Routine from the Quantification Tool

Site Information		**BMP 1**	
BMP ID			
Basin Area treated by BMP (Ac)			
Basin Length (ft)			
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			

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.

IV.4. Hydrology

The condition assessments shown in Table 1 include two function-based parameters to assess the hydrology functional category: Catchment Hydrology and Reach Runoff. The BMP Routine also includes a Runoff parameter; however, it is different than the Reach Runoff parameter.

IV.4.a. Catchment Hydrology

Catchment hydrology assesses the hydrologic health of the catchment *upstream* of the project reach. For projects that employ holistic watershed 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 watershed. An example could be a project that purchases the entire catchment and converts 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 effects the overall hydrology category score. For example, catchments with better upstream hydrology conditions will yield a higher hydrology category score.

This parameter should be assessed for all projects. The user should rely on answers from the Catchment Assessment worksheet, especially the questions from the Hydrology category, to select the appropriate field value (Table 3). The data collection for this measurement method is described in Section II.2.b. of this manual while guidance to discern between a high, medium or low watershed quality is provided in Section III.2.b. of the Spreadsheet User Manual.

The performance standard for the Catchment Assessment measurement method is based on best professional judgement.

Table 3: Catchment Hydrology Performance Standards

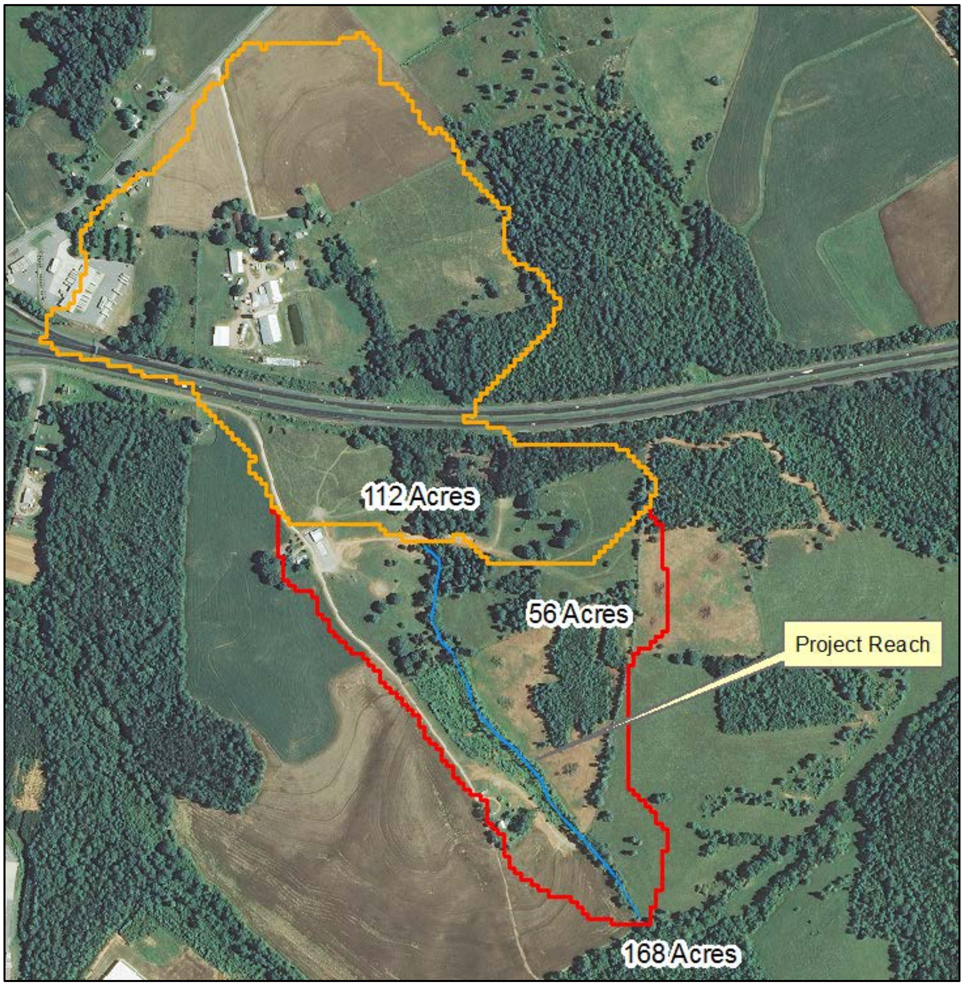
Field Value	Index Value	Condition
H3	1	Functioning
H2	0.9	
H1	0.8	
M3	0.6	Functioning-At-Risk
M2	0.5	
M1	0.4	
L3	0.3	Not Functioning
L2	0.2	
L1	0.1	

IV.4.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 IV.4.c. will address the Runoff parameter in the BMP Routine. 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 because it requires sample analysis by a soils laboratory. 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 watershed above the stream reach is assessed by the catchment hydrology parameter. The purpose of the reach parameter is to assess the watershed 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 watershed 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 watershed assessed by the reach runoff parameter.

Figure 9: Watershed Delineation Example for Reach Runoff.



1. Curve Number (CN)

The curve number measurement method characterizes the land use of the watershed assessed by the reach runoff parameter. 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 watershed draining directly to the project reach from adjacent land uses. 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 4 provides example curve numbers by land use type. The ranges represent different conditions with lower numbers equating to less runoff than higher numbers, i.e., a lower number is functionally better than a higher number.

Table 4: 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

Weighted curve numbers for both the existing and proposed conditions are calculated and entered into the SQT as field values.

For the 56-acre watershed 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. The existing condition field value for the curve number measurement method would be 59 and the proposed condition field value would be 51.

Table 5: 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).

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[9] Curve numbers for Farmsteads are provided in Table 2-2c of TR-55 (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 and increasing ground cover near the channel. Performance standards are based on best professional judgement and are provided in Table 6.

Table 6: Catchment Hydrology 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 and decrease soil porosity, thereby increasing runoff. 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 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 bulk density (g/cm^3) using the cylindrical core method as outlined in the Soil Quality Test Kit Guide (NRCS, 1999). This report provides guidance on when to sample, where to sample and how many samples to take. For annual samples in an agricultural field, the recommended time to sample is after harvest or at the end of the growing season. For other land uses, sample when the climate is stable and when there have not been recent disturbances. Samples taken for post-construction monitoring should be taken from the same site and at the same soil moisture condition. During a sampling event, a minimum of three samples 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 stratified by soil texture and based on the bulk density that restricts root growth (NRCS, 2008).

IV.4.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 watershed. 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 watershed 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 watersheds, 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): $$V = R_v * A * \left(\frac{P}{12}\right)$$

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 (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 watershed, 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

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

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 (ICM) research studies (Schueler et al., 2009).

IV.5. Hydraulic

Currently, the only function-based parameter included in the SQT to assess hydraulic functions is floodplain connectivity. However, two measurement methods are used to quantify floodplain connectivity: the bank height ratio (BHR) and the entrenchment ratio (ER). Both are described below.

IV.5.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 7 below provides an example of the weighted bank height ratio calculation in an assessment segment with four riffles.

Table 7: Example Weighted BHR Calculation

Riffle ID	Length (RL)	BHR	BHR * RL
R1	25	1.0	25
R2	50	1.5	75
R3	50	1.1	55
R4	30	1.2	36
Total	**155 ft**	**Total**	**191**
Weighted BHR = 191/155 = 1.2			

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. Both methods are described below.

Detailed Method

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.

Rapid Method

Rapid-based methods record measurements taken in the field using a stadia rod and a hand level and do not require a longitudinal profile survey. A line level can be used instead of a hand level for small streams. 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 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 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 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 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 8 for an example of the weighted entrenchment ratio calculation.

Table 8: Example Weighted ER Calculation

Riffle ID	Length (RL)	ER	ER * RL
R1	25	1.2	30
R2	50	2.1	105
R3	50	1.6	80
R4	30	1.8	54
Total	**155 ft**	**Total**	**269**
Weighted ER = 269/155 = 1.7			

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. Both methods are described below.

Detailed Method

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.

Rapid Method

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

IV.6. Geomorphology

The SQT contains the following function-based parameters to assess the geomorphology functional category: large woody debris, lateral stability, riparian vegetation, bed material characterization, bed form diversity, and sinuosity. Few projects will enter values for all geomorphic parameters. Refer to section III.1. of this manual for guidance on selecting parameters for a stream restoration project.

IV.6.a. Large Woody Debris

The Large Woody Debris Index (LWDI) is used to evaluate large woody debris within a stream channel, but not on the floodplain. This index was developed by the USDA Forest Service Rocky Mountain Research Station (Davis, et al., 2001) and should be used for all NC projects. In this methodology, large woody debris is defined as dead wood over 1m 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.

The Forest Service manual provides a brief description and rating system for evaluating LWD pieces and dams. In addition, Stream Mechanics and EPR have prepared technical guidance to clarify and standardize the Forest Service instructions. This guidance and a Powerpoint presentation showing examples of how the LWDI is determined is provided on the Stream Mechanics web page under the Pyramid Framework tab.[11]

For use with the SQT, an assessment reach of 100 meters 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 because denoting the area with the most wood is less subjective than making a judgment decision about an average condition. In addition, practitioners are incentivized to select the highest scoring reach during monitoring.

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[11] http://stream-mechanics.com/stream-functions-pyramid-framework/

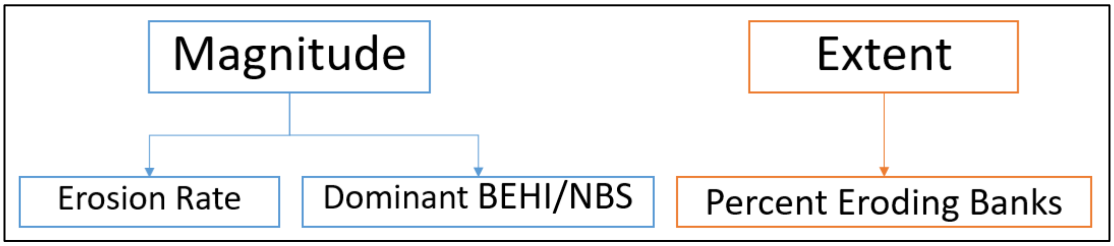
The current performance standards are based on data collected throughout the Piedmont and Mountain regions of North Carolina. A limited data set is available for the Coastal region. As more data are collected, additional performance standard curves will be developed.

IV.6.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 9.

Table 9: 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 10 shows the scoring associated with BEHI/NBS categories.

Table 10: 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 thalweg stream length. In the example provided in Table 9 where the total length of bank was 1100 feet, the 95 feet of High/High and Mod/High categories would be considered eroding bank (25+10+30+30 from 3rd column in Table 9). Therefore, 95/1100 = 9% streambank erosion.

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

IV.6.c. Riparian Vegetation

Riparian vegetation is a critical component of a healthy stream ecosystem. While riparian vegetation is a life form and could be included in the biology functional category, it directly effects channel stability (geomorphology) and supports denitrification and other water quality functions (physicochemical). 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 3. 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

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 taking the densiometer and estimating how much of the area is 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).

IV.6.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).[12]

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, watershed area, gradient, and lithology. When possible, pick reference reaches that are upstream of the project reach. For example, a stable C stream type with a forested watershed upstream of an unstable 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.

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

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 11.

Table 11: 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

IV.6.e. Bed Form Diversity

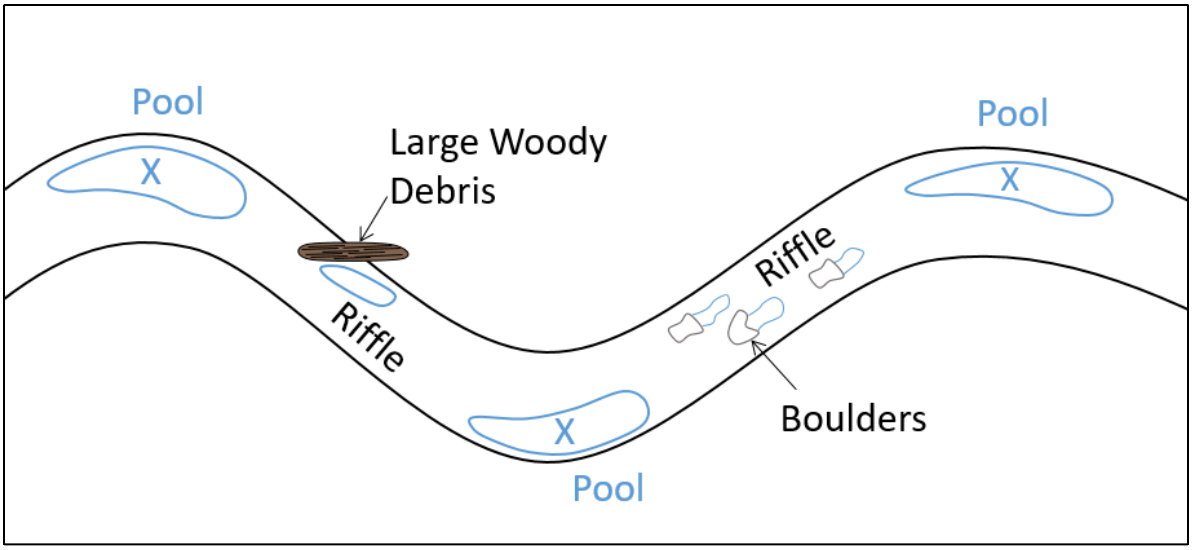
Bed forms include riffles, runs, pools and glides. Together, these bed features create important habitats for aquatic life. The location, stability, and depth of these bed features are symptomatic of sediment transport processes acting against the channel boundary conditions. Therefore, if the bed forms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

There are three measurement methods for this parameter: pool spacing ratio, pool depth ratio, and percent riffle. All three should be used for all projects and each is described below, including rapid and detailed methods. 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.

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

For use with the SQT, pools are only counted if they are located along the outside of the meander bend. Micro-pools within riffles are not counted using this method. Figure 14 provides an illustration of what is and is not counted as a pool. Since the figure illustrates a meandering stream, the pools located in the outside of the meander bend are counted within the pool spacing measurement. The X marks the approximate location of the deepest part of the pool. The micro pools associated with the large woody debris and boulder clusters are not counted because they are small pools located within the riffle.

Figure 14: Pool Spacing in Alluvial Valley Streams

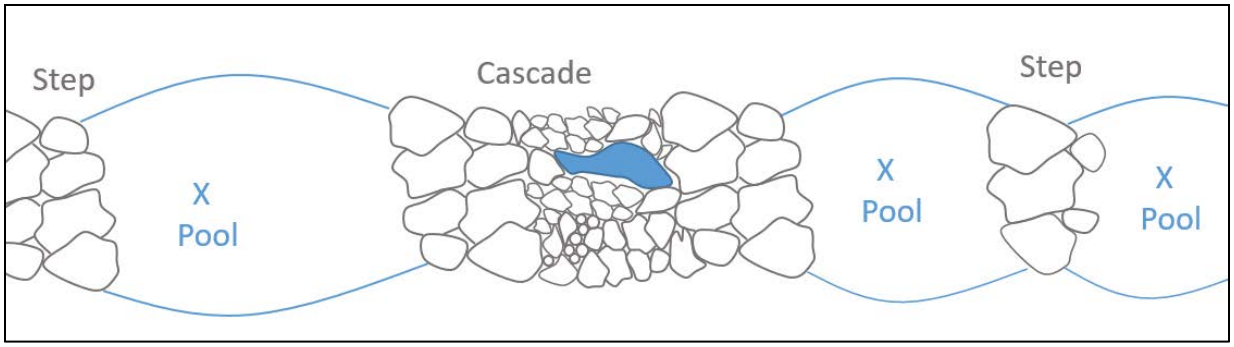


Compound pools that are not separated by a riffle within the same bend are treated as one pool. However, compound bends with two pools separated by a riffle are treated as two pools. Rosgen (2014) provides illustrations for these scenarios.

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. Pools within a riffle or cascade are not counted, just like pools within a riffle of a meandering stream are not counted. 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



1. Pool-Pool Spacing Ratio

The pool-to-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 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-to-pool spacing ratio is calculated for each pair of pools 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 provide further guidance on identifying pools. This guidance is provided below.

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 thalweg 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).

2. 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.

3. 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 thalweg 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.

IV.6.f. Sinuosity

Sinuosity 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.

Sinuosity is measured from the plan form of the stream reach. The sinuosity of a stream is calculated by dividing the stream thalweg distance by the straight- line valley length between two common points. These distances can be measured in the field or using orthoimagery 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).

Performance standards are stratified by stream type and are based on stream type classification and best professional judgement.

IV.7. Physicochemical

The SQT contains the following function-based parameters to assess the physicochemical functional category: 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 III.1. of this manual for guidance on selecting parameters for a stream restoration project.

IV.7.a. Temperature

Temperature plays a key role in both physicochemical and biological functions. Cooler water is less conductive and holds more oxygen than warmer water. These factors directly impact the water quality and ability of living organisms to survive in the stream. This measurement method requires deploying one or two recording temperature meters throughout the summer season (June, July and August). The meters should be set to record at regular intervals no more than every 15 minutes. If the user is deploying two meters in the reach, they should be placed near the beginning and end of the reach, and within the same type of bed feature, e.g., a pool. In the case that just one meter is deployed, it is recommended to place the meter near the downstream extent of the project.

The temperature meters should be placed in a shady pool, if available, at a depth that is approximately 2/3 of the maximum pool depth of that pool. Once the monitoring season is over, collect the meter(s) and download the data. Determine the average maximum observed temperature and enter it as a field value in the SQT (Swift and Messer, 1971).

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

IV.7.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).

IV.7.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.

IV.7.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 III.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.

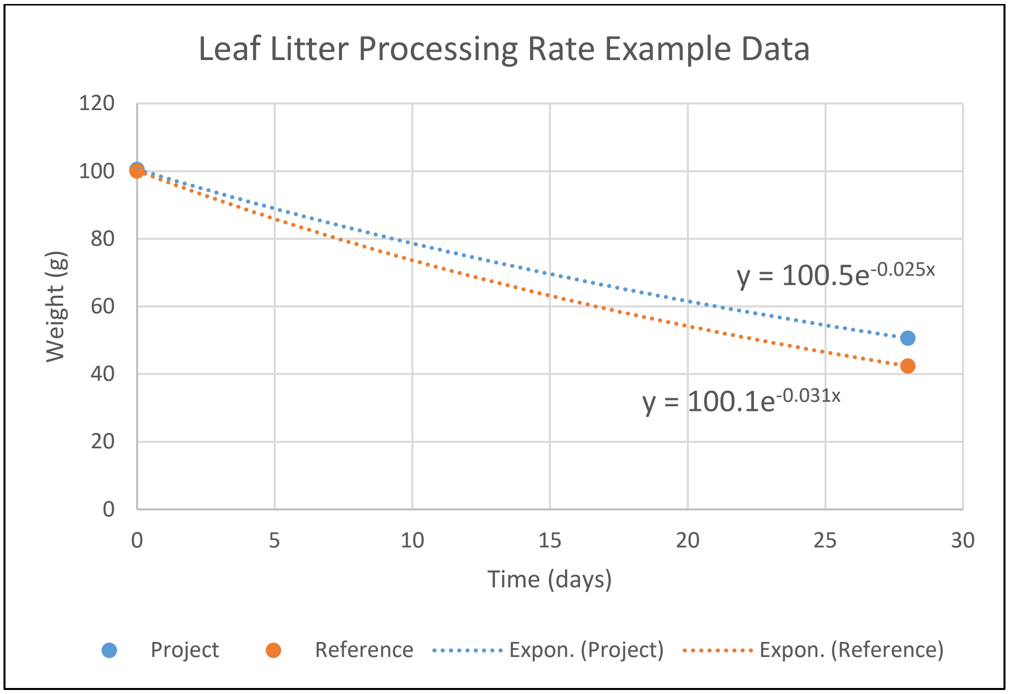
4. Place leaves in the bags and weigh them, placing roughly the same weight of leaves in each bag.
5. Securely fasten leaf bags to metal pegs (≥15-20 cm in length) and drive the pegs into a riffle section of each reach. The metal pegs are to be anchored to the stream bottom and driven beneath the bed 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 the 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 IV.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.

IV.7.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

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

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.

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 watershed 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).

IV.7.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 watershed 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

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

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 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).

IV.8. Biology

The function-based parameters included in the SQT for the Biology functional category are 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.

IV.8.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.

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

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;
- 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.

IV.8.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 Form

Catchment Assessment Form

Rater(s):

Date:

Overall Watershed Conditon

Purpose: This form is used to determine the project's restoration potential. The hydrology categories are used to determine the catchment hydrology score on the Quantification Tool sheet.

CATCHMENT ASSESSMENT

Categories		Description of Catchment Condition			Rating (P/F/G)
		Poor	Fair	Good	
1	Concentrated Flow (Hydrology)	Potential for concentrated flow/impairments to reach restoration site 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 (Watershed) (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	Many NPDES permits within watershed or some within one mile of project reach	A few NPDES permits within watershed and none within one mile of project reach	No NPDES permits within watershed 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 and 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-Based Assessment Field Form

Hydraulic and Geomorphic Assessment
Field Exercise

Date ____________________
Reach ____________________
Investigators ____________________

I. Bankfull Verification from Riffle Cross Section

A. Drainage Area ____________ sq. miles
B. Difference between bankfull stage and water surface ____________ feet
C. Bankfull Width (Measured) ____________ feet
D. Bankfull Area (Measured) ____________ sq. feet
E. Bankfull Mean Depth (Area/Width) ____________ feet
F. Bankfull Width (Regional Curve) ____________ feet
G. Bankfull Area (Regional Curve) ____________ sq. feet
H. Bankfull Mean Depth (Regional Curve) ____________ feet
I. Reach Length ($\geq 20 \times Bankfull\ Width$) ____________ feet

Area Calculations

II. Stream Classification

A. Bankfull W/D, calculate as

$$\frac{Bankfull\ Width}{Bankfull\ Mean\ Depth}$$

____________ ft/ft.

B. Bankfull Max Riffle Depth ____________ feet
C. Floodprone Area Width ____________ feet

D. Entrenchment Ratio, calculate as

$$\frac{Floodprone\ Area\ Width}{Bankfull\ Width}$$

____________ ft/ft.

E. Slope Estimate ____________ ft/ft.
F. Channel Material Estimate ____________
G. Stream Type ____________

III. Floodplain Connectivity

A. Bank Height/Riffle Data

	R_1	R_2	R_3	R_4	R_5	R_6
Low Bank Height (ft)						
Bankfull Height (ft)						
Bank Height Ratio						
Riffle Length (ft)						

Weighted BHR Calculations

B. Weighted Bank Height Ration, calculate as $\frac{\Sigma(Bank\ Height\ Ratio_i \times \text{Riffle Length}_i)}{\Sigma Riffle\ Length}$ ____________ ft/ft.

C. Entrenchment Ratio from Riffle ____________ ft/ft.

			Performance Standards		
	Field Value	Stream Type	Not Functioning	Functioning at Risk	Functioning
BHR			>1.5	1.5 – 1.3	< 1.3
ER		A, B, Bc	< 1.2	1.2 – 1.3	>1.3
		C, E	< 2.0	2.0 – 1.3	>1.3

D. Overall Floodplain Connectivity Score ____________

IV. Bedform Diversity

A. Pool Data

Bankfull Width (ft) ____________

Bankfull Mean Depth (ft) ____________

	P_1	P_2	P_3	P_4	P_5
Station					
Pool to Pool Spacing	▨				
Pool Spacing Ratio, $\frac{Pool\ Spacing}{Bankfull\ Width}$	▨				
Pool Depth					
Pool Depth Ratio, $\frac{Pool\ Depth}{Bankfull\ Mean\ Depth}$					

B. Average Pool Spacing Ratio __________ ft/ft.

C. Average Pool Depth Ratio __________ ft/ft.

D. Riffle Length (ft) __________ ft.

E. Percent Riffle, calculate as $\frac{Riffle\ Length}{Reach\ Length} \times 100$ __________ %

			Performance Standards		
	Field Value	Stratifiers	Not Functioning	Functioning at Risk	Functioning
Pool Spacing Ratio		Slope ≥ 4%	> 8 or < 0.1	8 – 5.1	5.1 – 0.1
		S < 4% & DA ≥ 10 Sq. Mi. & C or E Stream	< 3.3 > 7.8	3.3 – 3.6 7.8 – 7.4	3.7 – 7.3
		S < 4% & DA < 10 Sq. Mi. & C or E Stream	< 3 > 7	3 – 3.8 7 – 5.4	3.9 – 5.3
		S < 2% & Bc Stream OR Slope 2-4% & B Stream	> 6.5	6.5 – 4.1	< 4.1
Pool Depth Ratio		C or E Stream w/ Gravel Bed	< 1.2	1.2 – 1.5	> 1.5
		C or E Stream w/ Sand Bed	< 1.15	1.15 – 1.2	> 1.2
		A, B, or Bc Stream	< 1.2	1.2 – 1.5	> 1.5
Percent Riffle		Slope 3-10%	< 40 > 70	40 – 49 70 - 61	50 - 60
		S > 10%	< 70	70 - 75	> 75

		S < 3%	< 40 > 80	40 – 51 80 - 75	52 - 74

F. Overall Bedform Diversity Score ________________

V. Large Woody Debris

A. Number of Pieces per 100m ________________

B. Large Woody Debris Index ________________

			Performance Standards		
	Field Value	Stream Type	Not Functioning	Functioning at Risk	Functioning
LWDI		C or E	< 300	300 – 500	> 500
		Ephemeral & A	< 150	150 – 200	> 200
		A, B or Bc	< 200	200 - 299	> 299

VI. Lateral Stability

A. Bank Data

BEHI/NBS Score	Bank Length

B. Total Eroding Bank Length ________________ ft.

C. Total Bank Length ________________ ft.

D. Dominant BEHI/NBS Score ________________

E. Percent of Bank Erosion, calculate as

$$\frac{Total\ Eroding\ Bank\ Length}{Total\ Bank\ Length}$$ ________________ %

		Performance Standards		
	Field Value	Not Functioning	Functioning at Risk	Functioning
Dominant BEHI/NBS		Ex/Ex, Ex/VH, Ex/M, VH/H, H/H, M/VH	Ex/L, VH/M, H/M, M/H, L/Ex, M/L, L/H	L/M, M/VL, L/VL, L/L
% Eroding Bank		> 25	25 - 10	< 10

F. Overall Lateral Stability Score ____________________

VI. Riparian Vegetation

A. Riparian Vegetation Data

				Performance Standards		
	Left	Right	Stream Type	Not Functioning	Functioning at Risk	Functioning
Riparian/Buffer Width			A, B, Bc	< 13	$13 \leq x < 30$	≥ 30
			C, E	< 30	$30 \leq x < 45$	≥ 45
USFWS Score				No zones of vegetation well represented; runoff is primarily concentrated flow (extensive gulley and rill erosion); hillslopes >40%; hillslopes < 50ft from stream; ponding or wetland areas and litter or debris jams are not well represented or completely absent.	Only zone 2 of vegetation is well represented; runoff is equally sheet and concentrated flow (moderate gully and rill erosion); hillslopes 20 – 4%; hillslopes 50-100 ft from stream; ponding or wetland areas and litter or debris jams are minimally represented.	All 3 zones of vegetation exist; runoff is primarily sheet flow; hillslopes < 10%; hillslopes >200 ft from stream; ponding or wetland areas and litter or debris jams are well represented.
RBP Score				Width of riparian zone < 6 meters; little or no riparian vegetation due to human activity. (Poor; 0-2)	Width of riparian zone 12-18 meters; human activities have minimally impacted zone. (Sub-Optimal; 6-8) Width of riparian zone 6-12 meters; human activities have impacted zone a great deal. (Marginal; 3-5)	Width of riparian zone >18m; humans have not impacted zone. (Optimal; 9-10)

B. Basal Area

	Basal Area Plots					Performance Standards		
Riparian Buffer	1	2	3	4	5	Not Functioning	Functioning at Risk	Functioning
Left						< 40	$40 \le x < 77$	≥ 77
Right								

C. Stem Density

	Vegetation Plots					Performance Standards		
	1	2	3	4	5	Not Functioning	Functioning at Risk	Functioning
Stems/acre						< 156	$156 \le x \le 260$	> 260

D. Canopy Coverage

	Canopy Coverage Plots										Performance Standards		
Riparian Buffer	1		2		3		4		5		NF	FAR	F
Left											< 25	$25 \le x < 61$	≥ 61
Average											$\sum Avg$:	Avg. Performance:	
Right											< 25	$25 \le x < 61$	≥ 61
Average											$\sum Avg$:	Avg. Performance:	

E. Overall Riparian Vegetation Score ____________________

VII. Channel Evolution

A. Rosgen's Channel Type Succession Scenarios

	Performance Standards		
Channel Type Succession	Not Functioning	Functioning at Risk	Functioning
E → C → Gc → F → C → E	Gc, F	C → Gc and F → C	E, C
C → D → C	D	C → D and D → C	C
C → D → Gc → F → C	D, Gc, F	C → D and F → C	C
C → G → F → Bc	G, F	C → G and F → Bc	C, Bc
E → Gc → F → C → E	Gc, F	E → Gc and F → C	E, C
B → G → Fb → B	G, Fb	B → G and Fb → B	B
Eb → G → B	G	Eb → G and G → B	Eb, B
C → G → F → D → C	G, F, D	C → G and D → C	C
C → G → F → C	G, F	C → G and F → C	C
E → A → G → F → C → E	A, G, F	E → A and F → C	E
C → F → C → F → C	F	C → F	First and last C
C → G → F → C → C → C	G, F, Fourth C	C → G and C→ C	First and last C

B. Rosgen Channel Type Succession Score ____________________

C. Simon Channel Evolution Model Stages

	Performance Standards		
Channel Evolution Model Stages	Not Functioning	Functioning at Risk	Functioning
Sinuous, premodified			✓
Channelized	✓		
Degradation	✓		
Degradation and widening	✓		
Aggradation and widening	✓	✓*	
Quasi-equilibrium			✓

**Only late Stage 5 of the Simon model, where the stream has begun to construct a new floodplain at a lower elevation, is considered to be functioning at risk.*

D. Overall Channel Evolution Score ____________________

VII. Overall Functional Capacity for Hydraulic and Geomorphic Functions

Floodplain Connectivity ____________________

Bedform Diversity ____________________

Large Woody Debris ____________________

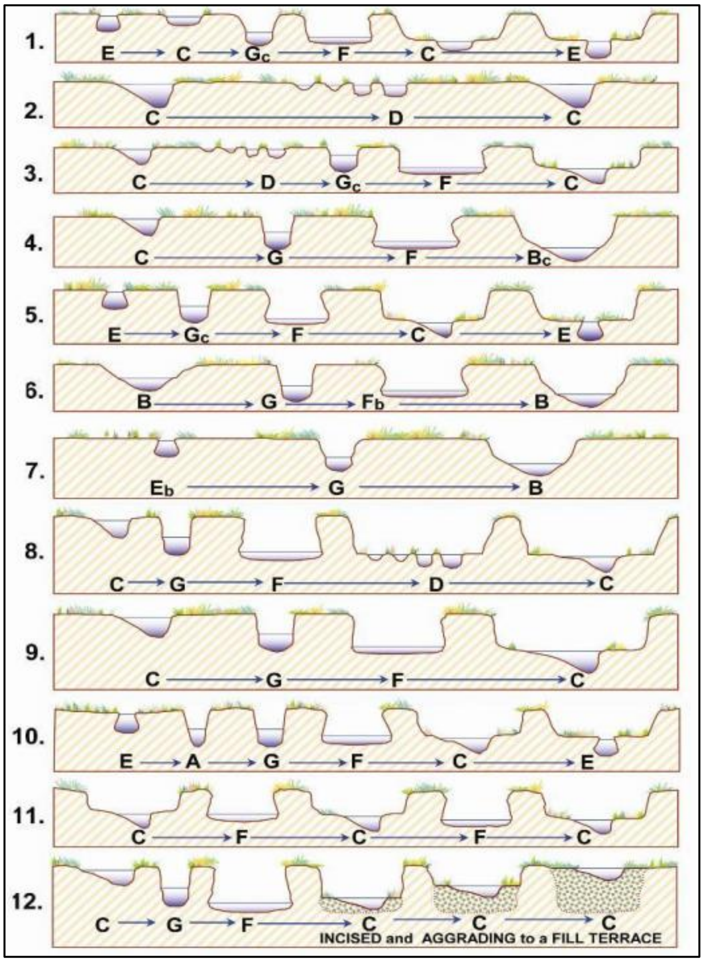
Lateral Stability ______________________

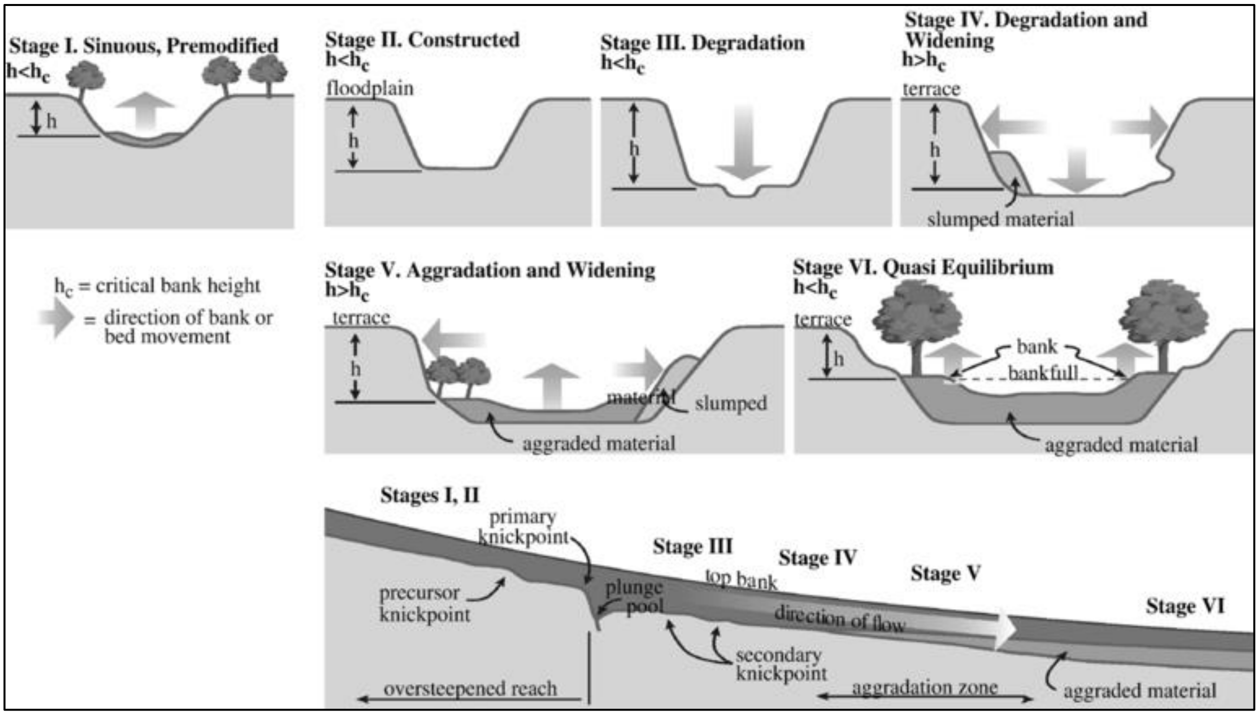
Riparian Vegetation ______________________

Channel Evolution ______________________

Overall ______________________

Various Stream Type Succession Scenarios




Stage I. Sinuous, Premodified
h<h_c
h
Stage II. Constructed
h<h_c
floodplain
h
Stage III. Degradation
h<h_c
h
Stage IV. Degradation and Widening
h>h_c
terrace
h
slumped material
h_c = critical bank height
= direction of bank or bed movement
Stage V. Aggradation and Widening
h>h_c
terrace
h
material
slumped
aggraded material
Stage VI. Quasi Equilibrium
h<h_c
terrace
h
bank
bankfull
aggraded material
Stages I, II
primary knickpoint
precursor knickpoint
Stage III
plunge pool
top bank
Stage IV
direction of flow
Stage V
Stage VI
secondary knickpoint
oversteepened reach
aggradation zone
aggraded material