US Army Corps of Engineers
Omaha District

Wyoming Stream Quantification Tool User Manual (Beta Version)

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User Manual
Beta Version

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Lead Agency:

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Wyoming Department of Environmental Quality

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The Wyoming Stream Quantification Tool is a modification of the Functional Lift Quantification Tool for Stream Restoration Projects in North Carolina (Harman and Jones, 2016). The North Carolina tool was developed by Stream Mechanics and Ecosystem Planning and Restoration with funding and project management support from the Environmental Defense Fund.

The WSQT and accompanying documents are available from the Stream Mechanics web page.

https://stream-mechanics.com/stream-functions-pyramid-framework/

Acronyms

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

CFR – Code of Federal Register

Corps – United States Army Corps of Engineers (also, USACE)

CN – Curve numbers

CWA 404 – Section 404 of the Clean Water Act

ECS – Existing Condition Score

F – Functioning

FAR – Functioning-At-Risk

FF – Functional Feet

LOM – List of Metrics

NF – Not Functioning

NRCS – Natural Resource Conservation Service

PCS – Proposed Condition Score

SFPF – Stream Function Pyramid Framework

SQT –Stream Quantification Tool

TMDL – Total Maximum Daily Load

USACE – United States Army Corps of Engineers (also, Corps)

USDOI – United States Department of Interior

USFWS – United States Fish and Wildlife Service

USEPA – US Environmental Protection Agency

UT – Unnamed tributary

WSEL – Water Surface Elevation

WDEQ WQD – Wyoming Department of Environmental Quality, Water Quality Division

WGFD – Wyoming Game and Fish Department

WYPDES – Wyoming Pollutant Discharge Elimination System

WSMP – Wyoming Stream Mitigation Procedure (USACE, 2013)

WSMP v2 – Wyoming Stream Mitigation Procedure version 2 (in draft)

WSQT – Wyoming Stream Quantification Tool

Glossary of Terms

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

Catchment – Land area draining to the downstream end of the project reach.

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

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

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

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

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

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

Equilibrium – Distinct from a stable, static state, a form that displays relatively stable characteristics to which it will return after a disturbance (Renwick 1992).

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

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

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

Functional Feet (FF) – Functional feet is the primary unit for communicating functional lift and loss, and is calculated by multiplying a condition score by stream length. ∆FF is the difference between the Existing FF score and the Proposed FF score.

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

Impact Severity Tiers – The Debit Tool provides estimates of proposed condition based upon the magnitude of proposed impacts, referred to as the impact severity tier. Higher tiers impact more stream functions.

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

Performance Standard – Observable or measurable physical (including hydrological), chemical and/or biological attributes that are used to determine if a compensatory mitigation project meets its objectives. Index values on a 0.00 to 1.00 scale are derived from performance curves based on available reference data and professional judgement. Each measurement method has defined performance standards to calculate index values. Performance standards are stratified by categories: functioning, functioning-at-risk, and not functioning.

Rapid Method – Suite of office and field techniques specific to the WSQT for collecting quantitative data to inform functional lift and loss calculations in the tool. Chapter 4 and Appendix A include descriptions of the rapid method and field forms. The rapid method will typically take three to six hours to complete per project reach.

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

Riparian Area Width - The percentage of the flood prone area width that contains riparian vegetation and is free from utility-related, urban, or otherwise soil disturbing land uses and development. The riparian corridor corresponds to (USDA 2014):

1) Substrate and topographic attributes -- the portion of the valley bottom influenced by fluvial processes under the current climatic regime,
2) Biotic attributes -- riparian vegetation characteristic of the region, and
3) Hydrologic attributes -- the area of the valley bottom flooded during the 50-year recurrence interval flow.

Riparian Vegetation – Plant communities contiguous to and affected by surface and subsurface hydrologic features of perennial or intermittent water bodies.

Stream Functions Pyramid Framework (SFPF) – The Stream Functions Pyramid is comprised of five functional categories stratified based on the premise that lower-level functions support higher-level functions and that they are all influenced by local geology and climate. The SFPF includes the organization of function-based parameters, measurement methods, and performance standards to assess the functional categories of the Stream Functions Pyramid (Harman et al. 2012).

Wyoming Stream Quantification Tool (WSQT) – The WSQT is a spreadsheet-based calculator that scores stream condition before and after restoration or impact activities to determine functional lift or loss, and can also be used to determine restoration potential, develop monitoring criteria and assist in other aspects of project planning. The WSQT is based on principles and concepts of the SFPF.

Wyoming Stream Technical Team – Group tasked with developing function-based parameters, measurement methods, and performance standards for the WSQT. Members included representatives from the U.S. Environmental Protection Agency (USEPA), the U.S. Army Corps of Engineers (Corps), the Wyoming Department of Environmental Quality (WDEQ), and the Wyoming Game and Fish Department (WGFD).

Overview

In the context of Section 404 of the Clean Water Act (CWA 404), stream assessment tools are needed to ensure that authorized stream impacts are adequately mitigated. The fundamental objective of mitigation is to compensate for the losses in aquatic resource function from unavoidable impacts resulting from permitted activities (33 CFR 332.3(a)). The focus on aquatic resource function is an important component of the regulations, which specifically define credits and debits as a unit of measure (e.g., a functional or areal measure or other suitable metric) representing the accrual or attainment of aquatic functions at a compensatory mitigation site, or the loss of aquatic functions at an impact or project site, respectively (33 CFR 332.2). The regulations further emphasize the need for adequate assessment methods for performance standards, namely that performance standards should be based on objective and verifiable ecosystem attributes to ensure a project is providing the expected functions (33 CFR 332.5).

There are many stream assessment methods used across the United States for a variety of purposes (ELI 2016; Somerville 2010). These methods vary in the types of data they use and the level of detail in data capture; and these differences are largely dependent upon the objectives of a particular protocol. Approaches that rely on subjective, qualitative criteria can generally be executed more rapidly than methods that use quantitative measures. However, quantitative approaches, which rely on actual measurements of stream and riparian variables tend to produce more objective, verifiable and repeatable results (Gilbert 2011). For purposes of determining compensatory mitigation, quantitative-based assessment methods improve the ability to document functional lift and loss, thereby improving the objectivity and level of detail with which they can inform a credit or debit calculation (ELI 2016).

The Wyoming Stream Quantification Tool (WSQT) is a Microsoft Excel Workbook that has been developed to characterize stream ecosystem functions by evaluating a suite of indicators that represent structural or compositional attributes of a stream and its underlying processes. The WSQT is an application of the Stream Functions Pyramid Framework (Harman et al. 2012), and uses function-based parameters and measurement methods to assess five functional categories: hydrology, hydraulics, geomorphology, physicochemical and biology. The WSQT approach integrates multiple indicators from these functional categories into a reach-based index score that can be used to quantify the amount of lift or loss of aquatic resource functions related to various impacts or restoration efforts. While the WSQT is not explicitly a rapid assessment, rapid-based, quantitative measurement methods are identified for most parameters.

The main goal of the WSQT is to produce objective, verifiable and repeatable results by consolidating well-defined procedures for objective measures of defined stream variables. The most important differences between the WSQT and existing assessment methods include:

1. The WSQT allows users to tailor their data collection to their particular site or project by selecting applicable metrics from the 14 parameters and 33 measurement methods included in the WSQT.
2. Metrics included in the WSQT represent functional parameters that are often impacted by authorized projects or affected (e.g. enhanced or restored) as a result of mitigation actions undertaken by restoration providers.
3. Many components and terms used within the WSQT directly align with guidance from the Federal Mitigation Rule.
4. The same metrics are used on the mitigation side as the impact side which makes for more consistent accounting of functional change.

5. The metrics are quantitative and repeatable, creating better resolution (ability to detect change) than existing methods.
6. There are rapid, quantitative measurement options provided for most parameters.
7. The focus is on the change in functional condition (aka, the delta) between existing and future conditions, and thus the delta is more important than the ambient stream condition.

The WSQT is a simple spreadsheet tool designed to inform permitting and mitigation decisions within the CWA 404 program. This manual describes the WSQT and how to collect and analyze data to enter into the WSQT. The companion document, the Wyoming Stream Mitigation Procedures (WSMP), provides the policy direction for how functional changes in streams are translated into credits and debits. The original WSMP (USACE, 2013) is being updated and revised to better accommodate the WSQT and the capabilities it provides. An updated guidance document, the WSMP v2, is currently in development.

Purpose and Use of the WSQT

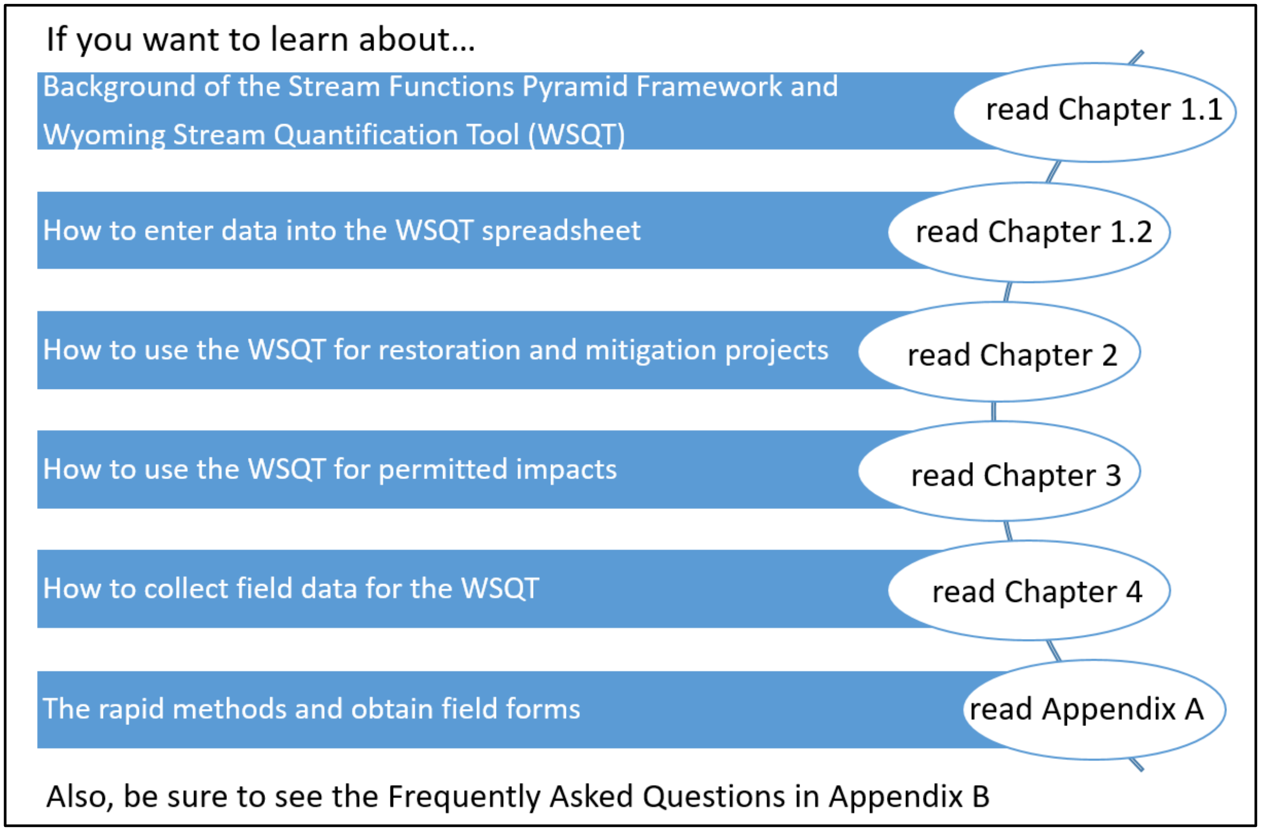
The purpose of the WSQT is to calculate functional loss and lift associated with stream impacts and restoration projects. In addition, the WSQT **can assist** in site selection, determining project specific function-based goals and objectives, understanding the restoration potential of a site, determining performance criteria, and developing a monitoring plan. Additional detail on these uses is provided below. Note that not all portions of the WSQT will be applicable to all projects; Figure 1 can be used to determine what sections of this manual to consult for specific project types.

Uses of the WSQT:

1. Restoration Potential – The catchment assessment form can be used to help determine factors that limit the potential lift achieved by a stream restoration or mitigation project.
2. Site Selection – The tool can help determine if a proposed site has enough lift and quality to be considered for a stream restoration or mitigation project. Rapid field assessment methods can be used to produce existing and proposed scores.
3. Function-Based Goals and Objectives – This tool can be used to describe project goals that match the restoration potential of a site. Quantifiable objectives and performance criteria can be developed that link restoration activities to measurable changes in stream functional categories and function-based parameters assessed by the tool.
4. Functional Lift or Loss – The tool is a simple calculator to quantify functional change between an existing and future stream condition. The future stream condition can be a proposed or active stream restoration project or a proposed stream impact requiring a CWA 404 permit. On the restoration side, this functional change can be estimated during the design or mitigation plan phase and is re-scored for each post-construction monitoring event (Chapter 2). On the impact side, functional loss can be estimated using several methods, including the Debit Tool (Chapter 3).
5. Credit Determination – Estimates of functional lift (Chapter 2) can inform CWA 404 mitigation decisions. Credit determination methods for mitigation projects are not included in this manual, but will be outlined in the WSMP v2 (in draft).
6. Debit Determination – Estimates of functional loss (Chapter 3) can inform CWA 404 permitting decisions. Debit determination methods are not included in this manual, but will be outlined in WSMP v2 (in draft).

7. Mitigation – The tool can be applied to on- or off-site and in-or out-of-kind permittee responsible mitigation, in-lieu fee mitigation, and mitigation banks to help determine if the proposed mitigation activities will offset the proposed impacts. This tool can be used to develop monitoring plans and performance standards.

Figure 1: Manual Directory



Overview of Document and Public Review

The purpose of this user manual is to provide instruction on the use of the WSQT in Wyoming streams to calculate functional lift and loss associated with stream impacts and restoration projects. The lift and loss values generated will inform crediting and debiting in accordance with the CWA 404 Regulatory program in Wyoming. Application of the WSQT in the CWA 404 Regulatory Program in Wyoming will be outlined in the version 2 of the Wyoming Stream Mitigation Procedures (WSMP v2; in draft). The WSMP v2 is the regulatory program policy document that provides instruction on WSQT implementation and how its products will be utilized to fulfill documentation requirements for CWA 404 permit actions and mitigation responsibilities. Users are encouraged to contact the Corps to obtain project-specific direction.

This document is organized into 4 chapters and 4 appendices:

- Chapter 1: This chapter provides background on the Stream Functions Pyramid Framework and an overview of the elements in the WSQT workbook.

- Chapter 2: This chapter outlines how the WSQT can be used with stream restoration projects to set project goals and objectives, determine restoration potential, and calculate functional lift.
- Chapter 3: This chapter outlines how the WSQT can be used to quantify functional loss of a project to inform CWA 404 permitting, and assist the Corps in determining how much mitigation may be required.
- Chapter 4: This chapter outlines the various data collection and analysis methods that can be input into the tool to calculate functional lift and loss. These methods include both existing metrics and new methods developed for the WSQT.
- Appendix A: This appendix consolidates rapid-based measurement methods and data collection methods into a cohesive field assessment protocol, including field data collection forms.
- Appendix B: This appendix includes a list of common Questions and Answers about the WSQT and how it can be applied.
- Appendix C: This appendix consists of Wyoming Fish Species Assemblages within the six major river basins in Wyoming. These assemblages are based on the Wyoming State Wildlife Action Plan (WGFD 2017).
- Appendix D: This appendix includes the List of Metrics which outlines the stratification, performance standards, and references for all parameters and measurement methods used in the WSQT.

The WSQT has been modified from the North Carolina Stream Quantification Tool (Harman and Jones 2016) and regionalized for use in Wyoming. Many of the parameters, measurement methods, and performance standards are therefore unique to this state and its ecoregions. Other stream quantification tools and user manuals are being developed for use in other states and regions. The Wyoming beta-version of the tool is available for initial field testing and public comment.

Chapter 1. Background and Introduction

The Stream Quantification Tool was developed for stream restoration projects completed as part of a compensatory mitigation requirement. However, the tool can also be more broadly applied to any stream restoration project, regardless of funding driver. Specific reasons for developing the tool include the following:

1. Develop a simple calculator to determine the numerical differences between an existing (degraded) stream condition and the proposed (restored or enhanced) stream condition. This numerical difference is known as functional lift or uplift. It is related to, and could be part of, a stream credit determination method as defined by the Rule.
2. Link restoration activities to changes in stream functions and processes by primarily selecting function-based parameters and measurement methods that are influenced by common stream restoration techniques.
3. Link restoration goals to a project's restoration potential. Encourage assessments and monitoring that matches the identified restoration potential.
4. Incentivize high-quality stream restoration and mitigation by calculating functional lift associated with physicochemical and biological improvements.
5. Apply the same calculator at an impact site to determine the numerical differences between an existing stream condition and the proposed (degraded) stream condition. This numerical difference is known as functional loss.

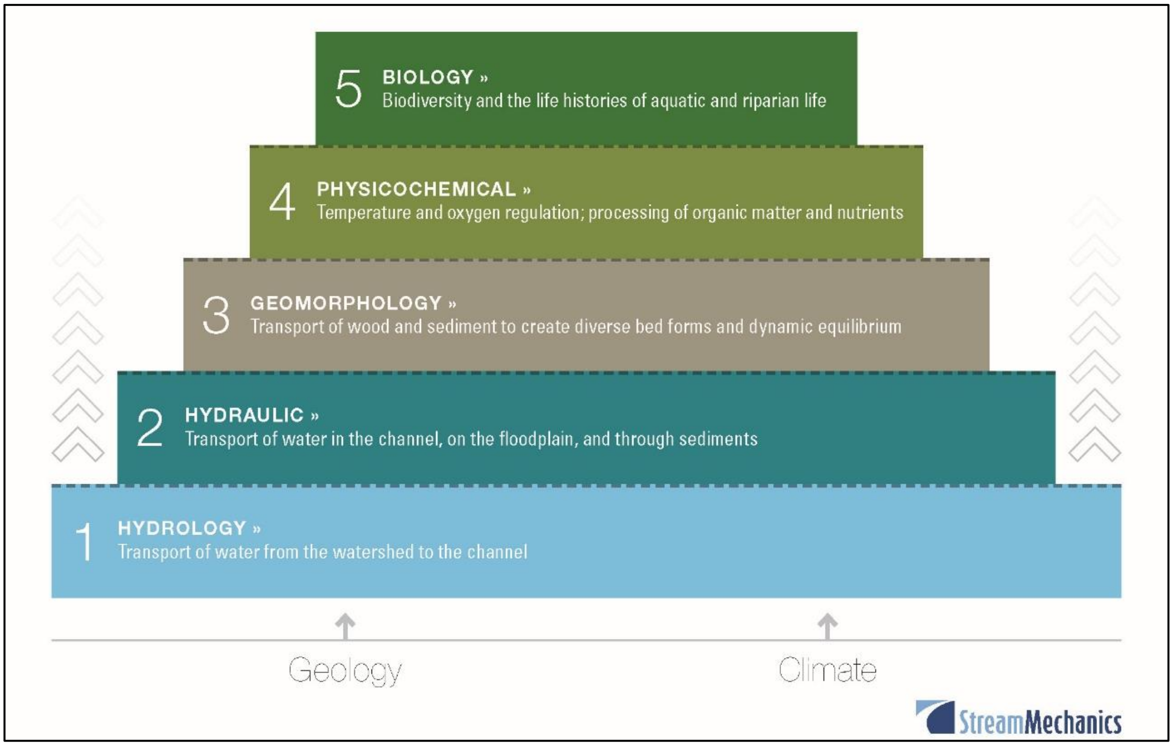
The Wyoming Stream Quantification Tool (WSQT) is an application of the Stream Functions Pyramid Framework (SFPF). Therefore, to understand the structure of the WSQT, it's important to first understand the SFPF. This chapter provides an overview of the SFPF followed by a detailed section on the development and content of the WSQT (WSQT).

1.1. Stream Functions Pyramid Framework (SFPF)

In 2006, the Ecosystem Management and Restoration Research Program of the Corps noted that specific functions for stream and riparian corridors had yet to be defined in a manner that was generally agreed upon and suitable as a basis for which management and policy decisions could be made (Fischenich 2006). In an effort to fill this need for Corps programs, an international committee of scientists, engineers, and practitioners defined 15 key stream and riparian zone functions aggregated into 5 categories. These five categories include system dynamics, hydrologic balance, sediment processes and character, biological support, and chemical processes and pathways. This work informed the development of the Stream Functions Pyramid Framework (Harman et al. 2012) which provides the scientific basis of the WSQT.

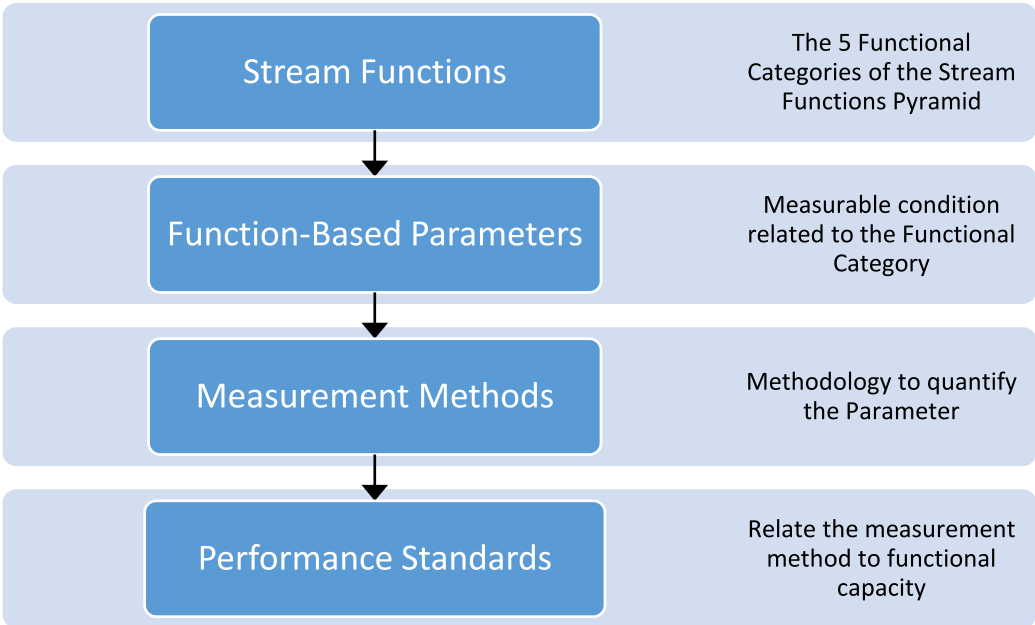
The Stream Functions Pyramid (Figure 2), includes five functional categories: Level 1: Hydrology, Level 2: Hydraulics, Level 3: Geomorphology, Level 4: Physicochemical, and Level 5: Biology. The Pyramid organization recognizes that lower-level functions generally support higher-level functions (although the opposite can also be true) and that all functions are influenced by local geology and climate. Each functional category is defined by a functional statement.

Figure 2: Stream Functions Pyramid (Image from Harman et al. 2012)



The SFPF illustrates a hierarchy of stream functions but does not provide specific mechanisms for addressing functional capacity, establishing performance standards, or communicating functional change. The diagram in Figure 3 expands the Pyramid concept into a more detailed framework to quantify functional capacity, establish performance standards, evaluate functional change, and establish function-based goals and objectives.

Figure 3: Stream Functions Pyramid Framework



This comprehensive framework includes more detailed forms of analysis to quantify stream functions and functional indicators of underlying stream processes. In this framework, function-based parameters describe and support the functional statements of each functional category, and the measurement methods are specific tools, equations, and/or assessment methods that are used to quantify the function-based parameter. Performance standards are measurable or observable end points of stream restoration.

The SFPF formed the basis of the SQT, first developed in North Carolina (Harman and Jones 2016), and regionalized for Wyoming. Frequently asked questions about the tool and its development have been collected in Appendix B.

1.2. Wyoming Stream Quantification Tool (WSQT)

Following the SFPF, function-based parameters and measurement methods were selected to quantify stream condition across the ecoregions and stream types found in Wyoming for each level in the stream functions pyramid. Each measurement method is linked to performance standards derived from reference data, literature, or best professional judgement where data are sparse. Performance standards relate to functional capacity on a 0.00 to 1.00 scale that ranges from functioning (0.70 to 1.00), to functioning-at-risk (0.30 – 0.69), to not functioning (0.00 – 0.29). See Table 1 for definitions of these functional capacity categories. In the WSQT, field values for a measurement method are assigned an index value (0.00 – 1.00) using the applicable performance standard. The complete list of function-based parameters and measurement methods is provided in the List of Metrics (Appendix D) along with performance standards and their stratification.

Table 1. Performance Standards in Relation to Reference Condition

Functional Capacity	Definition	Numeric Score Range
Functioning [F]	A functioning score means that the measurement method is quantifying or describing the functional capacity of one aspect of a function-based parameter in a way that **does support** a healthy aquatic ecosystem. In other words, it is functioning at reference condition. The reference condition concept used here aligns with the definition laid out by Stoddard, et al. (2006) for a reference condition for biological integrity. It is important to note that a reference condition does not simply represent the best attainable condition; rather, a functioning condition score represents an unaltered or minimally impacted system.	0.70 to 1.00
Functioning-at-risk [FAR]	A functioning-at-risk score means that the measurement method is quantifying or describing one aspect of a function-based parameter in a way that **can support** a healthy aquatic ecosystem. In many cases, this indicates the function-based parameter is adjusting in response to changes in the reach or the catchment. The trend may be towards lower or higher function. A functioning-at-risk score indicates that the aspect of the function-based parameter, described by the measurement method, is between functioning and not functioning.	0.30 to 0.69

Functional Capacity	Definition	Numeric Score Range
Not functioning [NF]	A not functioning score means that the measurement method is quantifying or describing one aspect of a function-based parameter in a way that **does not support** a healthy aquatic ecosystem. In other words, it is not functioning like a reference condition.	0.00 to 0.29

Although the WSQT is a reach-based assessment, one of the goals of the WSQT is to link restoration goals to the restoration potential of a site. Restoration takes place in the context of the contributing catchment and the WSQT includes a catchment assessment to identify factors that can limit restoration. Restoration potential, and how it is implemented in the WSQT, is described in Chapter 2.

The WSQT is comprised of 7 visible worksheets and one hidden worksheet. There are no macros in the spreadsheet and all formulas are visible, though some worksheets are locked to prevent editing. One Microsoft Excel Workbook should be assigned to each reach in a project. The worksheets include:

- Project Assessment
- Catchment Assessment
- Quantification Tool (locked)
- Debit Tool (locked)
- Monitoring Data (locked)
- Data Summary (locked)
- Performance Standards (locked)
- Pull Down Notes – This worksheet is hidden and contains all the inputs for drop down menus throughout the workbook.

The Quantification Tool, Debit Tool, Monitoring Data, Data Summary and Performance Standards worksheets are locked to protect the formulas that provide scores and calculate functional change. Each of the worksheets is described in the following sections.

1.2.a. Project Assessment Worksheet

The purpose of the Project Assessment worksheet is to describe the proposed project and its effect on the stream reach. This worksheet is used for all projects. If the proposed project is restoring a stream channel this worksheet will communicate the goals of the project and its restoration potential. If the proposed project is impacting a stream channel, then this worksheet will describe the proposed impacts to the stream reach. For projects with multiple reaches and multiple workbooks, the general project information on this worksheet will likely be similar or identical for each reach in the project.

For users proposing on-site compensatory mitigation for CWA 404, in most cases the impacted area and mitigation area will be located on different reaches within the overall project area. The functional loss at the impacted reach should be evaluated consistent with the instructions provided in Chapter 3, and the functional lift at the mitigation reach should be evaluated within a separate workbook consistent with the instructions provided in Chapter 2. For example, if a user is proposing to channelize a portion of a stream, the functional loss would need to be calculated for the channelized, impacted, stream reach (Chapter 3). The user would have another WSQT workbook to calculate the functional lift for the stream reach that is restored to mitigate for those impacts (Chapter 2). In the unique circumstance that the impacts and mitigation are proposed for the same stream reach within the project site, it is recommended that the user consult with the Corps to determine how to apply the WSQT to calculate functional lift and loss.

Programmatic Goals (all projects) – Programmatic goals represent big-picture goals that are often broader than function-based goals and are determined by the project owner or funding entity. Select Mitigation – Credits, Mitigation – Debits, TMDL, Grant, or Other from the drop-down menu (Figure 4).

Figure 4. Programmatic Goals for Impact Projects

Programmatic Goals			
	Select:		Debit Option:
	Mitigation - Debits		2

Reach Description (all projects) – Space is provided to describe the reach and the characteristics that separate it from other reaches within the project. Guidance on identifying project reaches is provided in Chapter 4: Data Collection and Analysis.

Aerial Photograph of Project Reach (all projects) – Provide a current aerial photograph of the project reach. The photo could include labels indicating where work is proposed, the project easement, and any important features within the project site or catchment.

Impacts (impact projects only) – This section of the spreadsheet should be filled out for projects requiring a CWA 404 permit. The proposed project and anticipated impacts to stream reach functions and parameters should be explained.

Restoration (mitigation and restoration projects only) – This section provides the user space to expand on the programmatic goals, discuss restoration potential, and define project goals and objectives.

The connection between the restoration potential and the programmatic goals should be explained in the second text box. The restoration potential is described as Level 3: Geomorphology, Level 4: Physicochemical, or Level 5: Biology. The restoration potential is also entered on the Quantification Tool worksheet. Restoration potential is described in Section 2.2.a.

The third text box under Restoration provides space to describe the function-based goals and objectives of the project. These goals should match the restoration potential. More information on developing goals and objectives is provided in Section 2.2.b.

Restoration example:

If the programmatic goal is to create mitigation credits, then the first text box could provide more information about the type and number of credits desired.

If the restoration potential is Level 3, then the second text box would explain how bringing geomorphology to a functioning level would create the necessary credits and identify any constraints preventing the restoration of physicochemical and biological functions to a reference condition.

The goals of the project would match the restoration potential, i.e. targeting fully functioning habitat and maybe functioning-at-risk biology. Accompanying objectives could identify parameters that will be restored and which measurement methods will be used to monitor restoration progress.

1.2.b. Catchment Assessment Worksheet

The purpose of the Catchment Assessment is to assist in determining the restoration potential of the project reach (Chapter 2) and to score the catchment hydrology parameter (Chapter 4).

The Catchment Assessment includes descriptions of processes and stressors that exist outside of the project reach that may limit functional lift (Table 2). It also highlights factors necessary to consider or address during the project design in order to maximize the likelihood of a successful project. Most of the categories describe potential problems upstream of the project reach since the contributing catchment has the most influence on the project reach's hydrology, water quality and biological health. However, there are a few categories, such as impoundments, that consider influences both upstream and downstream of the project reach. Detail on completing the catchment assessment is provided in Chapter 4, Section 4.3.

This worksheet should be completed for all projects, though not every category needs to be addressed for every project. For functional loss calculations, it may only be necessary to complete categories 1 – 3. Details on calculating functional loss are provided in Chapter 3.

Table 2: Catchment Assessment Categories

Categories		Descriptions
1	Impoundments	Proximity of impoundments to the project, both upstream and downstream.
2	Flow Alteration	Degree to which flow regime is reduced or augmented by anthropogenic barriers or withdrawals.
3	Urbanization	Degree and amount of urban growth and development.
4	Fish Passage	Presence or absence of anthropogenic barriers affecting fish passage upstream or downstream.
5	Organism Recruitment	Condition of channel bed and bank immediately upstream and downstream of the restoration site.
6	Wyoming Integrated Report (305(b) and 303(d)) status	Occurrence of fisheries or aquatic life impairment upstream of project.
7	Percent of Catchment Being Enhanced or Restored	Percent of catchment included in the project's easement.
8	Development: Oil, Gas, Wind, Pipeline, Mining, Timber Harvest, Roads	Proximity, degree and potential for development in catchment.
9	WYPDES Permits	Proximity and degree to which WYPDES permitted facilities contribute to the project's baseflow.
10	Historic Tie Drives	Historic occurrence of large scale tree harvesting and degree to which effects persist.
11	Riparian Vegetation	Percent of contributing stream length that has a contiguous and natural riparian buffer.
12	Sediment Supply	Potential sediment supply from upstream bank erosion and surface runoff.
13	Other	Choose your own.

1.2.c. Quantification Tool Worksheet

The Quantification Tool worksheet is the main sheet of the WSQT. It is the calculator where users enter data describing the existing and proposed conditions of the project reach and functional lift or loss is quantified.

The Quantification Tool worksheet contains three areas for data entry: Site Information and Performance Standard Stratification, Existing Condition Assessment field values, and Proposed Condition Assessment field values. Cells that allow input are shaded grey and all other cells are locked. Each section of the worksheet is discussed below.

1. Site Information and Performance Standard Stratification

The Site Information and Performance Standard Stratification section consists of general site information and information necessary to determine what performance standards are applied in the WSQT for calculating index values of some measurement methods. Figure 5 shows the fields in this section; more information on each and guidance on how to select values is provided in Chapter 4, Section 4.5. While it is not necessary to fill in all of the fields, some measurement methods will not be scored, or may be scored incorrectly if sufficient data are not provided in this section.

For fields with drop-down menus, if a certain variable is not included in the drop-down menus, then data to inform performance standards for that variable are not yet available for Wyoming.

Figure 5: Site Information and Performance Standard Stratification Input Fields

Site Information and Performance Standard Stratification	
Project Name:	
Reach ID:	
Restoration Potential:	
Existing Stream Type:	
Reference Stream Type:	
Ecoregion:	
Bioregion:	
Drainage Area (sq.mi.):	
Proposed Bed Material:	
Existing Stream Length (ft):	
Proposed Stream Length (ft):	
Stream Slope (%):	
River Basin:	
Stream Temperature:	
Riparian Soil Texture:	
Reference Vegetation Cover:	
Stream Productivity Rating:	
Valley Type	

2. Existing and Proposed Condition Assessment Data Entry

Once the Site Information and Performance Standard Stratification section has been completed, the user can input data into the field value column of the Existing and Proposed Condition Assessment tables.

The user will input field values for the measurement methods associated with each applicable function-based parameter (Figure 6). The function-based parameters are listed by functional category, starting with hydrology. The Existing Condition Assessment field values are derived from measurements and procedures detailed in Chapter 4 of this manual. An existing condition score uses baseline data collected from the project site before any work is completed. The Proposed Condition Assessment field values should consist of reasonable values for either the restored condition or the impacted condition. A proposed condition is comprised of estimated field values based on design studies/calculations, reports, and best available science. More detail on how to determine and document reasonable values for stream restoration and impacts are provided in Chapters 2 and 3 respectively. For a stream restoration project, the proposed condition scores are estimated during the development of the mitigation plan and then verified during the monitoring phase.

A project would rarely, if ever, enter field values for all parameters and measurement methods included in the WSQT. This manual provides limited guidance on parameter selection in Chapters 2 and 3. Parameter selection requirements for projects associated with CWA 404 will be provided in WSMP v2 (in draft).

As shown in Figure 6, some function-based parameters in the WSQT have more than one measurement method. Some parameters have measurement methods that complement each other, while some measurement methods are redundant. For example, the dominant bank erosion hazard index (BEHI) measurement method and erosion rate measurement method for lateral stability are redundant since BEHI is used to estimate an erosion rate. Alternatively, the floodplain connectivity parameter should be assessed using both the bank height ratio and entrenchment ratio measurement methods. Bank height ratio quantifies the frequency that the floodplain is inundated and the entrenchment ratio quantifies the lateral extent of floodplain inundation. Each of these measurements contributes differently to an overall understanding of floodplain connectivity. The relationship between each measurement method and the function-based parameter it describes is detailed in Chapter 4.

Important Notes:

- If a value is entered for a measurement method in the Existing Condition Assessment, a value must also be entered for the same measurement method in all subsequent condition assessments (e.g. proposed, as-built, and monitoring).
- For measurement methods that are not assessed (i.e., a field value is not entered), the measurement method is removed from the scoring. It is NOT counted as a zero.

For guidance on collecting and calculating the field values associated with each measurement method, see Chapter 4.

Figure 6: Field Value Data Entry in the Condition Assessment Table

Functional Category	Function-Based Parameters	Measurement Method	Field Value
Hydrology	Catchment Hydrology	Catchment Assessment	
	Reach Runoff	Curve Number Concentrated Flow Points Soil Compaction	
	Flow Alteration	Q_Low, Measured / Q_Low, Expected	
Hydraulics	Floodplain Connectivity	Bank Height Ratio Entrenchment Ratio	
Geomorphology	Large Woody Debris	LWD Index # Pieces	
	Lateral Stability	Erosion Rate (ft/yr) Dominant BEHI/NBS Percent Streambank Erosion (%)	
	Riparian Vegetation	Left Riparian Width Ratio Right RiparianWidth Ratio Left Woody Vegetation Cover Right Woody Vegetation Cover Left Herbaceous Vegetation Cover Right Herbaceous Vegetation Cover Left Non-native Plant Cover (%) Right Non-native Plant Cover (%) Left Hydrophytic Vegetation Cover (%) Right Hydrophytic Vegetation Cover (%) Left Stem Density (stems/acre) Right Stem Density (stems/acre) Greenline Stability Rating	
	Bed Material Characterization	Size Class Pebble Count Analyzer (p-value)	
	Bed Form Diversity	Pool Spacing Ratio Pool Depth Ratio Percent Riffle Aggradation Ratio	
	Sinuosity	Plan Form	
Physicochemical	Temperature	Mean Daily Aug Temp (ºC) MWAT 7-day Average	
	Nutrients	Chlorophyll	
Biology	Macros	WSII RIVPACS	
	Fish	Number Native Fish Species (% of expected) SGSN Absent Score Game Species Biomass (% Increase)	

3. Scoring Functional Lift and Loss

Scoring occurs automatically as field values are entered into the Existing Condition Assessment or Proposed Condition Assessment tables. A field value will correspond to an index value ranging from 0.00 to 1.00 for that measurement method. Measurement method index values are averaged to calculate parameter scores; parameter scores are averaged to calculate functional category scores. Functional category scores are weighted and summed to calculate overall condition scores. Each of these components is explained below.

Note that the WSQT will display a warning message above the Functional Category Report Card reading “WARNING: Sufficient data are not provided” if data are not entered for the following parameters:

1. Floodplain Connectivity
2. Lateral Stability
3. Riparian Vegetation

4. Bed Form Diversity

Users should keep in mind that the WSQT is a tool designed to evaluate functional change, and is not intended to provide an ambient assessment of stream condition. There may be stream functions or processes not captured within the tool which affect its ambient condition. Thus, caution must be taken in interpreting the results. For example, while the tool may report that a stream is functioning at a physicochemical level using only the temperature parameter, there may be indicators in the catchment assessment to suggest that other factors not measured by the WSQT may be a concern in the stream. The scores provided by this tool should only be used to inform the functional change between pre- and post-project conditions, and may not be applicable for ambient monitoring.

Index Values. The performance standards available for each measurement method are visible in the Performance Standards worksheet and summarized in Appendix D. When a field value is entered for a measurement method on the Quantification Tool worksheet an index value between 0.00 and 1.00 is assigned to the field value.

When a field value is entered in the Quantification Tool worksheet, the neighboring index value cell calculates an index value based on the appropriate performance standard (see Example 1). If the index value cell returns FALSE instead of an index value, the Site Information and Performance Standard Stratification section may be missing data.

Example 1: index values that automatically populate when field values are entered.

Measurement Method	Field Value	Index Value
Pool Spacing Ratio	5	0.86
Pool Depth Ratio		
Percent Riffle	60	0.28
Aggradation Ratio		

Missing data example: Check the Site Information and Stratification section of the worksheet and List of Metrics workbook.

Measurement Method	Field Value	Index Value
Pool Spacing Ratio	5	FALSE
Pool Depth Ratio		
Percent Riffle	60	Need Slope
Aggradation Ratio		

If the WSQT does not return an index value, the user should check the Site Information and Performance Standard Stratification for data entry errors and then check the stratification for the measurement method in Appendix D to see if there are performance standards applicable to the project. Incorrect information in the Site Information and Performance Standard Stratification section may result in applying performance standards that are not suitable for the project.

Roll Up Scoring. Measurement method index values are averaged to calculate parameter scores; parameter scores are averaged to calculate category scores. The category scores are then weighted and summed to calculate overall condition scores (Table 3). The hydrology and hydraulics categories each provide 20% of the overall score, geomorphology provides 30% and physicochemical and biology each provide 15% of the overall score.

The original NC SQT weighted each of the five functional categories equally (e.g., 20% of the total score). However, the WSQT was modified to weight the geomorphology category at 30% to account for the number and breadth of functional parameters included in this category. Adjustments were also made to the weighting for the physicochemical and biological categories (15% weighting each) because they can be heavily influenced by land use and other changes upstream of the restoration project and often take longer to show improvement post restoration. Functional improvement in these categories often occurs due to improvements in hydrology, hydraulics and geomorphology functions (assuming that catchment-scale stressors do not themselves limit physicochemical or biological improvements). Monitoring is often the only activity specifically focused on showing lift to physicochemical and biological functions. The 15% weight still incentivizes restoration practitioners to attempt to improve and include higher level monitoring if supported by the restoration potential. The maximum overall condition score achievable without monitoring these levels is 0.70.

A functioning overall condition in the WSQT can only be achieved if all functional categories are functioning. Figure 7 depicts an overall condition score for a reach of 0.77, but the physicochemical functional category is functioning-at-risk; therefore, the overall condition is described as functioning-at-risk.

Table 3: Functional Category Weights

Functional Category	Weight
Hydrology	0.20
Hydraulics	*0.20*
Geomorphology	*0.30*
Physicochemical	*0.15*
Biology	*0.15*

Figure 7: Roll Up Scoring Example

Functional Category	Function-Based Parameters	Parameter	Category	Category	Overall	Overall
Hydrology	Catchment Hydrology	0.80	0.81	Functioning	0.77	Functioning At Risk
	Reach Runoff	0.62				
	Flow Alteration	1.00				
Hydraulics	Floodplain Connectivity	0.78	0.78	Functioning		
Geomorphology	Large Woody Debris		0.90	Functioning		
	Lateral Stability	0.77				
	Riparian Vegetation Structure	1.00				
	Bed Material Characterization					
	Bed Form Diversity	0.93				
	Sinuosity					
Physicochemical	Temperature		0.33	Functioning At Risk		
	Nutrients	0.33				
Biology	Macroinvertebrates	0.87	0.87	Functioning		
	Fish					

4. Functional Lift and Loss Summary Tables

The Quantification Tool worksheet summarizes the scoring at the top of the sheet, next to and under the Site Information and Performance Standard Stratification section. There are four summary tables: Functional Change Summary, Mitigation Summary, Functional Category Report Card, and Function Based Parameters Summary.

The Functional Change Summary (Figure 8) provides the overall scores from the Existing Condition Assessment and Proposed Condition Assessment sections. This table illustrates the overall condition scores, functional change occurring at the project site, and incorporates the length of the project to calculate the overall Functional Foot Score (FF).

Figure 8. Functional Change Summary Example

FUNCTIONAL CHANGE SUMMARY	
Exisiting Condition Score (ECS)	0.54
Proposed Condition Score (PCS)	0.84
Change in Functional Condition (PCS - ECS)	0.30
Existing Stream Length (ft)	1000
Proposed Stream Length (ft)	1000
Change in Stream Length (ft)	0
Existing Functional Foot Score (FF)	540
Proposed Functional Foot Score (FF)	840
Proposed FF - Existing FF	300
Functional Change (%)	56%

The change in functional condition is the difference between the proposed condition score (PCS) and the existing condition score (ECS). The table includes the existing and proposed stream lengths in order to calculate and communicate functional foot scores (FF). A functional foot is the product of a condition score and the stream length. Since the condition score must be 1.00 or less, the functional foot score is always less than or equal to the actual stream length.

$$Existing\ FF = ECS * Existing\ Stream\ Length$$

$$Proposed\ FF = PCS * Proposed\ Stream\ Length$$

The Proposed FF – Existing FF is the amount of functional lift or loss resulting from the project-related activities, and can be used to inform a calculation of debits and credits based upon the WSMP v2 (in draft). The functional lift is also shown as the percent lift in functional feet for a project reach.

$$Functional\ Change = \frac{Proposed\ FF - Existing\ FF}{Existing\ FF} * 100$$

The Proposed FF – Existing FF score is also reported in the Mitigation Summary. If this value is a positive number, then functional lift is occurring at the project site. A negative number represents a functional loss as shown in Figure 9.

Figure 9. Mitigation Summary Example (Debit Option 1)

MITIGATION SUMMARY		
-120	**(FF)**	**Loss**

To evaluate projects that consist of multiple reaches, the Proposed FF – Existing FF score for each reach can be summed to create an overall project functional foot value.

The Functional Category Report Card pulls the existing and proposed condition scores for each of the five functional categories from the Condition Assessment sections of the worksheet for a side-by-side comparison of the category scores (Figure 10). This table can be used to provide a general overview of the functional changes pre- and post-project to illustrate where the functional change is anticipated.

Figure 10. Functional Category Report Card Example

FUNCTIONAL CATEGORY REPORT CARD			
Functional Category	**ECS**	**PCS**	**Functional Change**
Hydrology	0.66	0.68	0.02
Hydraulics	0.00	0.70	0.70
Geomorphology	0.14	0.75	0.61
Physicochemical	0.11	0.17	0.06
Biology	0.21	0.32	0.11

The Function Based Parameters Summary also provides a side-by-side comparison, but for individual parameter scores (Figure 11). Values are pulled from the Condition Assessment sections of the worksheet. This table can be used to better understand how the category scores are determined. For example, while the physicochemical category may be functioning which would suggest the stream could support biology functions, it is possible that only chlorophyll was assessed and water temperature is too high to support functioning biology. This table also makes it possible to quickly spot if a parameter was not assessed for both the existing and proposed condition assessments.

Figure 11. Function Based Parameters Summary Example

FUNCTION BASED PARAMETERS SUMMARY			
Functional Category	**Function-Based Parameters**	**Existing Parameter**	**Proposed Parameter**
Hydrology	Catchment Hydrology	0.60	0.60
	Reach Runoff	0.71	0.75
	Flow Alteration		
Hydraulics	Floodplain Connectivity	0.00	0.70
Geomorphology	Large Woody Debris	0.00	0.70
	Lateral Stability	0.25	0.80
	Riparian Vegetation	0.13	0.48
	Bed Material		
	Bed Form Diversity	0.31	0.78
	Sinuosity	0.00	1.00
Physicochemical	Temperature		
	Nutrients	0.11	0.17
Biology	Macros	0.21	0.35
	Fish	0.20	0.28

1.2.d. Debit Tool Worksheet

The purpose of the Debit Tool worksheet is to calculate functional loss for projects when data to inform proposed condition scores are not available. Chapter 3 of this manual lays out three options to calculate functional loss using the WSQT. Debit Option 1 uses only the Quantification Tool worksheet while Debit options 2 and 3 require the Debit Tool worksheet. It is recommended that a user coordinate with the Corps and WSMP v2 (in draft) regarding the use and applicability of the Debit Tool for a specific project that may require a CWA 404 permit.

The Debit Tool worksheet contains two areas for data entry: Site Information and Impact Severity Tier. Cells that allow input are shaded grey and all other cells are locked. The Site Information section for the Debit Tool is an abbreviated form of the Site Information and Performance Standard Stratification section of the Quantification Tool worksheet (Figure 5, page 16) and requires only the project name, reach ID, and existing and proposed stream lengths measured in feet. In addition to the three areas for data entry, there is a table describing the impact severity tiers, an Existing Condition Scores (ECS) table, and a PCS Calculator. These sections of the worksheet are described below. The worksheet also includes a Functional Loss Summary similar to the table in the Quantification Tool worksheet.

1.2.e. Monitoring Data Worksheet

The Monitoring Data worksheet contains 11 condition assessment tables identical to the Existing and Proposed Condition Assessment sections in the Quantification Tool worksheet (Figure 6, page 18). The first table on the Monitoring Data worksheet is identified as the As-Built condition followed by 10 condition-assessment tables for monitoring. The user can enter the monitoring year at the top of each condition assessment table. The methods for calculating index values and scoring are identical to the Quantification Tool worksheet (Section 1.2.c). If a value is entered for a measurement method in the Existing Condition Assessment, a field value must also be entered for the As-Built condition and every monitoring event completed in the Monitoring Data worksheet. This is critical to being able to track progress over the monitoring period.

1.2.f. Data Summary Worksheet

This worksheet provides a summary of project data from the existing condition, proposed condition, as-built condition, and monitoring assessments, as pulled from the Quantification Tool and Monitoring Data worksheets. The Data Summary worksheet features a function-based parameter summary, a functional category report card, and four plots showing this information graphically. **This worksheet is included for information purposes and does not require any data entry.**

1.2.g. Performance Standards Worksheet

The Performance Standards worksheet contains the performance curves used to convert measurement method field values into scores, or index values. **This worksheet is included for information purposes and does not require any data entry.** Index values range from 0.00 to 1.00 and are categorized as functioning (0.70 to 1.00), functioning-at-risk (0.30-0.69), and not functioning (0.00-0.29; See Table 1, page 11). Performance curves are based on best fit equations and identified breaks between functioning (F), functioning-at-risk (FAR) and not functioning (NF) from existing data, published research and best professional judgement where data are sparse. Performance standards may be based on a single continuous curve or two or more equations pieced together. Additional detail on how performance curves were developed and stratified is included in Appendix D.

The Performance Standards worksheet is locked to protect the performance standard calculations and prevent the user from making changes. The Corps will regularly review the WSQT and performance standards and provide updates. Users are encouraged to provide additional data and information to the Corps to inform these changes. Additionally, there may be instances where better data are available for a particular project, and the Corps can approve an exception to using the performance data within the tool. More detail on this process is provided in Section 2.2.c. Examples of factors that may indicate the need to alternative performance standards include geographic or ecoregion differences, local reference reach data, or better modeling, depending on the parameter and measurement method.

On this worksheet, measurement method performance standards are organized into columns based on functional category and appear in the order they are listed on the Quantification Tool worksheet. One measurement method can have multiple sets of performance standards depending on stratification requirements. For example, the entrenchment ratio has different performance standards based on the proposed stream type (Table 4). The full list of performance standards and their stratification is provided in Appendix D.

Table 4. Entrenchment Ratio Performance Standards

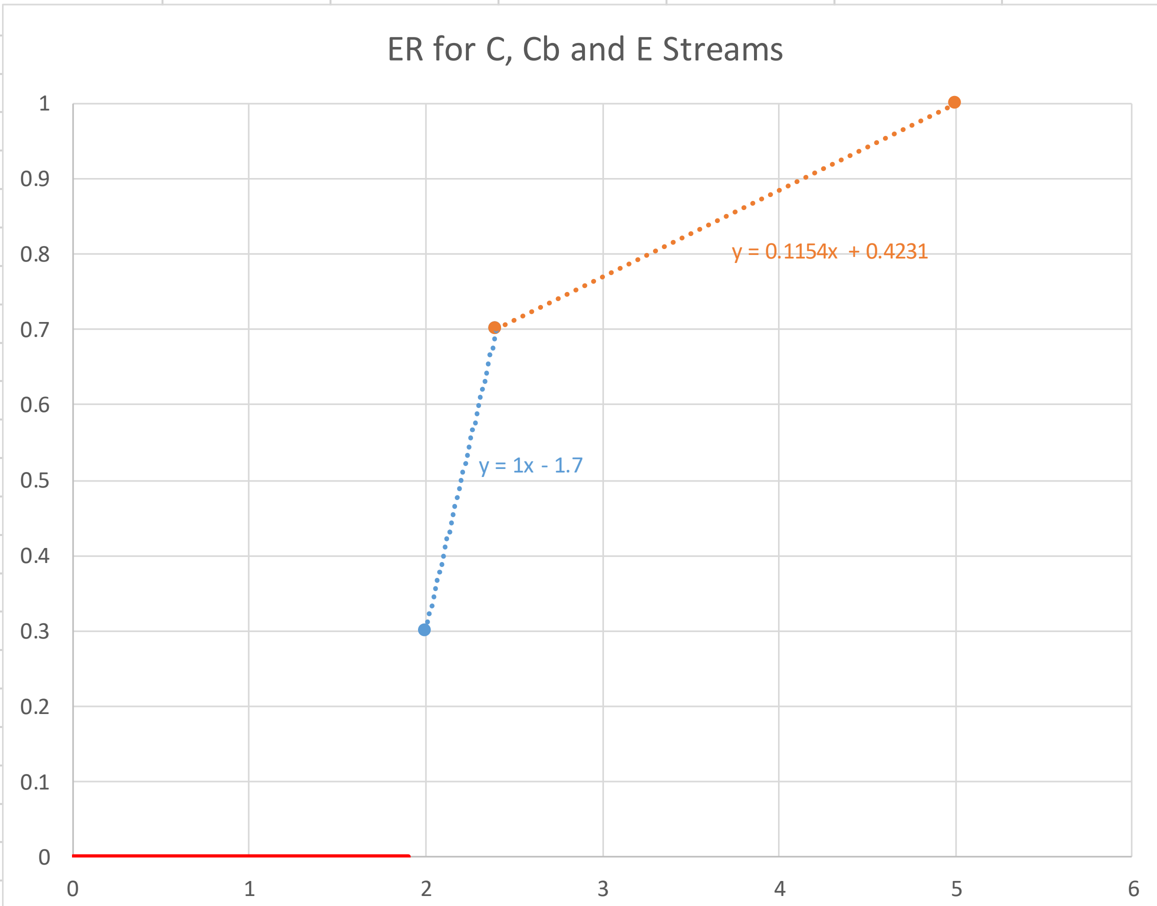
Measurement Method (Units)	Performance Standard Stratification		NF Score		FAR Score		F Score	
	Type	Description	Min	Max	Min	Max	Min	Max
Entrenchment Ratio (ft/ft)	Reference Stream Type	C, Cb or E	< 2.0		2.0	2.3	2.4	≥ 5
	Reference Stream Type	A, B, Ba or Bc	< 1.2		1.2	1.3	1.4	≥ 2.2

For a C-type channel, an entrenchment ratio of 2.4 or greater is considered functioning while an entrenchment ratio of less than 2.0 is considered not functioning. An entrenchment ratio of 5 or greater will give the maximum index value possible in the WSQT. The Performance Standard worksheet uses these breaks to define equations that relate field values (x) to index values (y). The performance standard curve for entrenchment ratio of C, Cb or E channels is shown in Figure 12.

Figure 12. Entrenchment Ratio Performance Standards for C, Cb and E Stream Types

Entrenchment Ratio (ER) C, Cb and E Streams						
Field Value			2		2.4	5
Index Value	0	0.29	0.3	0.69	0.7	1

	Coefficients - Y = a * X + b	
	F	FAR & NF
a	0.1154	1
b	0.4231	-1.7



The Quantification Tool worksheet links to the coefficients on the Performance Standards worksheet to calculate index values (y) from the field values (x). The red line shown at the bottom of Figure 12 indicates where a cliff occurs in the performance standard curve. For C and E proposed stream types, it is not possible to receive an index value of between 0.00 and 0.29; therefore, any entrenchment ratio less than 2.0 will yield an index value of 0.00.

The equations in the Performance Standard worksheet are used in the Quantification Tool and Monitoring Data worksheets to translate field values into index values. The equation for calculating the entrenchment ratio index value is shown in Figure 13.

Figure 13: Index Value Equation Example for Entrenchment Ratio. Colors help match IF STATEMENTS to corresponding explanation.

<u>Cell F54 of the Quantification Tool worksheet:</u>

"=IF(E49="","",IF(OR(B$7="A",B$7="Ba"B$7="B",B$7="Bc"), IF(E49<1.2,0, IF(E49>=2.2,1, ROUND(IF(E49<1.4,E49*'Performance Standards'!$K$84+'Performance Standards'!$K$85, E49*'Performance Standards'!$L$84+'Performance Standards'!$L$85),2))), IF(OR(B$7="C", B$7="Cb", B$7="E"),IF(E49<2.0,0, IF(E49>=5,1, ROUND(IF(E49<2.4,E49*'Performance Standards'!$L$49+'Performance Standards'!$L$50,E49*'Performance Standards'!$K$49+'Performance Standards'!$K$50),2))))))"

<u>Translation:</u>

If field value not entered, provide no index value.

If Proposed Stream Type is A, Ba, B, or Bc, then

If Field Value ≤ 1.2, then index value = 0

Else, if Field Value ≥ 2.2, then index value = 1,

Else, if Field Value < 1.4, then (Field Value) * $a_{FAR \& NF}$ + $b_{FAR \& NF}$,

Else, (Field Value) * a_F + b_F

If Proposed Stream Type is C, Cb or E, then

If Field Value < 2.0, then index value = 0

Else, if Field Value ≥ 5, then index value = 1,

Else, if Field Value < 2.4, then (Field Value) * $a_{FAR \& NF}$ + $b_{FAR \& NF}$,

Else, (Field Value) * a_F + b_F

Chapter 2. Calculating Functional Lift

The WSQT determines both functional lift and loss in units of functional feet (FF) calculated using stream length and the existing and proposed reach condition scores (ECS and PCS respectively) as follows.

$$Existing\ FF = ECS * Existing\ Stream\ Length$$

$$Proposed\ FF = PCS * Proposed\ Stream\ Length$$

$$\Delta FF = Proposed\ FF - Existing\ FF$$

Functional lift is generated when the existing condition is more functionally impaired than the proposed condition, and the third equation above yields a positive value. A negative value would represent a functional loss. A positive functional foot score can be used to inform credits for compensatory mitigation requirements as outlined in version 2 of the Wyoming Stream Mitigation Procedures (WSMP v2; in draft).

The data entry required for restoration projects using the WSQT is summarized in Table 5.

Table 5. WSQT Worksheets Used for Restoration Projects

Worksheets	Relevant Sections
Project Assessment (Section 1.2.a)	○ Programmatic Goals ○ Reach Description ○ Aerial Photograph of Project Reach ○ Restoration
Catchment Assessment (Section 1.2.b)	○ Complete entire form ○ Determine restoration potential
Quantification Tool (Section 1.2.c)	○ Site Information and Performance Standards Stratification ○ Existing Condition field values* ○ Proposed Condition field values*
Monitoring Data (Section 1.2.e)	○ As-Built Condition field values* ○ field values for up to 10 monitoring events*
Data Summary	No data entry in this worksheet
Debit Tool	Not applicable for functional lift
Performance Standards	No data entry in this worksheet

*Guidance on parameter selection is provided in Section 2.2.c and detailed instructions for collecting and analyzing field values for all measurement methods is provided in Chapter 4.

This chapter primarily addresses preliminary steps and concepts that should be considered during restoration project planning using the WSQT, including projects providing mitigation under CWA 404 (e.g., mitigation banks, in-lieu fee projects, or on-site/off-site permittee responsible mitigation projects).

2.1. Site Selection

The WSQT can be used to assist with selecting a potential stream restoration or mitigation site. The key word here is “assist.” There are many other elements to include in a thorough site-selection process (ELI 2016; Starr and Harman 2016). This section only illustrates the role of the WSQT.

In the tool, functional lift is estimated from the difference in pre- and post-project condition scores, expressed as an overall functional-foot score. Therefore, if the user is deciding between multiple sites, the WSQT can be used to rank sites based on the amount of functional lift available and overall site condition. Due to time constraints, the user may want to evaluate potential mitigation or restoration project sites using rapid methods (see Chapter 4 and Appendix A). At this stage, a user will likely have to estimate post-project condition using best professional judgement. While evaluating different sites, it is generally recommended to focus on whether a proposed site can achieve the following post-project condition scores:

1) Within the ‘functioning’ range for floodplain connectivity, bed form diversity, and lateral stability; and
2) Within the mid to high portion of the functioning-at-risk range, or higher, for riparian vegetation.

If the purpose of the project is to provide mitigation under CWA 404, the user should also refer to the WSMP v2 (in draft) and/or consult with the Corps for further guidance on site selection.

2.2. Restoration or Mitigation Project Planning

2.2.a. Restoration Potential

Restoration potential is a key application from the Stream Functions Pyramid Framework. Restoration potential is defined as the highest level (on the pyramid) of restoration that can likely be achieved, after considering limiting factors such as the condition of the contributing catchment, the condition of the project reach and other anthropogenic constraints. A restoration potential of Level 5 means that the project has the potential to restore biological functions to a reference condition. This can only happen if the contributing catchment has hydrology and water quality conditions that can support functioning biological communities after restoration activities have been implemented. Examples of anthropogenic constraints include adjacent sewer lines, easement width, and infrastructure.

This evaluation does not consider natural features that may limit restoration potential, such as natural hillslope processes, the presence of bedrock or other natural barriers to fish migration (Harman et al., 2012). Natural conditions are not included in the constraints analysis or the determination of restoration potential because they are not anthropogenic stressors that would limit a project’s ability to achieve biological lift. It is possible that natural conditions, such as bedrock waterfalls, could prevent fish passage, but this would be natural for that watershed. These natural conditions should be explained separately from the restoration potential analysis to keep the cause and effect relationships between watershed drivers and stream function clear. Natural conditions create biodiversity, providing suitable habitats for some species and not others. Anthropogenic stressors limit the biology that would naturally occur in a watershed.

If the contributing catchment is somewhat impaired and/or anthropogenic constraints limit restoration activities, then the restoration potential may be less than Level 5. Typical stability focused projects in impaired catchments would reach a restoration potential of Level 3 (Geomorphology). Level 3 projects can improve floodplain connectivity, lateral stability, bed form diversity, and riparian vegetation (function-based parameters describing geomorphology functions) to a reference condition, but not physicochemical or biological functions. Biological or physicochemical improvement can still be obtained; however, the improved condition will not likely achieve a reference condition. Understanding the restoration potential allows a practitioner to tailor restoration design goals and objectives, as well as monitoring efforts, to focus on appropriate and achievable functional lift.

Projects aimed at restoring water quality (Level 4) are not as commonly proposed for purposes of CWA 404 mitigation as Level 3 projects, but can result in higher overall functioning at the project site. Level 4 restoration projects typically include stormwater or agricultural best management practices (BMPs), restoration of riparian buffers, or other adjacent land use changes. For example, Level 4 restoration goals could be achieved within 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. Similar to Level 3 projects, biological communities may improve, but the improved biological condition may remain in the functioning-at-risk or not functioning category due to other limiting factors.

The WSQT includes the Catchment Assessment worksheet to assist in determining the restoration potential of a site. It is recommended that the user determine the restoration potential for each reach within a project and use this to create function-based design goals and objectives.

The Catchment Assessment worksheet includes 12 descriptions of processes and stressors that exist outside of the project reach that may limit functional lift (Section 1.2.b). Detail on completing the catchment assessment is provided in Chapter 4, Section 4.3. This section covers how to interpret the Catchment Assessment results to determine restoration potential. Table 6 shows how the catchment assessment can be used to determine restoration potential.

Table 6: Connecting Catchment Condition and Restoration Potential

Restoration Potential	Results from Catchment Assessment
Level 5 (Biology)	Overall Score = Good. The catchment has very few stressors and would support water quality and biology at a reference condition level if the reach-scale problems are corrected. Note: It is possible to achieve a Level 5 with a Poor to Fair catchment score if the percent of the catchment being treated is very high (see category 3). However, it may take a long period of time to achieve.
Level 4 (Physicochemical)	Overall Score = Poor to Fair. The catchment will have hydrology impairments from runoff entering the project reach from adjacent sources, e.g. parking lots or heavily grazed areas. Stormwater and agricultural BMPs can be used to reduce runoff and nutrient levels to reference condition at a sub-catchment scale (catchment draining to the BMP).

Restoration Potential	Results from Catchment Assessment
Level 3 (Geomorphology)	Overall Score = Poor to Fair. Catchment health will not support water quality and biology to a reference condition. For catchments that score near the higher end of fair, reach-scale restoration may improve water quality and biology, just not to a reference condition. The chances of water quality and biological improvement will increase with project length and percent of catchment being treated.
None	It is possible to have a catchment health score so low that reach-scale restoration is unattainable. In addition to the catchment score, however, this is dependent on the reach length, reach condition, and constraints.

Overall catchment condition is left as a subjective determination so that the user can assess and interpret the information gathered about the catchment. It is possible that one or more of the categories is a “deal breaker,” meaning that the result of that category overrides all other answers. For example, high levels of metals in a stream impacted by historic mining operations could indicate there is little potential for biological lift even if the other categories showed a good condition. Conversely, it is also possible for a good category score to overcome catchment stressors. For example, “percent of catchment being treated” is included as a category to show that a project could be large enough to overcome catchment stressors.

2.2.b. Function-Based Design Goals and Objectives

Function-based design goals and objectives can be developed once the restoration potential is determined. Design goals are statements about *why* the project is needed at the specific project site and outline a general intention for the restoration project. These goals communicate the reasons behind the project’s development. Design objectives explain *how* the project will be completed. Objectives are specific, tangible and can be validated with monitoring and performance standards. Objectives, in combination with the stated goals, describe what the practitioner will do to address the functional impairment. Typically, objectives will explain how key function-based parameters like floodplain connectivity, bed form diversity, lateral stability, and riparian vegetation will be changed in order to meet the goals. Design goals and objectives can be used to inform parameter selection within the WSQT. Note: Design goals and objectives are different than programmatic goals, which generally relate to the project’s funding source and may be independent of the project site (Harman et al., 2012).

Design goals and objectives are communicated in a narrative form and entered into the WSQT Project Assessment worksheet. The design goals should be cross referenced with the restoration potential of the project site to ensure that the goals do not exceed the restoration potential. For example, restoring native greenback cutthroat trout biomass (Level 5) is not feasible if the restoration potential is Level 3, perhaps due to the level of catchment development and higher water temperatures entering the project reach. In this example, the design goal could be revised to restore physical habitat for cutthroat trout, a Level 3 goal that matches the restoration potential. If native cutthroat trout populations in the project reach are to be monitored, increasing native cutthroat trout biomass could be possible even with a restoration potential of Level 3; however, restoring native cutthroat trout populations to reference conditions would not be expected or possible. If catchment-level improvements are implemented, over time, the restoration potential could shift from a Level 3 to 5. Notice however, that this outcome would require reach-scale *and* catchment-scale restoration efforts.

2.2.c. Parameter Selection

Parameter selection for a stream reach should follow a catchment assessment and determination of restoration potential. For CWA 404 mitigation projects, it is recommended that practitioners coordinate early in the project planning stages with the Corps to determine a list of parameters suitable for each project. This coordination can assist the user in determining whether project goals and objectives are appropriate and whether any performance standards need to be adjusted based on local data. For projects with fisheries-related goals and objectives, it is recommended the user consult with local Wyoming Game and Fish Department fisheries biologists to select the appropriate metrics within the fish parameter.

The following four parameters should always be included: **floodplain connectivity, lateral stability, bedform diversity and riparian vegetation**. These parameters are important indicators of the stability and resiliency of stream systems. For example, riparian planting may not be a successful restoration approach if the channel is incised and actively eroding the bed and/or banks. In addition, it is recommended that all projects evaluate reach runoff and sinuosity parameters. Appendix A includes rapid methods and data forms to assess these parameters, along with several other additional parameters that can be assessed rapidly.

The WSQT can also be tailored to a specific project through the selection of additional parameters that tie to the project's function-based goals, objectives and restoration potential.

For projects proposed under CWA 404, early consultation with the Corps is recommended to identify any additional parameters or metrics that may be needed for a specific project. For instance, projects with a restoration potential of Level 4 (Physicochemical) and goals and objectives related to water quality improvements should include an evaluation of the temperature and/or nutrient parameters. For projects with a restoration potential of Level 5 (Biology), the user should evaluate

<u>Typical Project with Level 3 Restoration Potential</u>

Potential: The catchment draining to the project is mostly range or irrigated hay land. While the overall catchment health is fair, biological uplift is likely to be limited by flow alteration.

Goals: Improve aquatic habitat and reduce sediment supply from bank erosion.

Approach: Fence out cattle, establish riparian buffer, with some channel re-construction.

Possible Parameter List:

- Reach Runoff
- Flow Alteration
- Floodplain Connectivity
- Lateral Stability
- Riparian Vegetation
- Bed Form Diversity
- Sinuosity
- Nutrients
- Macros
- Fish

While the project only has level 3 restoration potential, there is monitoring at levels 4 and 5 because the project is expected to show some improvement in these functional categories. However, the project is not expected to return nutrients, macros and fish parameters back to a reference condition.

the macroinvertebrate and fish parameters.

The tool includes several other parameters that can be selected based on their applicability to the project reach:

- Catchment Hydrology (Hydrology) – this parameter should be evaluated where the user is proposing to acquire or improve a sufficient portion of the catchment to improve hydrology to the reach.
- Flow alteration (Hydrology) – this parameter should be evaluated where the user is proposing to modify the flow regime within the project reach to restore baseflows.
- Bed Material Characterization (Geomorphology) – this parameter is recommended for stream reaches with potentially altered sediment transport processes. For example, streams with a gravel bed and sandy banks, or transport or sediment-limited reaches where there is potential to coarsen the bed.
- Large Woody Debris (Geomorphology) – this parameter is recommended in stream reaches in forested areas, where LWD would likely be more of significant component in stream systems.

The tool can also accommodate additional parameters and measurement methods that are accompanied by specific and defensible performance standards and index values. Any additional parameters or metrics should be provided in a written proposal to the Corps for consideration.

2.3. Passive Versus Aggressive Restoration Approaches

The WSQT evaluates the functional lift of restoration activities through changes in function-based parameters and not by the amount of heavy equipment used in a project or the number of in-stream structures installed. Therefore, the tool can evaluate a range of restoration approaches, from passive to more aggressive activities that involve significant modification to the channel. While an aggressive approach that includes significant modification may be necessary for some stream reaches, this is not always the case.

In Wyoming, the most common type of mitigation is small permittee responsible projects. The WSQT can show functional lift in smaller projects, assuming that several fundamental parameters (e.g., floodplain connectivity, bedform diversity, lateral stability and/or riparian vegetation) are already in a functioning condition or have the potential to trend in that direction without significant manipulation.

The examples in this section include three types of restoration approaches and the potential lift that can be captured using the WSQT. The three example approaches include: Passive, Moderate, and Aggressive, which relate to the amount of landscape modification needed to achieve functioning condition. All three examples evaluate the following parameters in the WSQT:

- Catchment Hydrology
- Reach Runoff
- Floodplain Connectivity
- Large Woody Debris
- Lateral Stability
- Riparian Vegetation

- Bed Form Diversity
- Sinuosity

In order to show the added benefit of monitoring physicochemical and biology functioning using the WSQT, each restoration approach was assumed to lead to modest improvements in nutrients, macroinvertebrate and fish parameters.

Passive Restoration Approach

In this hypothetical example, the stream is flowing through open rangeland. An existing condition assessment showed that the stream had not been channelized in the past and meandered within an alluvial valley (functioning sinuosity). The stream was not incised (functioning floodplain connectivity). Cattle had access to the stream; however, due to the meandering nature of the stream, bed form diversity was functioning (pools were located in the outside of the meander bends and were deep). Most of the riparian vegetation was removed by grazing (not-functioning riparian vegetation), which led to moderate erosion of several outside meander bends but not significant incision (functioning at risk). Erosion was not higher because bank heights were low, and floodplain connectivity remained in the functioning range.

The mitigation approach is to remove intensive grazing pressure by fencing out the cattle and planting a riparian buffer. This passive approach is feasible because floodplain connectivity and bedform diversity are already functioning (note, it often takes significant channel modification to fix these two parameters). With these functions in place, a newly planted riparian corridor will increase lateral stability and support higher level functions in the physicochemical and biology functional categories (Figure 13).

Figure 13: Passive Restoration Approach WSQT Example

Function-Based Parameters	Existing Parameter	Proposed Parameter
Catchment Hydrology	0.60	0.60
Reach Runoff	0.71	0.75
Flow Alteration		
Floodplain Connectivity	0.70	0.70
Large Woody Debris	0.00	0.00
Lateral Stability	0.57	0.80
Riparian Vegetation	0.13	0.48
Bed Material		
Bed Form Diversity	0.78	0.78
Sinuosity	1.00	1.00
Temperature		
Nutrients	0.11	0.17
Macros	0.21	0.35
Fish	0.20	0.28

For this type of restoration approach, it is likely that removing the cattle would, within the monitoring period, benefit water quality, and if the reach is connected to suitable habitat, the macroinvertebrates and fish parameters as well.

Moderate Approach

In this hypothetical example, the stream reach is in a similar setting as the passive example with one major exception - the stream reach has been channelized. Due to the presence of bedrock, however, the stream has not incised (still maintains functioning floodplain connectivity). The channelization and removal of large wood has prevented pool-forming processes within the stream reach and bedform diversity is now not functioning. Due to grazing practices, the riparian vegetation is not functioning. The lack of riparian vegetation negatively affects lateral stability; however, the functioning floodplain connectivity and corresponding low bank heights support lateral stability. The overall result is a lateral stability score in the functioning-at-risk range.

In this scenario, the mitigation approach involves fencing out the cattle, planting a riparian buffer, and adding large woody debris and a few in-stream structures to create step-pools in the straightened channel. The addition of large wood will improve the large woody debris score and the new step-pool structures will improve the bedform diversity score (Figure 14).

Figure 14. Moderate Restoration Approach WSQT Example

Function-Based Parameters	Existing Parameter	Proposed Parameter
Catchment Hydrology	0.60	0.60
Reach Runoff	0.71	0.75
Flow Alteration		
Floodplain Connectivity	0.70	0.70
Large Woody Debris	0.00	0.70
Lateral Stability	0.57	0.80
Riparian Vegetation	0.13	0.48
Bed Material		
Bed Form Diversity	0.31	0.78
Sinuosity	0.00	0.00
Temperature		
Nutrients	0.11	0.17
Macros	0.21	0.35
Fish	0.20	0.28

Aggressive Approach

In this hypothetical example, the stream reach is in a similar setting as the last two examples, except now the stream has been channelized and is incised (not functioning floodplain connectivity). Riparian vegetation and bed form diversity are not functioning for reasons explained in former examples. Lateral stability is now not functioning because the bank heights are high due to the floodplain disconnection and channel incision, which is exacerbated by the lack of riparian vegetation.

Since the channel is disconnected from its floodplain, a passive restoration approach is not likely to see improvements in channel condition during monitoring as flood flows will continue to erode the channel. Significant modification is needed to establish a new channel geometry and reconnect the stream to a floodplain, either by raising the bed or lowering the floodplain. The new channel pattern is used to create meander pools instead of step-pool structures used in the moderate example. Improvements in parameter scores are shown in Figure 15.

Figure 15. Aggressive Restoration Approach WSQT Example

Function-Based Parameters	Existing Parameter	Proposed Parameter
Catchment Hydrology	0.60	0.60
Reach Runoff	0.71	0.75
Flow Alteration		
Floodplain Connectivity	0.00	0.70
Large Woody Debris	0.00	0.70
Lateral Stability	0.25	0.80
Riparian Vegetation	0.13	0.48
Bed Material		
Bed Form Diversity	0.31	0.78
Sinuosity	0.00	1.00
Temperature		
Nutrients	0.11	0.17
Macros	0.21	0.35
Fish	0.20	0.28

The functional lift for each of the three scenarios outlined above is summarized in Table 7. Note that more functional lift can be documented for each restoration approach if the project monitors for lift in the physicochemical and biology functional categories. Also note that even though the proposed condition score is similar between all three scenarios, the most lift was achieved by the aggressive approach since the existing channel was in the worst condition.

Table 7. Summary of Restoration Approach Scenarios

Scenario	Functional Lift (FF) Monitoring through L3	Functional Lift (FF) Monitoring through L5
Passive (e.g., functioning or functioning-at-risk existing)	40	60
Moderate (e.g., functioning-at-risk existing condition)	88	104
Aggressive (e.g., not-functioning existing condition)	364	394

Chapter 3. Calculating Functional Loss

This chapter describes how to use the WSQT to calculate functional loss of CWA 404 permitted impacts to stream systems. This chapter provides step-by-step instructions on how project impacts and functional loss can be evaluated. This manual does not provide guidance on how the functional loss calculations will inform compensatory mitigation requirements, or what permits may be required for specific activities. It is recommended that a user coordinate with the Corps and review WSMP v2 (in draft) regarding the use and applicability of this tool for a specific project that may require a CWA 404 permit. The functional loss calculation does not consider temporal loss or make any adjustments based on the proximity of the mitigation to the impact or other factors that may be addressed in the WSMP v2 (in draft).

The WSQT determines functional loss and functional lift in units of functional feet (FF), calculated using stream length and the existing and proposed reach condition score (ECS and PCS, respectively) as follows.

$$Existing\ FF = ECS * Existing\ Stream\ Length$$

$$Proposed\ FF = PCS * Proposed\ Stream\ Length$$

$$\Delta FF = Proposed\ FF - Existing\ FF$$

Functional loss is generated when the proposed condition is more impaired than the existing condition, and the third equation above yields a negative value.

For permitted impacts, data to inform proposed condition scores may not be available for various reasons. This chapter lays out three options to calculate functional loss using the WSQT. Additional approaches to determining debits or compensation requirements that do not rely on the WSQT or Debit Tool may be available; users should consult the WSMP v2 (in draft) for guidance.

3.1. Selecting a Debit Option

The three debit options require varying levels of information and effort to calculate functional loss. To that end, not all WSQT worksheets are required to complete a loss calculation. In general, debit option 1 requires the most information and effort, while debit option 3 requires the least. The debit options are outlined in detail in the following sections, while a summary of the worksheets required to implement each are illustrated in Table 8.

For purposes of calculating functional loss, the Catchment Assessment is only used to score the catchment hydrology parameter. Instructions for using the catchment assessment to score catchment hydrology are provided in Section 4.6.a.

Table 8: Summary of Debit Options

Debit Option ID	Existing Condition Score (ECS)	Proposed Condition Score (PCS)	Worksheets to complete
1	Assess existing condition using detailed or rapid methods	Estimate stream reach proposed condition	Project Assessment Catchment Assessment (Categories 1,2,3) Quantification Tool (ECS and PCS)
2	Assess existing condition using detailed or rapid methods	Use Debit Tool	Project Assessment Catchment Assessment (Categories 1,2,3) Quantification Tool (ECS only) Debit Tool
3	Assume a score of 1	Use Debit Tool	Project Assessment *Catchment Assessment (Categories 1,2,3) *Quantification Tool (Catchment Hydrology field value in the Existing Condition Assessment) Debit Tool

** Only required for Tier 5 impacts (See Table 9).*

3.2. Debit Option 1

Users that have detailed information about the proposed impact condition may choose debit option 1 and use the Quantification Tool worksheet to calculate the existing and proposed condition using detailed project designs or modeling results. For this option, the user must be able to accurately predict the functional loss through the geomorphology category (Level 3) using project design reports, drawings, field investigations, etc. For projects that impact higher-level functions, the user must also be able to reasonably predict how these lower-level impacts will affect physicochemical and biology functions.

The following steps are required to complete debit option 1:

1. Determine the parameters and measurement methods that will be used to assess the reach. Users should consult with the Corps to determine the parameters necessary to evaluate impacts. Typically, the methods presented in Appendix A will be sufficient to evaluate impacts.
2. Complete the Project Assessment worksheet (see Section 1.2.a).
3. Complete categories 1, 2, and 3 on the Catchment Assessment form (see Section 4.3.)
4. Complete the Site Information and Performance Standard Stratification section of the Quantification Tool worksheet (see Sections 1.2.c and 4.5).

5. Complete the Existing Condition Assessment section of the Quantification Tool worksheet (see Section 1.2.c and Chapter 4).
6. Complete the Proposed Condition Assessment section of the Quantification Tool worksheet (see Section 1.2.c and Chapter 4).

For this last step, the user should rely on available data and best professional judgement to estimate proposed condition field values. As with functional lift, the same parameters used to derive the existing condition score must also be used to determine the proposed post-impact condition score. Therefore, field values must be determined for all measurement methods used to assess the existing stream reach (Note: field value here refers to where data are entered into the worksheet and not the actual collection of field data to yield a field value). Proposed field values that describe the physical post-impact condition of the stream reach should be based on project design reports, drawings, field investigations, etc.

Post-Impact Condition Assessment Example

Impacts that result in relocating or straightening a channel could use construction documents to determine the cross-section and profile of the proposed channel. These data can be used to measure or estimate the entrenchment ratio and bank height ratio and score floodplain connectivity. Pool spacing ratio, pool depth ratio, and percent riffle can also be estimated from the project design plans to score bedform diversity. The proposed development plans should indicate the extent of impervious surfaces to be added to the reach catchment and the number of concentrated flow points that would be added. This information can be translated into riparian vegetation and reach runoff field values.

If physicochemical and biology parameters were assessed for the existing condition, then the degradation of the parameters outlined above would be used to estimate the extent of degradation expected for these parameters.

Since both the existing and proposed condition are scored in the Quantification Tool worksheet for debit option 1, the functional loss is calculated at the top of the sheet, next to and under the Site Information and Performance Standard Stratification section (See Section 1.2.c). The Functional Change Summary (Figure 16) provides the overall scores from the Existing Condition Assessment and Proposed Condition Assessment sections.

The Proposed FF – Existing FF score is also reported in the Mitigation Summary. The functional category report card and the function based parameter summary can be used to communicate lost functional capacity that is likely to result from the proposed impact.

Figure 16: Debit Option 1 Functional Change Summary Example

FUNCTIONAL CHANGE SUMMARY	
Exisiting Condition Score (ECS)	0.53
Proposed Condition Score (PCS)	0.39
Change in Functional Condition (PCS - ECS)	-0.14
Existing Stream Length (ft)	100
Proposed Stream Length (ft)	80
Change in Stream Length (ft)	-20
Existing Stream Functional Foot Score (FFS)	53
Proposed Stream Functional Foot Score (FFS)	31
Proposed FFS - Existing FFS	-22
Functional Change (%)	-41%

3.3. Debit Option 2

This option relies on the user to perform an existing condition assessment of the project reach in the same way as Option 1, using the Quantification Tool worksheet. Then, the user will use the Debit Tool worksheet (Section 3.3.a.) to estimate the proposed (post-impact) condition score and calculate functional loss. The Debit Tool provides estimates of proposed condition based upon the magnitude of proposed impacts, referred to as the Impact Severity Tier (Table 9). This method is best suited for users who are able to evaluate the existing condition, but do not have accurate data and information to inform the proposed condition within the WSQT.

The following steps are required to complete debit option 2:

1. Determine the parameters and measurement methods that will be used to assess the reach. Users should consult with the Corps to determine the parameters necessary to evaluate impacts. Typically, the methods presented in Appendix A will be sufficient to evaluate impacts.
2. Complete the Project Assessment worksheet (see Section 1.2.a).
3. Complete categories 1, 2, and 3 on the Catchment Assessment form (see Section 4.3.)
4. Complete the Site Information and Performance Standard Stratification section of the Quantification Tool worksheet (see Sections 1.2.c and 4.5).
5. Complete the Existing Condition Assessment section of the Quantification Tool worksheet (see Section 1.2.c and Chapter 4).
6. Complete the Debit Tool worksheet (Section 3.3.a.).

In the WSQT, the Debit Tool worksheet will automatically pull existing condition scores from the Quantification Tool worksheet entered in step 5 above. Instructions for completing step 6 and detail on how functional loss is calculated in the Debit Tool is provided below.

3.3.a. Using the Debit Tool Worksheet

The Debit Tool is a separate worksheet within the WSQT described in Section 1.2.d. In order to calculate functional loss using the debit tool, the following information is needed:

- Existing and Proposed Stream Lengths

- Impact Severity Tier

Following entry of this information, the Debit Tool will calculate a proposed condition score and functional loss. Note that the Debit Tool worksheet within the WSQT will automatically perform all scoring calculations.

1. Existing and Proposed Stream Lengths

Existing Stream Length. Calculate the length of the stream that will be directly impacted by the permitted activity. Stream length should be measured along the centerline of the channel. For example, the channel length before a culvert is installed.

Proposed Stream Length. Calculate the length of stream channel after the impact has occurred. For pipes, the proposed length is the length of the pipe. If the stream will be straightened by the permitted activity, the proposed length will be less than the existing length.

2. Determine the Impact Severity Tier

Determination of an impact severity tier is needed in order to calculate a Proposed Condition Score using the Debit Tool. The impact severity tier is a categorical determination of the adverse impact to stream functions, ranging from no loss to total loss. Tier 0 represents no permanent loss of stream functions and therefore no mitigation would be needed. Table 9 lists the impact severity tiers from 0 to 6 along with a description of impacts to key function-based parameters and example activities that may lead to those impacts. Note that some activities could be in multiple tiers depending on the magnitude of the impact and efforts taken to minimize impacts using bioengineering techniques or other low-impact practices.

Table 9: Impact Severity Tiers and Example Activities

Tier	Description (Impacts to function-based parameters)	Example Activities
0	No permanent impact	Bio-engineering of streambanks
1	Impacts to riparian vegetation and/or lateral stability	Bank stabilization and utility crossings.
2	Impacts to riparian vegetation, lateral stability, and bed form diversity	Utility crossings, bridges, bottomless arch culverts
3	Impacts to riparian vegetation, lateral stability, bed form diversity, and floodplain connectivity	Bottomless arch culverts, small channelization/grading projects
4	Impacts to riparian vegetation, lateral stability, bed form diversity, and floodplain connectivity. Potential impacts to temperature, processing of organic matter, macroinvertebrate and fish communities	Channelization, bottomless arch culverts, weirs/impoundments
5	Removal of all aquatic functions except for hydrology	Pipes
6	Removal of all aquatic functions	Fill of small channels from mining or development

The following is a description of each impact tier.

Tier 0. If the proposed activity does not impact any of the key function-based parameters, then the impact severity tier is 0 and the user does not need to continue with the debit tool.

Tiers 1 – 4. The applicant selects the tier that best fits the proposed activity. This information can come from project plans and documents, permit applications, discussions between the permit applicant and the regulatory agencies, etc.

Tier 5. This tier is exclusive to enclosed pipes. Any pipe that is installed into a stream channel will automatically be included in this tier.

Tier 6. This tier is exclusive to projects that completely fill the stream channel, so that the original channel is eliminated. For example, filling of a channel for purposes of relocation would be included in this tier.

3. Calculate the Proposed Condition Score

The Debit Tool calculates the proposed condition score differently depending on which impact severity tier is selected (summarized in Table 10). For example, impacts falling within Tiers 1 – 3 result in functional losses to hydrology, hydraulics and geomorphology functions while, filling a Tier 6 impacts result in complete loss of all functions within that stream reach.

Table 10: Impact Severity Tiers and PCS calculation

Tier	PCS =
1	ECS * Multiplier
2	
3	
4	
5	Fraction of Hydrology Category score
6	0

Tiers 1-4
The existing condition score and the impact severity tier are used to calculate the proposed condition using the multipliers shown in Table 11 below. For example, a Tier 3 impact on a reach with an ECS of 0.52 would result in a proposed condition score of 0.31 (0.37 * 0.52 =0.31). This means that the proposed condition score is 37% of the existing condition score. The inverse is also true, meaning that there was a corresponding 63% loss of stream function. These multipliers were developed from linear regression equations of modeled impact scenarios using a simplified version of the WSQT.

Table 11: PCS Equations

Impact Severity Tier	PCS Equation	Percent Loss
1	PCS = 0.83 * ECS	17%
2	PCS = 0.65 * ECS	35%
3	PCS = 0.37 * ECS	63%
4	PCS = 0.27 * ECS	73%

More detail on how the multipliers in Table 11 were developed is provided in a white paper on the debit tool (Harman and Jones, 2017). The WSQT modified the multipliers used in the white paper to accommodate the use of the rapid method which only assess up through geomorphology. The percent loss associated with impact severity tiers 1 – 3 is calculated using an existing condition score based on an evaluation of functions within hydrology, hydraulics and geomorphology (e.g., based on the rapid methods in Appendix A). In these tiers, there is no anticipated permanent functional loss to physicochemical or biology functions. As such, the equation is based on a maximum existing condition score of 0.70. For Tier 4, however, there is potential permanent loss in physicochemical and biological functions and thus, this equation considers a maximum existing condition score of 1.00. The Debit Tool worksheet will assume an existing condition score of 1.00 for these functional categories unless data are provided in the existing condition assessment of the Quantification Tool worksheet.

Tier 5

Piping activities exclusively make up Tier 5, and the proposed condition score is calculated using the catchment hydrology and reach runoff function-based parameters within the hydrology functional category. The catchment hydrology parameter score is not changed between existing and proposed condition. However, the proposed reach runoff parameter is scored as a 0.00 since natural runoff processes within the impacted reach are eliminated. The proposed overall hydrology score is calculated and multiplied by 0.20 to determine an overall reach score. For this Tier, it is assumed that no hydraulic, geomorphology, physicochemical and biology functions are present in this reach. An example calculation is provided below.

1. Catchment hydrology score from catchment assessment equals an index value of 0.50, representing a fair hydrologic catchment condition.
2. A reach runoff score of 0.00 is used.
3. The hydrology functional category score is the average of the results from steps 1 and 2. For example, the average of 0.50 and 0.00 is 0.25.
4. The overall proposed condition score then equals 0.25 X 0.20 = 0.05.
   Note, the calculation in number 4 represents zero scores in hydraulics, geomorphology, physicochemical, and biology.

Tier 6

Activities that completely fill the channel remove all aquatic functions are assigned to tier 6. Their PCS is an automatic 0, meaning that all aquatic functions have been lost.

4. Functional Loss

Once the PCS is calculated, the Debit Tool worksheet uses the existing and proposed stream lengths to calculate the ΔFF using the equation introduced at the beginning of this chapter. The functional loss summary table (similar to the functional change summary table in the Quantification Tool worksheet) provides summarizing information for the functional loss calculation (Figure 17).

Figure 17: Debit Option 2 Functional Loss Summary Example – Tier 3 Impact

FUNCTIONAL LOSS SUMMARY	
Exisiting Condition Score (ECS)	*0.47*
Proposed Condition Score (PCS)	*0.17*
Condition Loss	*-0.30*
Existing Stream Length (ft)	*1000*
Proposed Stream Length (ft)	*800*
Proposed - Existing Stream Length (ft)	*-200*
Existing Functional Feet (FF)	*470*
Proposed Functional Feet (FF)	*136*
Proposed FF - Existing FF	***-334***
Functional Loss (%)	*-71%*

3.4 Debit Option 3

Debit option 3 is identical to debit option 2, except users would not perform an existing condition assessment. In this case, the user simply assumes that the existing condition score (ECS) is equal to 1.00, which is the default ECS value in the Debit Tool worksheet. Just as with debit option 2, the Debit Tool is used to estimate the proposed (post-impact) condition score and calculate functional loss. This option is available for users who are unable to perform an assessment of the project reach prior to impact. This option is the fastest and easiest method for determining functional loss.

The following steps are needed to complete debit option 3:

1. Complete the Project Assessment worksheet (see Section 1.2.a.)
2. For Tier 5 impacts only, complete categories 1 – 3 on the Catchment Assessment form (see Section 1.2.b.)
3. Complete the Debit Tool worksheet (Section 3.3.a.)
    a. Enter existing and proposed stream lengths.
    b. Select an impact severity tier.

Chapter 4. Data Collection and Analysis

The purpose of this chapter is to provide instruction on how to collect and analyze data needed by the WSQT. Few measurements are unique to the WSQT, and data collection procedures are often detailed in other instruction manuals or literature. Where appropriate, this chapter will reference the original methodology to provide technical explanations and make clear any differences in data collection or calculation methods needed for the WSQT.

Before performing a field assessment, the user will need to determine what data needs to be collected and the field methods to be used. A user would rarely, if ever, enter field values for all measurement methods included in the WSQT. Some parameters have multiple measurement methods that complement each other, while some measurement methods are redundant. Individuals collecting and analyzing these data should have experience and expertise in ecology, hydrology and/or geomorphology. Interdisciplinary teams with a combination of these skillsets is beneficial to ensuring consistent and accurate data collection. Field trainings in the methods outlined herein, as well as the Stream Functions Pyramid, are recommended to ensure that the methods are executed correctly and consistently. Practitioners should coordinate early in the project planning stages with the Corps to determine the parameters, measurement methods, and field methods appropriate for a proposed project.

The methods and metrics in the WSQT have been selected to be sensitive to reach-scale anthropogenic manipulations, specifically restoration practices and impacts. There may be stream functions or processes not captured within the tool which affect its ambient condition, and thus the methods and metrics are not intended for use as an ambient assessment method.

4.1. Rapid vs. Detailed Measurement Methods

The WSQT considers a suite of functional indicators that can characterize changes related to the types of impacts and mitigation projects that are common in the CWA 404 program. The level of analysis and documentation for evaluating projects under CWA 404 should be commensurate with the scale and scope of the project (USACE 2008a). The Corps routinely evaluates projects where stream impacts range from very minor, localized impacts to projects with direct and secondary impacts spanning broad geographic scales. As such, approaches that have flexibility in their application, where impacts can be evaluated via rapid assessment or more detailed quantitative approaches for selected applications, are beneficial within the CWA 404 program (Somerville and Pruitt 2004).

Many of the measurement methods in the WSQT accommodate both rapid and detailed field methods. The detailed and rapid methods can be used interchangeably within the WSQT. Which methods are used is at the Corps' discretion; therefore, users should consult with the Corps prior to using the WSQT on a particular project. While each approach is broadly considered below, their specific application will be determined by the Corps.

<u>Rapid Methods</u>: These methods yield a WSQT score based upon a rapid field evaluation of select parameters within the hydrology, hydraulic, and geomorphology categories. Rapid does not mean qualitative. Instead, the rapid method includes quantitative measures collected without the use of standard survey equipment like total stations and laser levels. An example of a rapid measure is to physically measure the space between two pools using a tape measure rather than surveying a longitudinal profile and calculating the spacing from survey data. The field methods for this evaluation are presented in this chapter but are also consolidated in Appendix

A along with data forms. These methods are intended to incorporate site-specific measurements that are already commonly collected in the planning and design stages of many stream projects. The rapid method will typically take three to six hours to complete per project reach.

Detailed Methods: Detailed geomorphic methods rely on a survey level or total station to measure longitudinal profiles and cross sections 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 detailed methods also include a broader suite of parameters, including physicochemical and biological metrics, that may require additional post-collection processing or more extensive field protocols. These additional parameters can be used to assess specific project objectives and/or impacts.

For measurement methods described in this chapter, rapid and detailed techniques will be provided as appropriate.

4.2 Reach Delineation and Representative Sub-Reach Determination

Stream impact and restoration projects can vary substantially in length. It is common for restoration projects to extend several miles and include main-stem channels with numerous tributaries. Some headwater restoration projects can even encompass all or many stream channels within a catchment. Alternatively, other projects such as culvert placement or removal, are short and measured in linear feet, not miles.

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

Delineating stream reaches within a project area occurs in two steps. The first step is to identify whether there are multiple reaches within the project area based on differences in stream physical characteristics and differences in project designs. The second step assists in identification of the appropriate sub-reach lengths to meet measurement method assessment requirements. The process to define project reaches is described in detail below. The process to delineate a reach is described first, followed by specific guidance on selecting sub-reaches by parameter.

4.2.a. Reach Delineation

The user should determine whether their project area encompasses multiple homogeneous stream reaches. For this purpose, a reach is defined as a stream segment with similar valley morphology, stream type (Rosgen 1996), stability condition, riparian vegetation type and bed material composition. Stream reaches may be short or long depending on the variability of the physical stream characteristics within the project area. Length is not used to delineate a stream reach, i.e., stream reaches can be short or long depending on their characteristics.

Professional judgement is required to make the physically-based reach selection. Therefore, the practitioner should provide justification for the final reach breaks in the Reach Description section of the Project Assessment worksheet. Specific guidance is 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 contributing drainage area, such as a tributary confluence within the project area, should lead to a reach break. Typically, when a 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.
- Reach breaks should occur where there are distinct changes in the level of anthropogenic modifications, such as narrowed riparian width from road embankments, concrete lined channels, or culverts/pipes.
- Multiple reaches are needed where there are differences in the magnitude of impact or mitigation approach within the project area. For example, where proposed restoration activities or practices change, e.g., restoration versus enhancement or Rosgen Priority 1 versus Priority 3. Another example could be a culvert removal project, where the user would assess the culvert's footprint as a separate reach because the act of converting a pipe into a natural channel creates more lift than restoration efforts elsewhere along the stream.

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 18). Reach breaks are described below (Table 12), 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 and an Excel Workbook would need to be completed for each of these 11 reaches.

Figure 18: Reach Identification Example

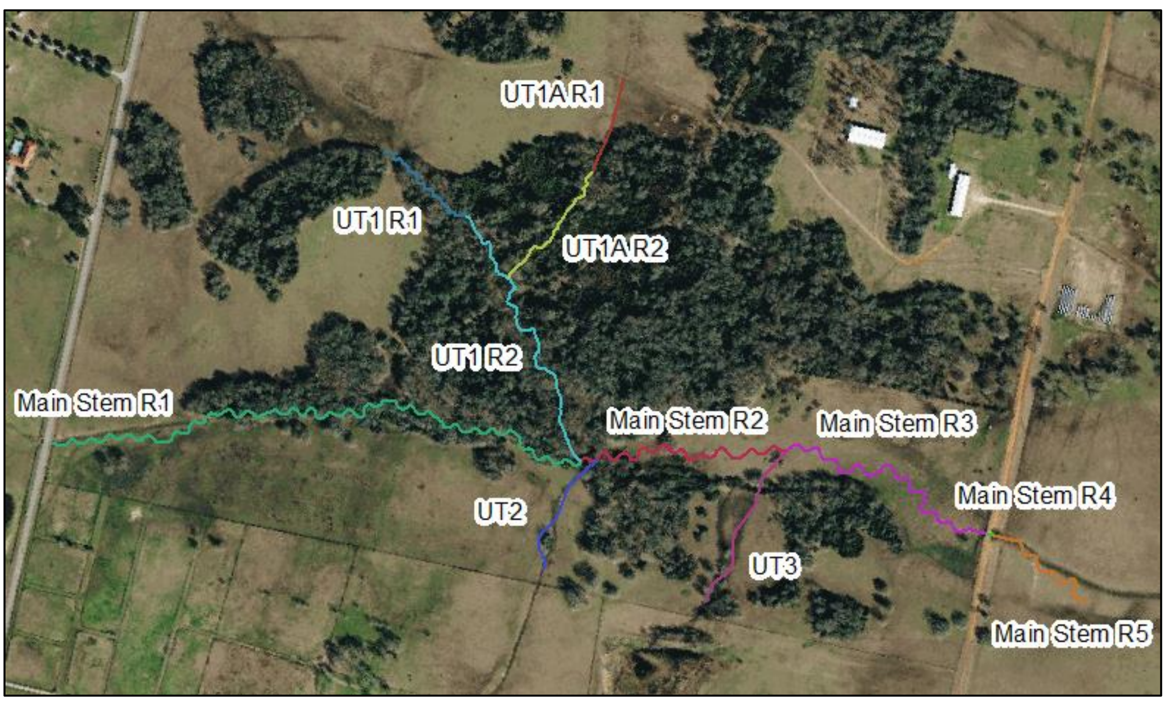


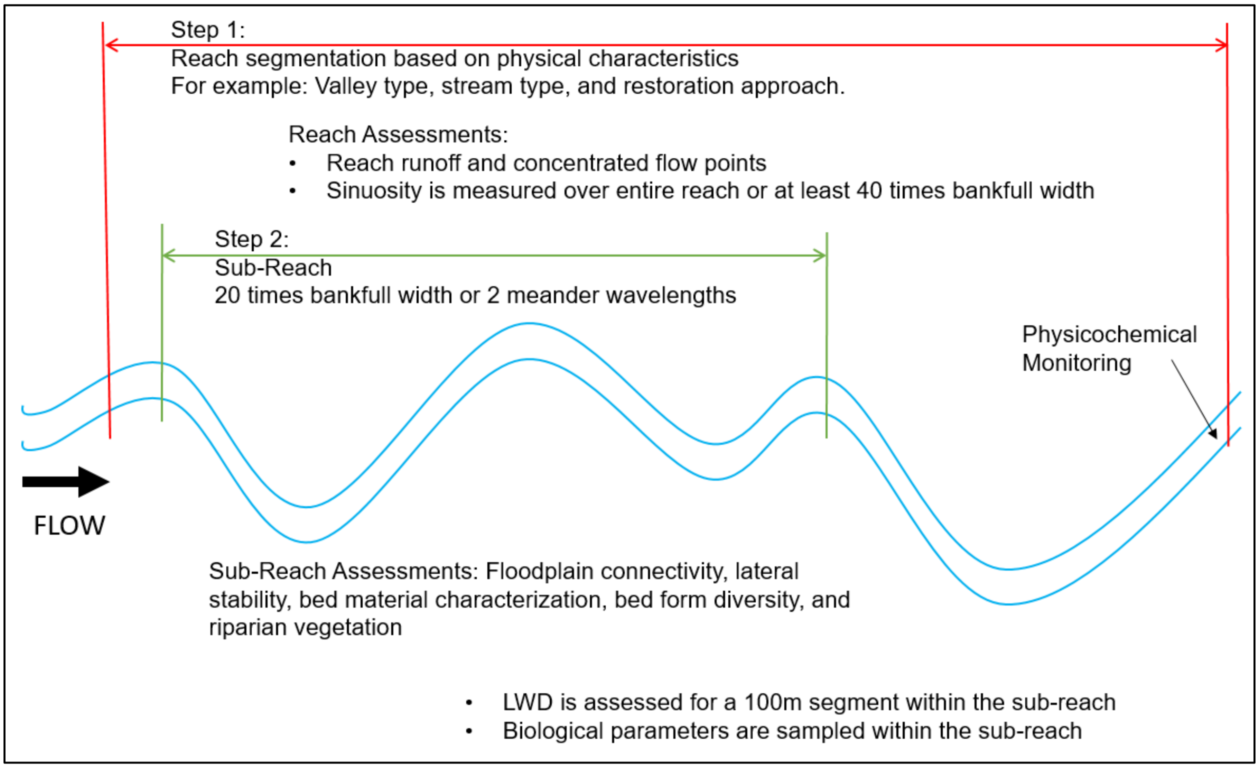
Table 12. Reach Identification Example

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

4.2.b. Representative Sub-Reach Determination

Some parameters, such as sinuosity and concentrated flow points, will be evaluated along the entire stream length within the project area, but other parameters will only be evaluated within a representative sub-reach (Figure 19). Selecting a representative sub-reach is necessary to avoid having to quantitatively assess very long reaches with similar physical conditions. The stream length evaluated will vary by functional category and parameter. For smaller projects, the representative reach may encompass the entire project area. Guidelines and examples are provided below for each functional category.

Figure 19: Reach and Sub-Reach Segmentation



1. *Hydrology Functional Category*:
    a. The catchment hydrology parameter is assessed at the catchment or sub-catchment scale rather than the reach scale.
    b. Reach runoff parameters are evaluated for the entire length of each reach.
    c. The baseflow alteration parameter is evaluated for the catchment draining to the downstream extent of the reach.
2. *Hydraulic and Geomorphology Functional Categories*:
    a. Riparian vegetation, floodplain connectivity, lateral stability, bed material characterization, and bed form diversity are assessed within a sub-reach 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 sub-reach length is 100 meters (Davis, et al., 2001), and whenever possible should be evaluated within the same sub-reach as the bedform diversity assessment. 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.
    c. Sinuosity is assessed over a length that is at least 40 times the bankfull width (Rosgen, 2014) and preferably for the entire project reach. If the project reach is less than 40 times the bankfull width, sinuosity must extend proportionally into the upstream and downstream reach to achieve a length of at least 40 times the

bankfull width. For small streams that are not long enough to meet this criterion, the entire length of stream should be used to calculate sinuosity.

3. *Physicochemical and Biology Functional Categories*: Sampling locations are described for each measurement method in these categories. Note that the user may choose to assess a location at the upstream end of the reach, thus providing an upstream/downstream comparison. This information is ancillary to the WSQT input in that it provides supporting information about functional lift or loss. However, the WSQT 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 WSQT could show scoring differences in a downstream direction.

Other stream situations such as braided systems and the presence of side channels should always be noted and considered in selecting applicable parameters and measurement methods. Data collection methods may vary in these reaches; discuss proposed sampling plan with the Corps prior to performing the field work.

4.3. Catchment Assessment

The Catchment Assessment worksheet 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. The Catchment Assessment worksheet includes descriptions of processes and stressors that exist outside of the project reach and may limit functional lift. Instructions for collecting data and describing each process and stressor are 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.

4.3.a. Catchment Assessment Worksheet Categories

The catchment assessment relies on digital data available from various online or local resources and some site data that can be obtained through site walks or other observations within the project area. There are 12 defined categories with space for an additional user-defined category. There is no requirement to provide an answer for all categories listed. There are three choices to describe the catchment condition for each category: Good, Fair and Poor. Data necessary to assess each category are provided below. Data to support each selection should be documented.

1. Impoundments

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 if the dam is serving as a barrier to fish passage. 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. 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 within the catchment can be determined through field walks, recent orthoimagery, or review of other landscape-scale information. Generally, this metric can be evaluated at the local level (e.g., within several stream miles or at the HUC 12 or HUC 14 watershed level); however, consideration should be given to large impoundments or critical fish barriers that may not be proximate, but affect a large catchment area.

2. Flow Alteration

Flow alteration represents the role dams, water allocation and effluent discharges can play in altering the hydrology within a catchment. Examples of flow alteration include diversion dams for irrigation or municipal/industrial use, water storage reservoirs, hydroelectric operations, effluent discharges and trans-basin diversions (either depleting or augmenting flows). Landscape-scale information can be used to inform conclusions about flow alteration, including dam storage ratios, dam density and the density of agricultural ditches. These data are available through EPA's 2017 Preliminary Healthy Watersheds Assessment (EPA 2017) for each HUC 12 watershed in WY. Dam storage ratios reflect the storage within the watershed compared with the average annual flow. Dam density is calculated as dams per kilometer of stream within each watershed.

A catchment in good condition has a natural flow regime with little to no reduction or augmentation occurring upstream of the project reach. A catchment in poor condition has stream flows that are heavily depleted or augmented.

3. Urbanization

Land use is temporally variable and catchments that are currently in good or fair condition can degrade quickly with development. Active construction within a catchment can cause excessive erosion and sediment supply. Urban and residential development can drastically change the hydrology and quality of water coming into the project reach. A catchment in good condition based on land use change consists of rural, or otherwise slow growth potential, communities. Catchments evaluated as poor in this category, such as urban or urbanizing communities, have ongoing development or imminent large-scale development.

Trends in land use can be determined through examining orthoimagery from the last 20 years or by examining land cover data available online through the National Land Cover Database (NLCD).[1] The NLCD will provide datasets for percent impervious cover, developed, and forested land from 1992, 2001, 2006, and 2011. Zoning designations and development plans can also be obtained from local governments and assessed for the project catchment. Landscape-scale information is also available through EPA's 2017 Preliminary Healthy Watersheds Assessment for each HUC 12 watershed in WY.[2] Relevant data from this assessment include natural cover within the watershed, population density, imperviousness, and road density.

[1] https://gapanalysis.usgs.gov/gaplandcover/data/download/
[2] https://www.epa.gov/hwp/download-2017-preliminary-healthy-watersheds-assessments

4. Fish Passage

This metric takes into consideration anthropogenic barriers that reduce the mobility of aquatic species or otherwise limit their natural ranges. These barriers can include impoundments, but can also include other anthropogenic factors that limit natural movements of fish, such as culverts, low head dams and other physical or hydraulic barriers. This metric should be evaluated even in situations where these barriers are only historically present within the system. Information similar to that described in the flow alteration or impoundment sections can be used to inform this metric. In addition, consultation with the Regional Fish Biologist from Wyoming Game and Fish Department may yield additional information regarding the presence and severity of barriers within the catchment.

5. Organism Recruitment

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

The most important source of recolonization of benthic insects is drift from upstream. If upstream reaches or unimpacted tributaries are hardened, recolonization of restored reaches will take much longer. Emphasis needs to be given to the quality of upstream reaches for organism recruitment. This category may not limit the future restoration potential, since benthic insects can recolonize via adult egg deposition from nearby catchments if drift from upstream reaches is unlikely. However, this kind of recruitment process may take much longer. This category can be assessed by walking the site and the stream reaches immediately upstream and downstream of the project reach to determine if there are any impairments to organism recruitment including concrete, piped or hardened stretches of channel.

6. Wyoming Integrated Report (305(b) and 303(d) status) for Aquatic Life Uses

The Wyoming Department of Environmental Quality (WDEQ), Water Quality Division (WQD) maintains a list of 303(d) Impaired Waterbodies. Waters with impaired fisheries or aquatic life uses have exceeded water quality standards and require a Total Maximum Daily Load (TMDL) to determine pollutant reductions necessary to achieve standards. Once a TMDL is completed and approved by EPA, the impaired waterbody is removed from the 303(d) list even though water quality standards may still be exceeded. It is therefore important to check for both 303(d) listed waters and completed TMDLs in the catchment. Most stream restoration projects do not restore a sufficient portion of the stream or catchment to overcome poor water quality. A poor or fair catchment condition in this category would indicate that a restoration potential of level 4 or 5 would be difficult or impossible unless a large percent of the catchment is being restored (i.e. good condition rating is achieved for Category 6 of the Catchment Assessment).

There are likely many waters with degraded biological condition that are unassessed, thus they never have been on the 303(d) list. The rest of the categories in this catchment assessment will assist in identifying potentially degraded waters that are not on the 303(d) list or do not have an approved TMDL. 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 WDEQ.

7. Percent of Catchment Stream Length Enhanced or Restored

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 drainage network is included in the project area a restoration potential closer to level 4 or level 5 may be possible.

The proportion of the catchment being restored can be determined by dividing the stream length within the project reach by the total stream length within the catchment. A catchment rated as good condition in this category is one where more than 15% of the catchment stream length is being restored or enhanced. Where the project stream length is less than 5% of the total catchment stream length 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.

8. Development (oil, gas, wind, pipeline, mining, timber harvest, roads)

Development near the project site can significantly impact the functioning and restoration potential of a stream reach depending on the type of development and proximity to the project site. For example, 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. This category asks the user to assess whether impacts are likely to occur near the project, within 1 mile, and the potential severity of the impact to stream function. Impacts that have a high potential to impact the project reach would include sites that are significant sources of contaminants and/or sediment during rain events.

The presence of energy infrastructure, mining and silviculture operations, and 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 the Wyoming Geospatial Hub[3] and the Wyoming Natural Resources and Energy Explorer (NREX).[4] The most recent State Transportation Improvement Program (STIP)[5] is available from the Wyoming Department of Transportation (WY DOT) to determine what projects are expected to receive funding during a 5-year time span. Landscape-scale information is also available through EPA's 2017 Preliminary Healthy Watersheds Assessment for each HUC 12 watershed in WY.[2] Relevant

[3] http://geospatialhub.org/
[4] https://nrex.wyo.gov/
[5] http://www.dot.state.wy.us/home/engineering_technical_programs/stip_project_listing.default.html

data from this assessment includes mining density, road density, and road stream crossing density.

9. WYPDES Permits

The WY DEQ hosts maps of the minor and major Wyoming Pollutant Discharge Elimination System (WYPDES) permitted facilities. The WYPDES program regulates water quality and monitoring procedures for point source discharges to water bodies. While the program ensures discharged water meets minimum water quality standards, standards may not exist for all relevant parameters (e.g. nutrients), or effluent limits may be technology-based rather than water quality-based, thus discharges may limit level 4 and 5 restoration potential. A catchment in good condition would have no WYPDES facilities upstream of the project reach while a poor catchment in this category would have WYPDES permitted facilities comprising a high percentage of the baseflow in the project reach or one or more facilities present within two miles upstream of the project reach.

10. Historic Railroad Tie Drives

From 1867 through the early 1900's, Wyoming trees were harvested in great numbers and milled into railroad ties. Ties were frequently cut in the winter and stacked near rivers to be run downstream in the spring during high flows. To accommodate the ties, channels were straightened, natural wood jams were removed, banks were sloped and channels were generally simplified. There are many channels today that are still adjusting to the effects of this anthropogenic disturbance. Rivers throughout the Medicine Bow Mountains, the Big Horns, the upper Wind River and the Green River all had periods of tie drives. A catchment in which many of the streams experienced tie drives may today still be below potential, especially for channel complexity and large woody debris metrics.

11. 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. 2006). Catchments in good condition will have natural riparian plant communities comprising more than 2/3 the active floodplain, which are over 80% contiguous along the contributing catchment stream length. Catchments in poor condition will have natural plant communities comprising less than 1/3 of the active floodplain, with vegetation gaps exceeding 30% or more of the contributing catchment stream length. These numeric criteria are based on best professional judgment of the Wyoming Stream Technical Team and select reviewers.

The active floodplain can be estimated using available elevation data or Federal Emergency Management Agency delineated floodplains. The prevalence of riparian vegetation on streams draining to the project reach can be determined using recent orthoimagery and/or by field observations within the catchment. Landscape-scale information is also available through EPA's 2017 Preliminary Healthy Watersheds Assessment for each HUC 12 watershed in WY.[6] Relevant data from this assessment could include population density within the riparian zone,

[6] https://www.epa.gov/hwp/download-2017-preliminary-healthy-watersheds-assessments

road density within the riparian zone, natural cover within the hydrologically active zone, and high intensity land cover in the riparian zone.

12. 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 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. Note that this category is applicable to reaches where aggradation would be considered a problem as opposed to naturally aggradational systems.

Figure 20: 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 20). 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 (Rosgen, 2006) if this data set will be used elsewhere in the project. WARSSS is an intensive level of effort that is not necessary for this catchment assessment.

13. 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.

4.4. Bankfull Verification

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

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

Detailed assessments require a longitudinal profile and cross section survey within the project reach using a level, total station, or similar equipment. Four profiles are surveyed, including: thalweg, water surface, bankfull, and top of low bank. From the longitudinal profile, a best-fit-line is plotted through the bankfull stage points. Rosgen (2014) provides step-by-step instructions on how to survey a longitudinal profile and compare best-fit-lines through the water surface and bankfull points. The bankfull determination is suspect if the bankfull slope is different from the water surface slope and/or if the best-fit line through the bankfull points has a correlation coefficient (R^2 value) of less than 0.80.

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

- Stable width and depth, no signs of bank erosion or headcutting. The bank height ratio is near 1.0.
- Cross-sectional area plots within the range of scatter used to create the regional curve. More information is provided in the following paragraphs.
- The bankfull width/depth ratio is on the lower end of the range for the reach.
- Note: In a highly degraded reach, a stable riffle cross section may be used from an adjacent upstream or downstream reach. If a stable riffle is still not identified, the bankfull width and mean depth from the regional curve should be used.

The bankfull dimensions of cross-sectional area, width, and mean depth should be calculated for at least one surveyed representative riffle cross section, as described above. Additional cross sections may be necessary to quantify the effects of aggradation and the weighted entrenchment ratio. These methods are discussed later. The riffle cross sectional areas are plotted on their corresponding bankfull regional curve. The field data should fall within the range of scatter of the regional curve. If the field data are outside the range of scatter, the practitioner will need to determine if the wrong indicator was selected or if the regional curve represents a different hydro-physiographic region. Ideally the regional curve has been developed specifically for the study catchment. If catchment-specific regional curves are not available, the user can overlay the field data with established curves. For Wyoming, established curves are available only for the Rocky Mountain Hydrologic Region (Wyoming Basin, Southern Rockies, Middle Rockies; Foster 2012).

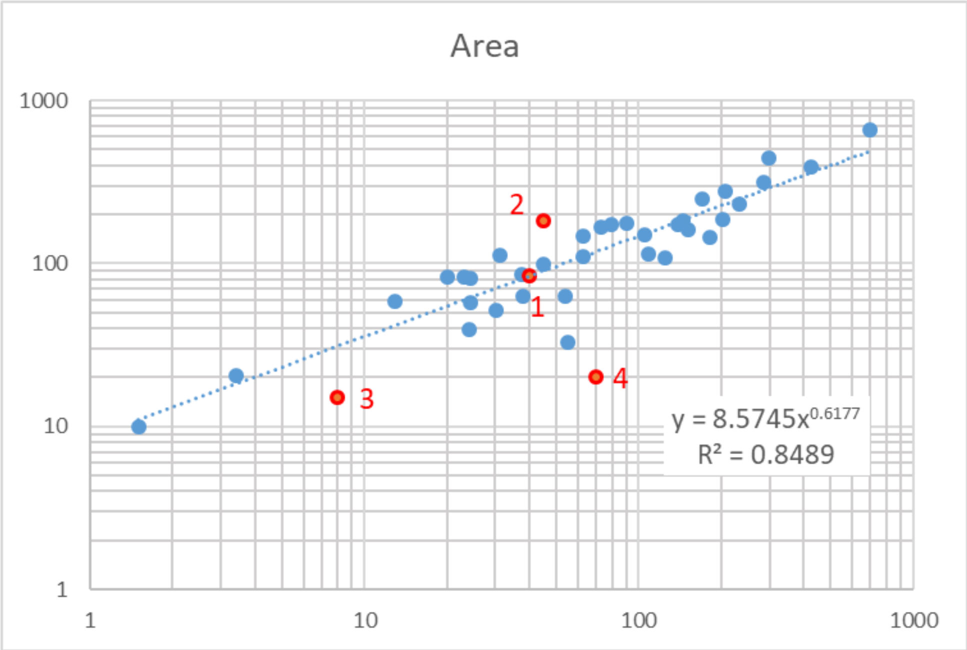
Figure 21 shows the USGS regional curve for the Rocky Mountain Region of WY along with four sample points, numbered and shown in red.

- Sample point 1 plots on the regional curve and can be considered verified.
- Sample point 2, however, falls slightly above the scatter for the regional curve. As the point is above the curve, the practitioner should check the percent impervious cover in the catchment and other factors that could effect runoff. The practitioner should also

check the surveyed cross section and profile to determine if there is another dominant feature at a lower elevation. 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 may be valid. However, more data and a new regional curve are required.

- Sample points 3 and 4 are outside the range of scatter for the regional curve. The cross sections should be compared to field photographs to determine if there is a higher bankfull feature. Note, an adjustment should only be made if there is a higher feature representing a breakpoint between channel formation and floodplain processes. If there is, then an adjustment can be made. If not, consider visiting multiple sites within the catchment of the field site and developing a local regional curve.

Figure 21: Verifying Bankfull with Regional Curves Example



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

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

4.5. Data Collection for Site Information and Performance Standard Stratification

The WSQT quantifies functional lift and loss through performance standards that translate a field value into an index score. For some measurement methods, performance standards are stratified by physical stream characteristics like stream type, temperature, stream location, etc.

Methods for determining values for the Site Information and Performance Standard Stratification section of the WSQT Quantification Tool worksheet are provided in this section.

Stream Type

The WSQT relies on the Rosgen Stream Type (Rosgen 1996) to stratify performance standards for some hydraulic and geomorphic measurement methods. This stream classification system and the fluvial landscapes in which the different stream types typically occur are described in detail in *Applied River Morphology* (Rosgen 1996). The existing stream type is determined through a field survey while the reference stream type is determined during the design process based on the fluvial landscape, historic channel conditions, and/or anthropogenic constraints. The design process is beyond the scope of this user manual; however, more detail can be found in the Natural Resources Conservation Service's National Engineering Handbook, Part 654 (Stream Restoration Design; 2007), Skidmore et al. (2011), and Yochum (2016).

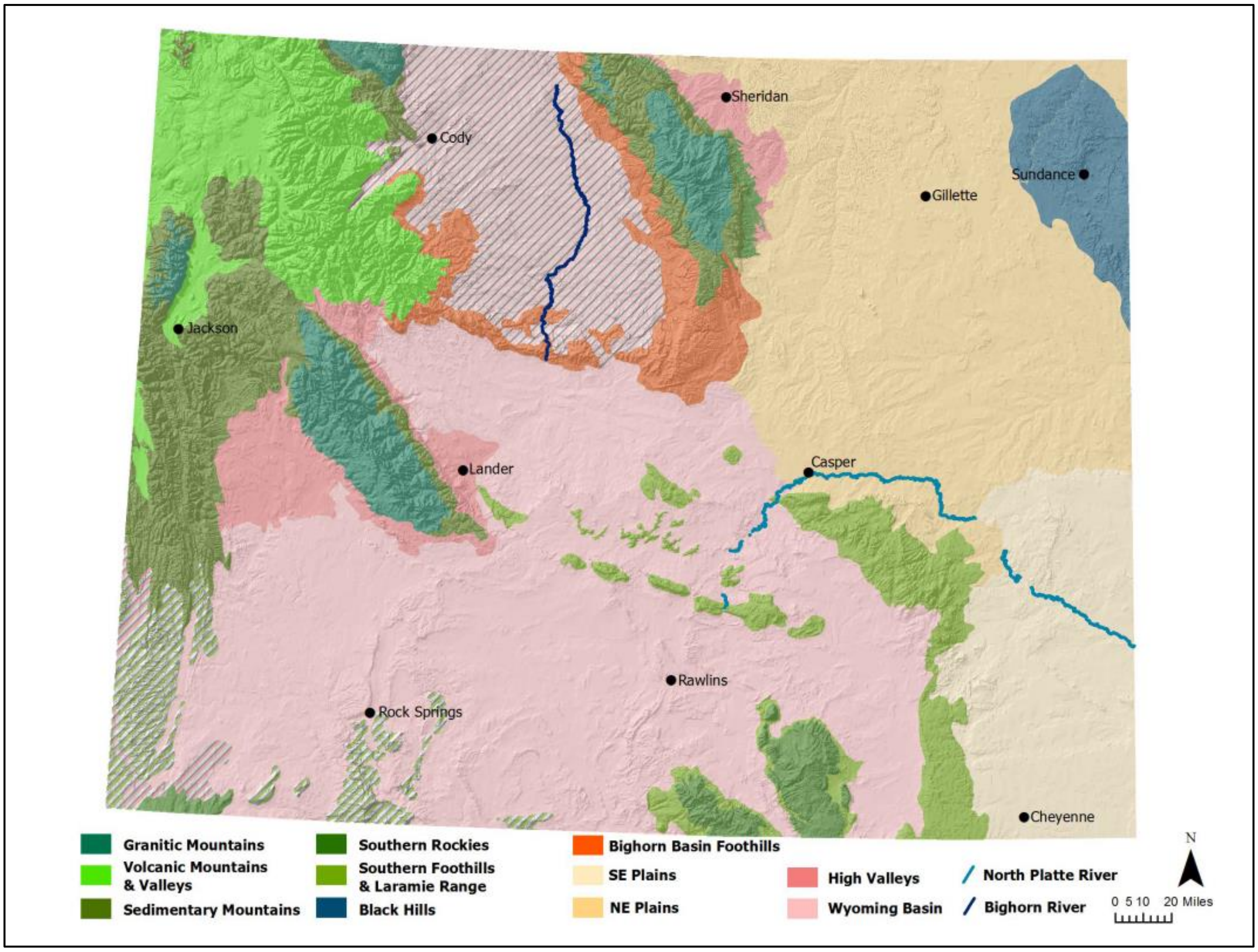
The existing stream type is not used in the scoring; it is only for communication purposes. The reference stream type is used to select the correct performance standards for entrenchment ratio, pool spacing ratio, aggradation ratio, and sinuosity.

Ecoregion and Bioregion

The WSQT uses the project's ecoregion and bioregion to stratify performance standards for some geomorphic, physicochemical, and biology measurement methods. The ecoregion is based on the Level I Ecoregion descriptions from the USEPA: Great Plains, North American Deserts, and Northwestern Forested Mountains. In Wyoming, the North American Desert Ecoregion consists of the Wyoming Basin and falls under the basin stratification in the WSQT. This selection is used to determine the correct performance standard table for woody vegetation cover and chlorophyll monitoring measurement methods.

Bioregions are defined by WDEQ to classify groups of streams with similar physical, chemical, and biological traits (Figure 22; Hargett and Zumberge 2013). Bioregions are delineated with available information, and should not be considered precise boundaries. When a site falls on the edge of two bioregions, professional judgment may be needed to determine the appropriate bioregion. This selection is used to determine the correct performance standard table for percent riffle and both macroinvertebrate measurement methods.

Figure 22: Wyoming Bioregions (reproduced from Hargett and Zumberge 2013)



<u>Drainage Area</u>

The drainage area for the project reach is delineated using available topographic data (ex. USGS maps, LiDAR or other digital terrain data). The drainage area is not used to stratify any performance standards and should be the land area draining water to the downstream end of project reach. This value should be calculated in square miles (sq.mi.).

<u>Proposed Bed Material</u>

The WSQT requires the bed material to select the correct performance standards for the bed material characterization measurement method. The bed material is determined using the Wolman Pebble Count method as modified for stream type classification, field methods are described in detail in *Applied River Morphology* (Rosgen 1996). The d50 (the value of the particle diameter at 50% in a cumulative distribution) is used to describe the bed material of a stream reach. The proposed bed material should reflect the expected d50 of a pebble count performed post-construction or post-impact.

Stream Length (ft)

The stream length is the length along the centerline of the stream reach. This can be determined by surveying the profile of the stream, stretching a tape in the field, or at a computer by tracing the stream pattern from aerial imagery. Stream length is not used for performance standard stratification, but is used to calculate the functional foot score. Therefore, the existing and proposed stream length must be measured.

Stream Slope (%)

The WSQT uses stream slope to select the correct performance standards for percent riffle. The stream slope is a reach average and not the slope of an individual bed feature, e.g., riffle. Both detailed and rapid methods are available to determine the slope of a stream reach.

For the detailed method, reach slope is determined using data from the survey of the stream profile. The slope is determined by:

1. Survey the water surface elevation (WSEL) at the head of the first riffle in the reach.
2. Survey the WSEL at the head of the last riffle in the reach.
3. Measure the stream length of the reach between these two points.
4. Calculate the change in WSEL.
5. Divide the change in WSEL by the length of the reach between the two points.
6. Multiply this number by 100 to convert feet/feet to percent.

For the rapid method, the distance will be limited by the line of sight and magnification of the hand level being used. Estimate the slope of the channel by:

1. Taking a stadia rod reading at the head of similar features (i.e. riffle to riffle, pool to pool, etc.).
2. Calculate the difference in stadia rod readings.
3. Measure the stream distance between the two shots.
4. Divide the difference in rod readings by the distance between these two points and multiple by 100.

River Basin

Wyoming can be subdivided into six large river basins (WGFD, 2017): Bear River, Green River, NE Missouri Basin, Platte River, Snake/Salt River, and Yellowstone River. Select the river basin that the project reach falls within. This input is not used in the scoring; it is used to select an appropriate fish species list for the number of native fish species measurement method. Appendix C contains fish assemblage lists for each river basin.

Stream Temperature

The stream temperature value is used to determine the correct performance standard table for the temperature parameter. Streams in Wyoming are classified by thermal tiers based on the modeled mean August stream temperature. To determine the thermal tier, use the mean modeled August Stream Temperature from the Air, Water, & Aquatic Environments (AWAE) Program (AWAE 2016). [7] Use Table 13 to select the tier that corresponds with the mean modeled August Stream temperature (Peterson, 2017).

Table 13. Stream Temperature Tiers in Wyoming

Modeled mean August temperature (°C)	Tier	Tier Description
< 15.5	I	Cold
15.5 – 17.7	II	Cold-Cool
17.7 – 19.9	III	Cool
19.9 – 24.4	IV	Cool-Warm
> 24.4	V	Warm

Riparian Soil Texture

The riparian soil texture is used to select the correct performance standards for hydrology measurement methods. The user should select between sandy, clayey or silty based on the predominant soil found in the riparian area of the project reach. This value can be determined in the field or via NRCS web soil survey.[8]

Reference Vegetation Cover

Reference vegetation cover is used to determine the correct performance standard table for some hydrology and riparian vegetation measurement methods. The user should select the reference vegetation cover as herbaceous, scrub-shrub, or forested. The reference vegetation cover should be the community that would occur naturally at the site if the reach were free of anthropogenic alteration and impacts. For example, a common reference vegetation cover is a scrub/shrub or forested system, while some plains systems and other E channels may have an herbaceous reference condition.

This value is used to determine the correct performance standards for curve number, woody vegetation cover, and herbaceous vegetation cover.

Stream Productivity Rating

The WSQT uses the stream productivity rating to select the correct performance standards for the game species biomass measurement method. The stream productivity rating is a classification determined by Wyoming Game and Fish Department based on trout pounds/mile

[7] https://www.sciencebase.gov/gisviewer/NorWeST/
[8] https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

(Annear et al 2006).[9] Use the provided link to identify if the stream is listed as blue, red, or yellow ribbon. If the stream is not listed, it is assumed to fall under the green-ribbon classification. If the stream supports non-trout game fish such as catfish, sturgeon or sauger, use the blue-ribbon classification.

Valley Type

Valley type is used to stratify performance standards for riparian width ratio and herbaceous vegetation cover. The valley type options are unconfined alluvial, confined alluvial or colluvial. Alluvial valleys are wide low gradient (typically less than 2% slope) valleys that support meandering stream types. Confined-alluvial valleys are those that support transitional stream types between step-pool and meandering or where meanders intercept hillslopes. Colluvial valleys are confined and support straighter, step-pool type channels.

The guidance below can also be used to determine the valley type for a stream reach.

1. Alluvial Valleys (unconfined). River can adjust pattern without intercepting hillslopes. Typically has a valley width/bankfull width ratio (valley width ratio) greater than 7.0 (Carlson 2009). Could also use a Meander Width Ratio (MWR) greater than 4.0 (Rosgen, 2014). Restored Stream Types: C, E, DA.
2. Confined Alluvial Valleys. Valley width ratio less than 7.0 and MWR between 3 and 4 Restored Stream Types: C, Bc.
3. Colluvial/V-shaped Valleys. Valley width ratio less than 7.0 and MWR less than 3. Stream Types: A, B, Bc.

4.6. Hydrology Functional Category Metrics

There are three function-based parameters to assess hydrology functions: catchment hydrology, reach runoff, and flow alteration. Each is discussed in the following sections.

4.6.a. Catchment Hydrology

Catchment hydrology assesses the hydrologic health of the catchment *upstream* of the project reach. For projects that employ holistic catchment methods, functional lift can be captured by this parameter if the proposed condition score is higher than the existing condition score. This could only happen if the practitioner improves the runoff condition of the catchment. 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 but does not result in functional change. For example, catchments with better upstream hydrology conditions will yield a higher hydrology category score but the difference between the existing and proposed catchment hydrology score would be zero.

This parameter has one measurement method, the Catchment Assessment. This is the only subjective measurement method in the WSQT. To determine the catchment assessment field value, the user should rely on answers from the Catchment Assessment worksheet that impact

[9] http://wgfd.maps.arcgis.com/apps/MapTools/index.html?appid=31c38ed91cf04fb7bb8aebd29515e108

the reach hydrology (categories 1 – 3), to select the appropriate field value. The categories in the catchment assessment are described in detail in Section 4.3.

The field values are scaled from Poor (P) to Good (G) with numerical delineations of 1, 2 or 3 to allow more options in scoring. P1 would likely consist of a catchment that is heavily regulated and the water rights over-allocated. G3 would be a natural catchment free from current and historic anthropogenic activities. Catchments should first be placed in the larger categories of good, fair or poor based on the hydrologic catchment assessment categories, then the impairments in each category scrutinized to determine the field value. For example, a catchment would first be determined to be fair and then the data gathered during the catchment assessment assessed to determine whether the catchment is solidly fair (F2), or leaning toward the good end of the spectrum (F3). Table 14 shows some example scoring combinations for catchment assessment categories 1, 2 and 3 and the typical field value.

Table 14: Catchment Hydrology Performance Standards

Description	Ex. Scoring for Categories 1-3	Field Value	Index Value	Condition
Good	G,G,G	G3	1	Functioning
	G,G,F or G,G,G	G2	0.9	
		G1	0.8	
Fair	G,F,F	F3	0.6	Functioning-At-Risk
	F,F,F or G,F,P	F2	0.5	
	F,F,P or G,F,P	F1	0.4	
Poor	G,P,P	P3	0.3	Not Functioning
	F,P,P or P,P,P	P2	0.2	
	P,P,P	P1	0.1	

4.6.b. Reach Runoff

The reach runoff parameter evaluates the infiltration and runoff processes of the land that drains laterally into the stream reach. The purpose is to assess the catchment that drains directly to the reach from adjacent land uses, and thus evaluates a different area than the catchment hydrology parameter which considers the catchment upstream of the stream reach (Figure 23).

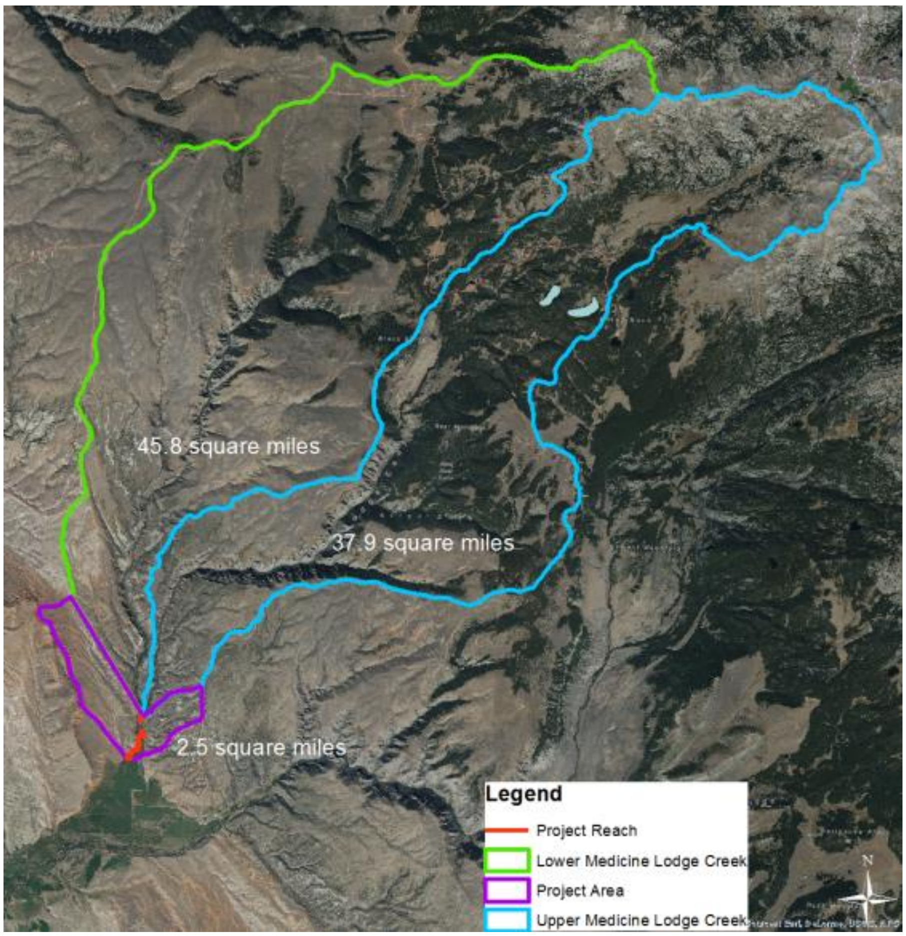
The reach runoff parameter consists of three measurement methods that quantify different aspects of reach runoff: curve number, concentrated flow points, and soil compaction. Each is described in detail in the following sections.

1. Curve Number (CN)

This measurement method is intended to serve as an indicator of runoff potential from land uses draining into the project reach between the upstream and downstream ends. Curve numbers (CN) were developed by the NRCS in their manual Urban Hydrology for Small Watersheds (NRCS, 1986), commonly known as the TR-55. TR-55 provides CN for various land use and cover descriptions in order to estimate runoff from those land use types. Note that the WSQT does not require any runoff calculations using the CN methodology. Rather, the WSQT uses a weighted value that combines the CN with the land use categories. The weighted CN is described below.

To determine the field value, delineate the different land use types using the best matching description from Table 15. Calculate the percent of the total area that is occupied by each land use. Use the CN associated with the land use description from Table 15 to calculate an area-weighted curve number for the catchment draining directly to the project reach from adjacent land uses. The area-weighted curve number equation and a simple example are provided below.

Figure 23: Catchment Delineation Example for Reach Runoff.



The green and blue polygons combined represent the 83.7 square miles draining to the upstream end of the project reach, and is the contributing catchment evaluated by the catchment hydrology parameter. The purple polygon represents the land draining laterally to the project reach (2.5 square miles) and is the catchment area assessed by the reach runoff parameter.

Table 15. NRCS Land Use Descriptions

Land Use Description (From TR-55)	CN [10]
Semiarid Rangelands Land Uses	
Pinyon-juniper – pinyon, juniper, or both; grass understory	41
Oak-aspen – mountain brush mixture of oak brush, aspen, mountain mahogany, bitter brush, maple, and other brush	30
Sage brush with grass understory	35
Herbaceous – mixture of grass, weeds, and low-growing brush, with brush the minor element	62
Desert shrub – major plants include saltbush, greasewood, creosotebush, blackbrush, bursage, palo verde, mesquite, and cactus	68
Urban Areas Land Uses	
Open Space (lawns, parks, golf courses, cemeteries, etc.)	61
Impervious areas	98
Gravel Roads	85
Dirt Roads	82
Natural desert landscaping (pervious areas only)	77
Commercial and business districts	92
Industrial districts	88
Residential districts by average lot size:	
1/8 acre or less (town houses)	85
¼ acre	75
1/3 acre	72
1/2 acre	70
1 acre	68
2 acres	65
Agricultural Lands	
Pasture, grassland, or range – continuous forage for grazing	61
Meadow – continuous grass, protected from grazing and generally mowed for hay	58
Brush – brush-weed-grass mixture with brush major element	48
Woods – grass combination (orchard or tree farm)	58
Woods	55
Farmsteads – buildings, lanes, driveways, and surrounding lots	74

Consider a 50 square mile catchment that consists of 20 square miles of pasture (CN = 61) and 30 square miles of a brush (CN = 48). The area weighted curve number would be:

$$CN_{Area\ Weighted} = \frac{\sum(Area_i * \ CN_i)}{Area_{total}} = \frac{20sq.mi. * 61 + 30sq.mi. * 48}{50\ sq.mi.} = 53$$

[10] Representative CN selected for lands in good condition on HSG B.

2. Concentrated Flow Points

Overland flow typically erodes soils relatively slowly through sheet flow; however, anthropogenic impacts can lead to concentrated flows that erode soils relatively quickly, transporting sediment into receiving stream channels (Al-Hamdan, et al., 2013). This measurement method assesses the number of concentrated flow points that enter the project reach per 1,000 linear feet of stream. For this method, concentrated flow points are defined as erosional features, such as swales, gullies or other channels, that are created by anthropogenic impacts. Anthropogenic causes of concentrated flow include agricultural drainage ditches, impervious surfaces, storm drains, and others. Figure 26 is an example of an agricultural ditch (ephemeral channel) used to drain water from the adjacent cropland into the project reach.

Figure 24: Agricultural ditch draining water from field into stream channel.

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. Development can negatively impact stream channels by creating concentrated flow points such as stormwater outfalls. Proposed grading and stormwater management plans for development should be consulted to determine whether, and how many concentrated flow points are likely to result from the proposed development.

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 (Figure 25).

Figure 25: 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 WSQT 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. This measurement method is only recommended for detailed assessments.

4.6.c. Flow Alteration

The flow alteration parameter evaluates the hydrologic impact of flow reduction and augmentation within the project reach. There is currently one measurement method to evaluate this parameter but the Wyoming Stream Technical Team would like to develop additional measurement methods to quantify flow alteration in future versions of the tool.

The base flow alteration measurement method compares the observed low flow condition in the channel to the expected low flow condition. For this measurement, low flow is defined as the monthly average flow for August. This measurement method requires a reference gage be identified for the project reach. The reference gage should have similar runoff characteristics to the project site and an assessment of reference gages should consider geology, elevation, and precipitation (Lowham 2009). It is recommended that the user performing this analysis be familiar with Wyoming hydrologic studies. Instream flow reports are available online from the Wyoming Water Resources Data System (WRDS). [11]

To determine the expected low flow condition:

1. Determine the average annual discharge Qaa expected for the site (Qaa_{site_exp}) using guidance from Lowham (1988) and Miselis et al.(1999) or another suitable reference for the region of the proposed project.
2. Analyze reference gage records. Example analysis is provided in Instream Flow Study Muddy Creek Basin Carbon County, Wyoming (Biota and Harmony 2014)
   a) Determine average annual discharge for the gage site (Qaa_{gage}).
   b) Identify Qaa_{gage} values to determine wet, dry, and average water years.
   c) Use data from average water years to calculate the mean monthly flow for August ($Qaug_{gage}$).
3. Normalize the site Qaa_{site_exp} value using the reference gage Qaa_{gage} value to generate a dimensionless ratio to scale flow values from the reference gage.

$$Dimensioness\ Ratio = \frac{Qaa_{site\_exp}}{Qaa_{gage}}$$

4. Use the dimensionless ratio to scale mean monthly August flow from the reference gage ($Qaug_{gage}$) and determine the expected mean monthly August flow ($Qaug_{exp}$).

[11] http://library.wrds.uwyo.edu/instream_flow/instream_flow.html

$$Qaug_{site\_exp} = \ Dimensioness\ Ratio * \ Qaug_{gage}$$

To measure the observed low flow condition, there are two monitoring options. For both options it is necessary to take field measurements of discharge. Discharge can be measured in the field using a current meter (EPA 2014).

The preferred option is to establish a site-specific rating curve and deploy a pressure transducer to record stage data from the project reach for the month of August. The site-specific rating curve is used to convert stage data to flow values and the mean monthly flow for August can be calculated from the flow record. Detailed instructions for establishing a rating curve and analyzing flow records is provided in EPA's 'Best Practices for Continuous Monitoring of Temperature and Flow in Wadeable Streams' (2014). Recent instream flow studies available from WRDS provide an overview of this process as well.

The second option is to follow the concurrent-discharge methodology as outlined by Lowham (2009) and collect individual flow measurement(s) during August. Taking three measurements is recommended and it may be necessary to consult with upstream water diversions to avoid sampling on days when low flow will be impacted by releases. The field measurement(s) of discharge are related to the reference gage values for the same day and the gage data can then be used to estimate the mean August monthly flow for the project reach.

The reference gage data analysis that identified wet, dry, and average water years (step 2b from above) should be used to inform a narrative, and potentially scale the observed discharge values to ensure that monitoring events are comparable and functional lift or loss are not achieved due to annual variations in climate.

The field value for the WSQT is the ratio of the observed low flow over the expected low flow.

$$Field\ Value = \frac{Qaug_{site\_obs}}{Qaug_{site\_exp}}$$

4.7. Hydraulic Functional Category Metrics

There is one function-based parameter included in the WSQT to assess hydraulic functions: floodplain connectivity. This parameter is discussed in detail in the following section.

4.7.a. Floodplain Connectivity

Floodplain connectivity is assessed using two measurement methods: Bank Height Ratio (BHR) and 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 an indicator of whether flood flows can access and inundate the floodplain. The measurement is described in detail by Rosgen (2014). The bank height ratio compares the low bank height to the maximum bankfull riffle depth, and the lower the ratio between the two, the more frequently water can access the floodplain. The low bank height is defined as the lower of the left and right streambanks, indicating the minimum water depth necessary to inundate the floodplain. The most common calculation for the BHR is the Low Bank Height divided by the maximum bankfull riffle depth (D_{max}).

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

To improve consistency and repeatability, this measurement should be taken at every riffle within the assessment reach. The low bank height and D_{max} should be measured at the midpoint of the riffle, half way between the head of the riffle and the head of the downstream run or pool, and the length of each riffle should be recorded. The BHR is calculated for each riffle and then a weighted BHR is calculated as follows (Table 16). A weighted BHR is used in the WSQT in order to remove subjectivity in selecting a value to represent incision occurring throughout the reach.

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

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

Table 16: Example Weighted BHR Calculation: the weighted bank height ratio calculation in an assessment segment with four riffles.

Riffle ID	Length (RL)	BHR	BHR * RL
R1	25	1.0	25
R2	200	1.5	300
R3	75	1.4	105
R4	40	1.2	36
Total	**340 ft**	**Total**	**466**
Weighted BHR = 466/340 = 1.4			

<u>Detailed Method</u>

The BHR can be calculated 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 and easily verified in the office, as it is measured directly from the surveyed longitudinal profile. To calculate the weighted BHR, extract the measurements for low bank height, thalweg depth and riffle length from the longitudinal stream profile for every riffle feature within the stream reach and calculate using the equations above. The weighted BHR should then be entered into the field within the WSQT Spreadsheet.

<u>Rapid Method</u>

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

1. Identify the middle of the riffle feature and the lower of the two streambanks.

2. Measure and record the difference in stadia rod readings from the thalweg to the top of the low streambank. This result is the Low Bank Height, the numerator of the BHR.
3. Measure the difference in stadia rod readings from the thalweg to the bankfull indicator, and enter this value in the denominator of the BHR.
4. Measure the length of the riffle.
5. Repeat these measurements for every riffle to enter values into the weighted BHR equation.

Note that in both the detailed method and rapid method, the low bank height was measured from the thalweg.

2. Entrenchment Ratio (ER)

Floodplain connectivity and width naturally varies by stream and valley type, where some streams are more naturally constrained than others. An entrenchment ratio characterizes the vertical containment of the river by evaluating the ratio of the flood-prone width to the bankfull width (Rosgen 1996). The ER is a measure of approximately how far the 2-percent-annual-probability discharge (50-year recurrence interval) will laterally inundate the floodplain (Rosgen 1996).

Entrenchment Ratio is calculated by dividing the flood prone width by the bankfull width of a channel, measured at a riffle cross section. 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).

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

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:

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

Where, RL_i is the length of the riffle where ER_i was measured. Refer to Table 17 for an example of the weighted entrenchment ratio calculation.

Table 17: Example Weighted ER Calculation

Riffle ID	Length (RL)	ER	ER * RL
R1	25	1.2	30
R2	200	2.1	420
R3	50	1.6	80
R4	30	1.8	54
Total	**305 ft**	**Total**	**584**
Weighted ER = 305/584 = 1.9			

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

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 the ER.
3. Measure the difference in stadia rod readings from the thalweg to the bankfull indicator.
4. Locate and flag the point along the cross section in the floodplain where the difference in stadia rod readings between the thalweg and that point is twice that of the difference measured in the previous step.
5. Repeat step 4 on the other bank.
6. Measure the distance between the flags and enter this value as the numerator of the ER.
7. Measure the length of the riffle and repeat these measurements for every riffle to enter values into the weighted ER equation if needed.

4.8. Geomorphology Functional Category Metrics

The WSQT contains the following function-based parameters to assess the geomorphology functional category: large woody debris, lateral stability, riparian vegetation structure, bed material characterization, bed form diversity, and sinuosity. Few projects will enter values for all geomorphic parameters. Refer to Chapter 2 of this manual for guidance on selecting parameters for a stream restoration project.

4.8.a. Large Woody Debris

There are two measurement methods to assess the large woody debris (LWD) parameter, one for the rapid method and a different method for detailed assessments. The rapid method is a LWD piece count per 100 meters of channel. The detailed method uses the large woody debris index (LWDI; Davis et al. 2001).

For both measurement methods in the WSQT, large woody debris is defined as dead wood over 1m in length and at least 10 cm in diameter at the largest end. The wood must be within the stream channel or touching the top of the streambank. An assessment reach of 100 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.

1. LWDI

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

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

2. Piece Count

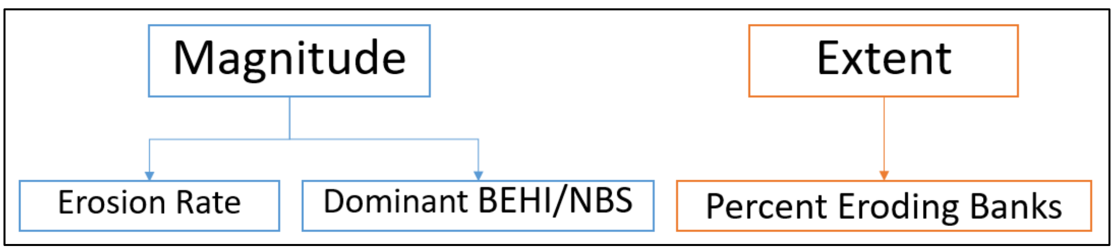
For this measurement method, the pieces of LWD are simply counted. For debris dams, each piece within the dam that qualifies as LWD is counted as a piece. This procedure and the rapid method data form are included in Appendix A.

4.8.b. Lateral Stability

Lateral stability is a parameter that assesses the degree of streambank erosion relative to a reference condition, and is recommended for all projects. Lateral stability within the representative reach 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 26). Percent eroding bank should not be used alone to describe lateral stability.

Figure 26: Relationship between measurement methods of lateral instability.



The stream banks can be measured by mapping the eroding 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 WSQT, calculate the weighted average of the erosion rates using the lengths of each bank segment.

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

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 model.

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 WSQT, 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 focuses 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 (Table 18) and a field form is included in Appendix A.

Table 18: Example Calculation for Dominant BEHI/NBS. 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.

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

<u>Total Percent by Category:</u>

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 19) of banks in each BEHI/NBS category (2nd column). For the example in Table 18, 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. Table 19 shows the scoring associated with BEHI/NBS categories.

Table 19: BEHI/NBS Category Performance Standards

Index		Category
0.00	Not Functioning	Ex/Ex, Ex/VH
0.10		Ex/H, VH/Ex, VH/VH, H/Ex, H/VH, M/Ex
0.20		Ex/M, VH/H, H/H, M/VH
0.30	Functioning-At-Risk	Ex/L, VH/M, H/M, M/H, L/Ex
0.40		Ex/VL, VH/L, H/L
0.50		VH/VL, H/VL, M/M, L/VH
0.60		M/L, L/H
0.70	Functioning	M/VL, L/M
0.80		
0.90		
1.00		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 19) 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 the sum of the left and right bank lengths, which is approximately twice the channel centerline length. In the example provided in Table 18 where the total length of bank was 150 feet, the 96 feet of High/High and Mod/High categories would be considered eroding bank (12+22+31+31 from 3rd column in Table 18). Therefore, 96/150 = 62% streambank erosion.

4.8.c Riparian Vegetation

Riparian vegetation is a critical component of a healthy stream ecosystem. Riparian vegetation is defined as plant communities contiguous to and affected by surface and subsurface hydrologic features of perennial or intermittent water bodies. While these plant communities are a biological component of the stream ecosystem, riparian vegetation plays such a critical role in supporting channel stability, physicochemical and biological processes that it is included in the geomorphic level of the stream functions pyramid.

This parameter should be assessed for all projects, but some measurement methods are optional. The measurement methods for this parameter may vary depending on the appropriate reference community type (e.g., forest and scrub-shrub versus herbaceous cover types) in Wyoming. There are seven measurement methods for riparian vegetation and all but one assesses the left and right bank separately. The measurement methods and intended application are listed in Table 20 and described below. Riparian vegetation should be assessed for a length that is 20 times the bankfull width or the entire reach length, using whichever is shorter (Leopold 1994).

Table 20. Riparian Vegetation Structure Measurement Method Applicability

Measure Method for Riparian Vegetation	Applicable Cover Type (Forested, Scrub-Shrub, Herbaceous)
Riparian Width Ratio	All
Woody Vegetation Cover	Forested & Scrub-Shrub
Herbaceous Vegetation Cover	All
Non-native Plant Cover	All
Hydrophytic Vegetation Cover	All
Stem Density	Forested & Scrub-Shrub
Greenline Stability Rating	All

The woody vegetation cover, herbaceous vegetation cover, non-native plant cover, hydrophytic vegetation cover and stem density measurement methods are collected from sampling plots along the reach. The methods are a combination of techniques borrowed from Corps of Engineers Hydrogeomorphic (HGM) Approach (Hauer et al. 2002), USEPA National Rivers and Streams Assessment (USEPA 2007), Bureau of Land Management AIM (BLM 2016), and Corps of Engineers Arid West Regional Supplement (USACE 2008b). Instructions for setting up and monitoring sampling plots is described below and the subsequent sections provide instruction on calculating field values for each measurement method.

<u>Sampling Plot Procedures – Plot Locations</u>

The minimum number of plots for a representative sample of each reach is determined using the sampling reach length as shown in Table 21. Plots will be systematically distributed along each bank such that the minimum number of plots are evenly spaced along the known length of the representative reach.

Table 21. Minimum Number of Sampling Plots Per Sampling Reach

Sampling Reach Length	Minimum Number of Plots per Riparian Area Side	Minimum number of plots for the reach
300 - 400 ft	3 plots	6 plots
400 - 600 ft	4 plots	8 plots
600 - 900 ft	6 plots	12 plots
900 - 1300 ft	8 plots	16 plots

Heterogeneous sites with greater variability in cover classes or amount of cover, or sites where functional lift in riparian vegetation may be more subtle, are likely to require more plots.

Random systematic riparian vegetation sampling (Elzinga et al. 1998) begins at the upstream end of the reach on the left-hand side (looking downstream) by selecting a random starting point within the first 20 feet. The spacing interval (reach length/ # of plots) may be measured using calibrated paces or a measuring tape. After the last plot is collected on the left side, cross the stream and place the first plot on the right side and move upstream collecting data on the remaining number of evenly spaced plots.

A nested plot approach (Kent and Coker 1992; Elzinga et al. 1998; Hauer et al. 2002) was selected to ensure that the plots are big enough to contain at least one plant of interest and enough plants to get a good and precise estimate of cover or density a reasonable amount of time. A 1 m by 1 m plot will be used to measure herbaceous vegetation consistently at the bankfull topographic/hydrologic zone (see Figure 27). A 5 m by 5 m plot will be used for mid-layer – understory (scrub-shrub) cover measurements. A 10 m by 10 m plot will be used for canopy – overstory (forested) cover and stem density measurements. The lower left-hand corner of each plot will be placed at that location where it intersects the edge of the bankfull stage.

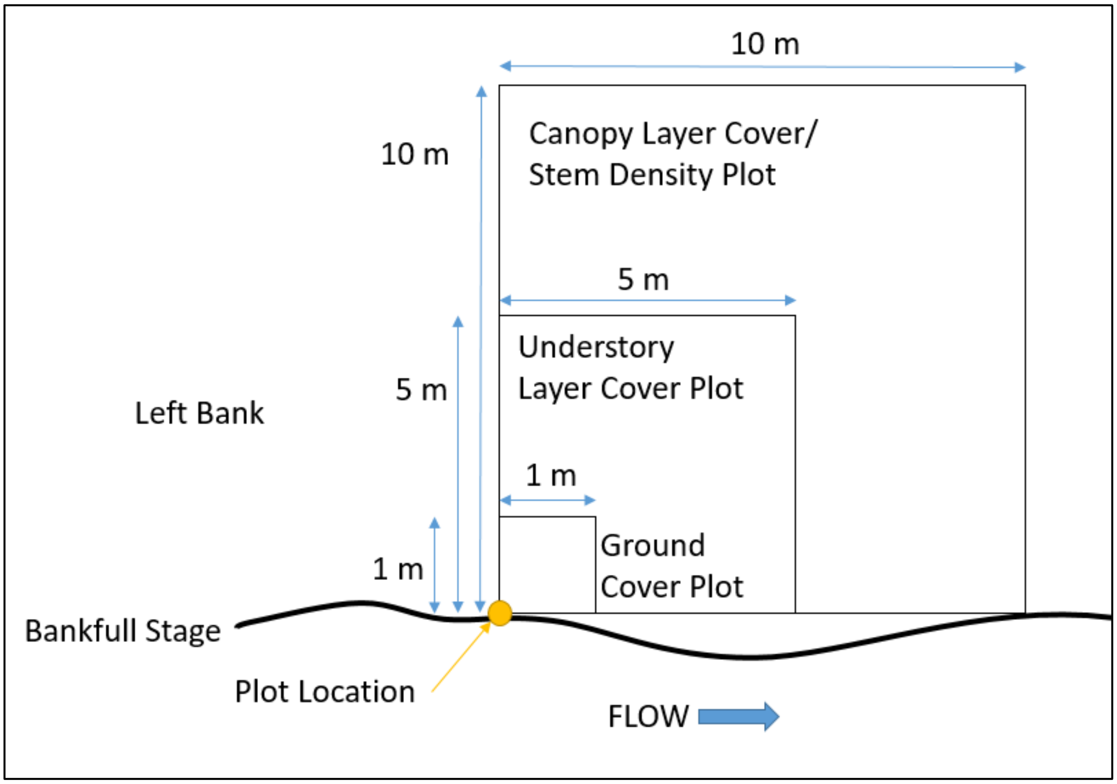
All vegetation sampling is conducted within the reach's expected riparian area width (see Riparian Width Ratio discussion below), and in degraded systems may involve sampling dryland (upland) vegetation as part of the larger plots. In narrower or colluvial valleys, square plots may need to be reshaped (to a rectangular plot of the same area) to keep the plots within the expected riparian area width of the reach.

Sampling Plot Procedures – Measurements

This protocol is meant to provide an estimate of vegetation structural complexity and riparian cover. Practitioners will need a basic knowledge of the native and nonnative plants commonly found in riparian zones within the region.

Within each sampling plot for the reach, visually estimate the percent aerial cover of three different layers of vegetation (groundcover, understory, and canopy) to determine vegetation structure and complexity (USEPA 2007, BLM 2016). Vegetative complexity is assessed across all vegetative types. Aerial cover is an estimate of the amount of shadow that would be cast by a particular category of vegetation if the sun were directly over the plot area.

Figure 27. Riparian Vegetation Sampling



The following procedure should be followed at each sampling plot location within the reach (refer to Riparian Vegetation Field Sheet in Appendix A):

1. The lower left-hand corner of the first plot will be placed at that location where it intersects the bankfull stage. At each plot location:
    a. Confirm the bankfull stage with geomorphic data for the reach;
    b. Identify the existing primary cover type and the proposed primary cover type (if applicable) as herbaceous, scrub-shrub, forested, mixed, or unknown. Consider the layer *Mixed* if more than 20% of the areal coverage is made up of the alternate cover type;
    c. Note the geomorphic location as inside meander, outside meander, or straight/riffle.

2. The Ground Cover layer (< 0.5 m) is measured at every plot location as the percent aerial coverage within a 1-m by 1-m plot.
    a. Visually estimate herbaceous cover, woody cover, bare ground/litter, and embedded rock (> 15 cm diameter) in the Ground cover layer.
    b. Record the dominant (covers the greatest area) herbaceous and/or woody plant species present.
3. The Understory layer (0.5 to 5 m) is measured as the percent aerial coverage within a 5 m by 5 m nested plot.

    a. Pace out the bounds of the plot from the lower left starting point and mark corners with pin flags.

   b. Visually estimate herbaceous cover and woody cover separately in the Understory layer. Understory woody cover includes small trees, shrubs and saplings any woody plants less than 10 cm in diameter at breast height (DBH) and between 0.5 m and 5 m tall.
   c. Record the dominant plant species within the Understory.

4. The Canopy layer (> 5 m) (USEPA 2007, BLM 2016) includes trees greater than 10 cm DBH and is measured as the percent aerial coverage within a 10-m by 10-m plot.
   a. Pace out the bounds of the plot from the lower left starting point and mark corners with pin flags.
   b. Visually estimate woody cover in the Canopy layer.
   c. Record the dominant woody species within the Canopy.
5. For measuring the non-native plant cover:
   a. When reading Ground layer, Understory layer and Canopy layer cover plots, identify the non-native species present in each.
   b. Consider each layer independently and estimate the percent aerial cover of the plot provided by non-native vegetation (herbaceous and woody combined).

6. If the hydrophytic vegetation cover measurement method is being used:
   a. When reading Ground layer cover, Understory layer and Canopy layer cover plots, identify and record all species by layer, their percent aerial cover and National Wetland Plant List indicator status (Lichvar et al., 2016).
   b. Hydrophytic vegetation are species that have a facultative (FAC), facultative wetland (FACW), or obligate wetland (OBL) indicator status in the appropriate USACE Great Plains, Western Mountains and Valleys, or Arid West Regional Supplement (2008, 2010a, 2010b).

Below are a few notes on sampling procedure.

- Percent aerial cover estimates within each layer cannot be greater than 100% but can total less than 100%.
- Aerial estimates among different layers are independent of each other (absolute cover by layer), so the sum of the aerial cover for the three layers combined could add up to 300%.
- Total areal percent cover for the canopy and understory layers can be less than 100%, but percent cover for the ground cover layer must equal 100% coverage.
- Plants over-hanging the plot do not need to be rooted in the plot to be counted as aerial cover.
- Standing dead shrubs/trees should be included in aerial cover estimates.
- Both riparian and non-riparian species can be counted as cover.

1. Riparian Width Ratio

The riparian width ratio is the portion of the expected riparian area width that currently contains riparian vegetation and is free from utility-related, urban, or otherwise soil disturbing land uses and development. The expected riparian area width corresponds to (USDA 2014):

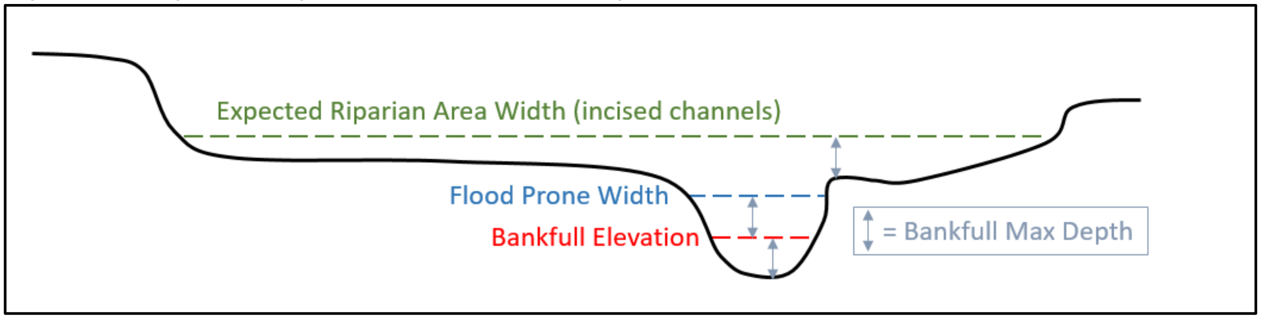
1) Substrate and topographic attributes -- the portion of the valley bottom influenced by fluvial processes under the current climatic regime,
2) Biotic attributes -- riparian vegetation characteristic of the region, and

3) Hydrologic attributes -- the area of the valley bottom flooded during the 50-year recurrence interval flow.

The riparian width ratio compares the observed, current extent of the riparian area to the expected, or reference, riparian area width. There are two options to determine the expected width of the riparian area for this measurement method: using the flood prone width or the meander width ratio. Each is described below. Measurements of both the current, observed riparian area width and expected riparian area width can be based on aerial imagery and verified in the field. Field measurements should be collected at the midpoint of riffles within the reach. If the valley width, riparian community, and extent of development is fairly consistent throughout the reach, the expected riparian area width field value can be estimated at the midpoint of the representative riffle. If valley width, impacts, restoration, ownership, protection level, or management vary throughout the reach then sufficient measurements should be taken to determine an average observed and expected riparian area width value for the reach.

The first option to measure the expected riparian area width as equivalent to the flood prone width. The flood prone width is measured as the cross-section width at an elevation two times the bankfull max depth. This measurement is part of the entrenchment ratio measurement method described in Section 4.7.a. However, in incised channels, the riparian area width should be measured as the cross-sectional width at an elevation equal to one bankfull max depth measured from the stream bank rather than the bottom of the channel (see Figure 28).

Figure 28. Expected Riparian Area Width Example for Incised Channels



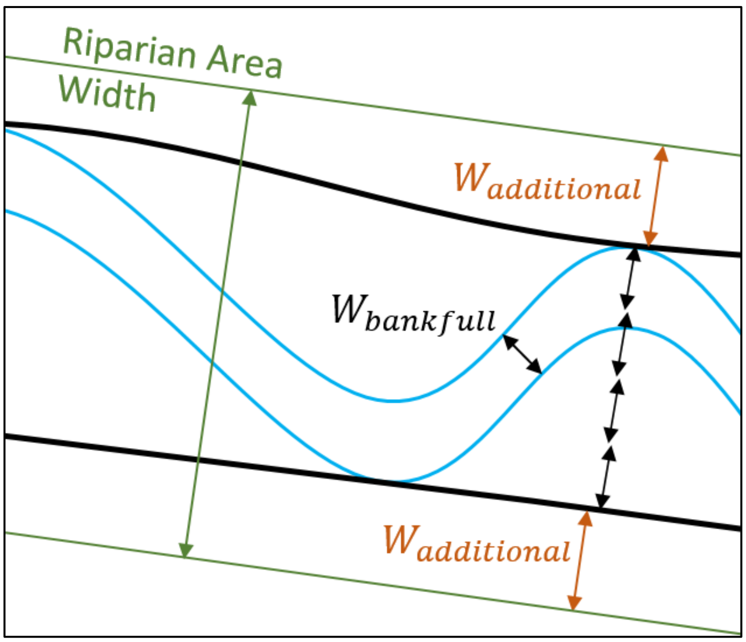
The second option for measuring the expected riparian area width is to use the meander width ratio (MWR). This method may be preferred in wide, flat valleys where the flood prone width (entrenchment ratio) method will yield widths that exceed the 50-year mark. The MWR is the belt width of a meandering stream in its valley divided by the bankfull width (Rosgen 2014). This option does not require the MWR to be measured but instead applied a typical MWR based on the valley type (Table 22). To determine the riparian area width using this method, multiply the bankfull width of the channel by a selected MWR for the given valley type and add an additional width for outside meander bends.

$$Riparian\ Area\ Width = W_{Bankfull} * MWR + W_{additional}$$

Table 22. How to Determine MWR using Valley Type (Adapted from Harman et al. (2012) and Rosgen (2014))

Valley Type	MWR	Additional Width $W_{additional}$
Alluvial Valley	4	25
Confined Alluvial	3	15
Colluvial	2	10

Figure 29. Example of expected riparian area width calculation relying on meander width ratio for alluvial valleys



Within the expected riparian area width, the user should record the width of the current, observed riparian area. This is the area that contains riparian vegetation and is free from urban, utility-related, or intensive agricultural land uses and development. Riparian areas have one or both of the following characteristics: 1) distinctly different vegetation species than adjacent areas, and 2) species similar to adjacent areas but exhibiting more vigorous or robust growth forms (USFWS 2009). Riparian areas are usually transitional between wetland and upland and can be limited by stream incision, human development or detrimental land use. The riparian width ratio is the percentage of the expected riparian area width that currently contains riparian vegetation and is free from development, as described above. The riparian width ratio is the field value entered into the WSQT.

$$Riparian\ Width\ Ratio = \frac{Observed\ Riparian\ Area\ Width}{Expected\ Riparian\ Area\ Width} * 100$$

2. Woody Vegetation Cover

This measurement method uses the data from the sampling plots collected according the instructions provided earlier in this section. The woody vegetation cover field value for the WSQT is the sum of percent woody plant cover from the canopy, understory and ground cover layers.

$$Woody\ vegetation\ cover = Woody_{Ground\ Cover} + Woody_{Understory} + Woody_{Canopy}$$

Note that estimates among different layers are independent of each other, so the sum of the woody cover for the three layers combined could add up to 300%.

3. Herbaceous Vegetation Cover

This measurement method uses the data from the sampling plots collected according the instructions provided earlier in this section. The herbaceous vegetation cover field value for the WSQT is the sum of percent herbaceous plant cover from the understory and ground cover layers.

$$Herbaceous\ vegetation\ cover = Herbaceous_{\ Ground\ Cover} + Herbaceous_{Understory}$$

Note that estimates among different layers are independent of each other, so the sum of the herbaceous cover for the two layers combined could add up to 200%.

4. Non-Native Plant Cover

This measurement method uses the data from the sampling plots collected according the instructions provided earlier in this section. The non-native plant cover field value for the WSQT is the sum of percent non-native plant cover from the canopy, understory and ground cover layers.

$$Non-Native\ Plant\ Cover = Non-Native_{\ Ground\ Cover} + Non-Native_{Understory} + Non-Native_{Canopy}$$

Note that estimates among different layers are independent of each other, so the sum of the non-native plant cover for the three layers combined could add up to 300%.

5. Hydrophytic Vegetation Cover

This measurement method uses the data from the sampling plots collected according the instructions provided earlier in this section. The hydrophytic vegetation cover field value for the WSQT is the sum of percent hydrophytic vegetation cover from the canopy, understory and ground cover layers. Recall that only hydrophytic species defined as those with a facultative (FAC), facultative wetland (FACW) or obligate wetland (OBL) indicator status for the appropriate region are considered in this measurement method. Region, as defined here, refers to the regional supplements to the Wetland Delineation Manual (Environmental Laboratory, 1987) developed by the Corps. There are three regional supplements in effect for Wyoming: Arid West (USACE 2008), Great Plains (USACE 2010a), and Western Mountains, Valleys, and Coast

(USACE 2010b). A wetland plant list for each region[12] can be consulted to determine a plant's indicator status.

$$Hydrophytic\ Vegetation\ Cover = Hydrophytic\ Vegetation_{Ground\ Cover} + Hydrophytic\ Vegetation_{Understory} + Hydrophytic\ Vegetation_{Canopy}$$

Note that estimates among different layers are independent of each other, so the sum of the hydrophytic vegetation cover for the three layers combined could add up to 300%.

6. Stem Density

This measurement method is an alternate way to assess woody vegetation abundance and potential structure. It is recommended for sites where a new scrub-shrub or forested cover type is being re-established and/or woody vegetation cover measurement is not practicable. In most forested systems, tree stem density and basal area increase rapidly during the early successional phases. This is also true in regional ecosystems that occur in Wyoming. Thereafter, tree density decreases and basal area increases as the forest reaches mature steady-state conditions (Spurr and Barnes 1980).

The following procedure should be followed at each sampling plot location within the reach. How to locate sampling plots within a sampling reach is described earlier in this section.

1. Use the Canopy Cover plot (10 m by 10 m) established for vegetation cover measurement methods.
2. Count the number of live shrub and tree stems that occur within the plot (Hauer et al. 2002).
   a. For shrubs that have multiple stems, consider all stems within 0.3 m of each other at ground level as the same plant and single stem.
   b. Include standing dead mature stems (trees > 10 cm) diameter at breast height (DBH) or multi-stemmed willows with a base diameter of >10 cm).
   c. Do not count seedlings or plantings less than 0.5 m high.
   d. Each stem may be recorded as young or mature using the 10 cm DBH threshold identified above for trees. Most multi-stem shrubs are considered mature if they have >10 stems and/or are over 1 m tall.

Report the number of stems within the 100 m^2 plot as the field value for stem density with the WSQT.

7. Greenline Stability Rating

Greenline stability ratings and related data may be collected along the greenline, which is a linear grouping of live perennial vascular plants on or near the water's edge. There is a strong interrelationship between amount and kind of vegetation along the water's edge and bank stability. Evaluation of the types of vegetation on the greenline area provides a good indication of stream health, in particular, a streambank's ability to buffer the hydrologic forces of moving water (Winward 2000).

[12] http://wetland-plants.usace.army.mil/nwpl_static/index.html

Data collection procedures are described in detail in the original Greenline methodology found in the U.S.Department of Agriculture publication, *Monitoring the Vegetation Resources in Riparian Areas* by Alma Winward (2000) or the U.S. Department of Interior publication, *Riparian Area Management: Multiple Indicator Monitoring (MIM) of Stream Channels and Streamside Vegetation* by U.S. DOI (2011). Use the MIM modification for additional species stability ratings.

4.8.d. Bed Material Characterization

Bed material is a parameter recommended for projects in gravel bed streams with sandy banks where fining of the bed material is occurring due to bank erosion or where activities are proposed that could lead to fine sediment deposition or armoring. Projects that implement lateral stability practices along a long project reach or restore flushing flows may be able to show a reduction in fine sediment deposition. Bed material is characterized using a Wolman Pebble Count procedure and the Size-Class Pebble Count Analyzer (v1).[13]

The following steps are required for the assessment reach and the reference reach. Bevenger and King (1995) provide a description of how to select and potentially combine reference reaches for bed material characterization. Note, reference reach stratification may include Rosgen stream classification, catchment area, gradient, and lithology. When possible, pick reference reaches that are upstream of the project reach and upstream of the source of sediment imbalance. For example, a stable C stream type with a forested catchment upstream of an unstable C4 or Gc/F4 stream type is ideal for this analysis. If a reference reach cannot be located, this assessment cannot be completed. Be sure to document the location of reference and assessment reaches on a map.

Steps for Completing the Field Assessment:

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

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

4.8.e. Bed Form Diversity

Bed forms include the various channel features that maintain heterogeneity in the channel form, including 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 responsive to 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 in equilibrium within the system.

There are four measurement methods for this parameter: pool spacing ratio, pool depth ratio, percent riffle, and aggradation ratio. It is recommended that the first three be evaluated at all project sites within a representative reach 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). It is important that users accurately characterize pools, and thus guidance for identifying pools in different valley types is provided below.

The fourth metric included here, aggradation ratio, is recommended for projects where symptoms of aggradation are present, such as mid-channel or transverse bars, or where sediment transport or hydrologic processes are anticipated to change due to changes in land use, recent wildfires or other factors within the contributing catchment.

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

For the methods outlined here, pools should only be included if they are located along the outside of the meander bend. Micro-pools within riffles are not counted using this method. Figure 30 provides an illustration of what is and is not counted as a pool (pools are marked with an ‘X’). The figure illustrates a meandering stream, where the pools located in the outside of the meander bend are counted for the pool spacing measurement, and 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 in this figure are not counted because they are small pools located within the riffle. 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.

<u>Identifying Pools in Colluvial and V-Shaped Valleys</u>

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

Figure 30: Pool Spacing in Alluvial Valley Streams

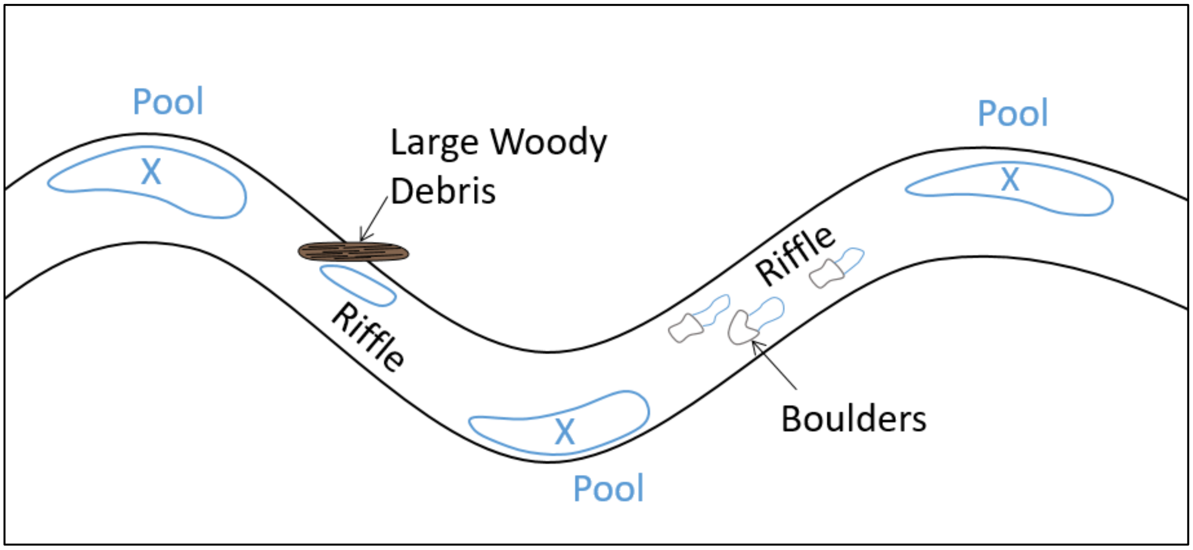
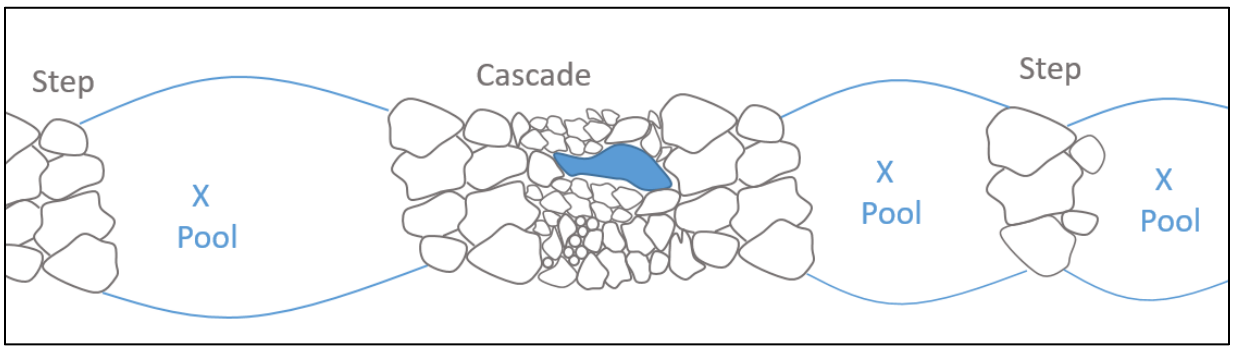


Figure 31: Pool Spacing in Colluvial and V-Shaped Valleys



1. Pool Spacing Ratio

Pool-to-pool spacing is essentially a measure of how many pools are present within a given reach and can be indicative of the channel stability and geomorphic function. The pool spacing ratio is the calculation of the pool spacing divided by the bankfull riffle width. The bankfull riffle width is from one representative riffle cross section rather than measured at each riffle. A low ratio reflects more pools and fewer riffles; a high ratio indicates fewer pools and more riffles. Channel stability concerns are greater with higher ratios. In a meandering stream, a moderate ratio is preferred over very low or very high ratios. In other words, having too many or too few pools can be detrimental to channel stability and geomorphic function. In steeper gradient perennial systems, the frequency of pools often increases with slope.

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

The pool spacing ratio is calculated for each pair of sequential pools in the assessment reach. Since the performance standard curve is bell-shaped for meandering channels, low and high field values (both non-functioning) could average to a functioning score. Therefore, the field value entered in the WSQT should be a median value based on at least three pool spacing measurements.

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

To collect this data rapidly, 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 minimum of one 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 the equation above.

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 described below.

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

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

Detailed Method

Pool depths are calculated from a longitudinal profile of the stream thalweg and reflect 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 method requires that the maximum bankfull depth of each pool in the reach be recorded. Three representative riffles are then selected from within the reach. The mean bankfull depth is calculated as the average of multiple depth measurements across the cross section. The equation above is used to calculate the pool depth ratio of each pool within the assessment reach.

3. Percent Riffle

The percent riffle is the total length of riffles within the assessment reach divided by the total assessment stream reach 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. A run is a transitional feature from the riffle to the pool and the glide transitions from the pool to the riffle (Rosgen, 2014).

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 method, 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 are recorded and used to calculate the individual riffle lengths.

4. Aggradation Ratio

Channel instability can result from excessive deposition that causes channel widening, lateral instability, and bed aggradation. Visual indicators of aggradation include mid-channel bars and bank erosion within riffle sections. The aggradation ratio is the bankfull width at the widest riffle within the assessment reach divided by the mean bankfull riffle depth at that riffle. This ratio is then divided by a reference width to depth ratio (WDR) based on stream type (Equation 13; Table 23). This measurement method is recommended mainly for C and E stream types, but could also apply to some Bc and B stream types.

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

Table 23: Reference Bankfull WDR Values by Stream Type (Rosgen, 2014)

Stream Type	Reference WDR
B	16
C	13
E	9

Detailed Method

For the detailed method, complete a cross sectional survey at the widest riffle in the assessment reach, and use the width and mean depth calculations to determine the study riffle WDR. Then, divide the study WDR ratio by a reference WDR ratio given in Table 23.

It is recommended to survey multiple riffle cross sections with aggradation features to ensure that the widest value for the reach is obtained and to document the extent of aggradation throughout the project reach.

Rapid Method

Recall that standard surveying equipment like laser levels or a total station are not used in the rapid method. Instead, survey tapes and stadia rods are used to simply take the measurements in the field. For the rapid-based assessment, measure the widest bankfull riffle width and estimate the mean depth as the difference between the edge of channel and the bankfull stage. Use these calculations to determine the study riffle WDR. Then, divide the study WDR ratio by a reference WDR ratio, as given in Table 23.

It is recommended to measure this metric at multiple riffle cross sections with aggradation features to ensure that the widest value for the reach is obtained and to document the extent of aggradation throughout the project reach.

4.8.f. Plan Form

Sinuosity is a recommended parameter for all projects located in alluvial valleys with Rosgen C and E stream types. This parameter is also recommended 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 the upstream and downstream extent of the project reach. 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).

4.9. Physicochemical Functional Category Metrics

The WSQT contains two function-based parameters to assess the physicochemical functional category: temperature and nutrients.

4.9.a. Temperature

Temperature plays a key role in both physicochemical and biological functions. For example, each species of fish have an optimal growth temperature but can survive a wider range of thermal conditions. Stream temperatures outside of a species' optimal thermal range result in reduced growth and reproduction and ultimately results in individual mortality and population extirpation (Cherry et al. 1977). Water temperature also influences conductivity, dissolved oxygen concentration, rates of aqueous chemical reactions, and toxicity of some pollutants. These factors directly impact the water quality and ability of living organisms to survive in the stream.

There are two measurement methods for this parameter: daily maximum temperature and maximum weekly average temperature (MWAT). Both are stratified by ambient stream temperature regime, where tier 1 is cold and tier 5 is warm. Metrics and performance criteria were derived using data and information presented in Peterson (2017). Placement and use of in-water temperature sensors should follow the USEPA's 'Best Practices for Continuous Monitoring of Temperature and Flow in Wadeable Streams' (2014).

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

1. Daily Maximum Temperature (°C)

The field value for the daily maximum temperature (measured in degrees Celsius) is the maximum temperature in the period of record that is sustained for at least 2 hours.

2. Maximum Weekly Average Temperature (°C)

The MWAT is the largest mathematical mean of multiple, equally spaced, daily temperatures over a seven-day consecutive period. To determine the field value for the MWAT (measured in degrees Celsius):

1. Calculate the average temperature recorded for each day in the sample period (minimum 31 days). These are the mean daily temperatures.
2. Calculate the weekly average temperatures on a rolling seven-day basis for the sampling period.
3. The maximum of the weekly average temperatures is the field value to be entered in the WSQT.

4.9.b. Nutrients

There is currently only one measurement method for the nutrient parameter, chlorophyll. Chlorophyll is the pigment that allows plants (including algae) to use sunlight to convert simple molecules into organic compounds via the process of photosynthesis, and is used in the WSQT as a surrogate for nitrogen and phosphorus. Chlorophyll α is the predominant type found in green plants and algae and concentrations are directly affected by the amount of nitrogen and phosphorus in stream. Excess nitrogen and/or phosphorus can cause excess plant and algal growth which can degrade stream microhabitats, cause periodic low oxygen concentrations, and even cause blooms of toxin producing algae.

The chlorophyll parameter is only applicable to stream reaches where riffles are present and contain gravel or larger bed materials. Chlorophyll sample collection and processing must be conducted according to the WDEQ Standard Operating Procedure (WDEQ/WQD 2015). Chlorophyll typically is collected at the same locations macroinvertebrates are collected. If macroinvertebrates will not be collected, chlorophyll samples must be collected from eight (8) randomly selected locations from a representative riffle. See the WDEQ SOP (WDEQ 2015) for direction on identifying random sampling locations within a riffle. Only the rock scrape method (epilithic method) is applicable to the WSQT. Chlorophyll data should be expressed as milligrams of chlorophyll α per square meter of sampled rock substrate (mg/m^2).

4.10. Biology Functional Category Metrics

The function-based parameters included in the WSQT for the biology functional category are macroinvertebrates and fish. The macroinvertebrate parameter is informed by the two biological condition models developed by WDEQ. Since there is no existing biological index used for fish in Wyoming, measurement methods and performance standards for fish were developed by the Wyoming Stream Technical Team in consultation with Regional Fish Biologists at the Wyoming

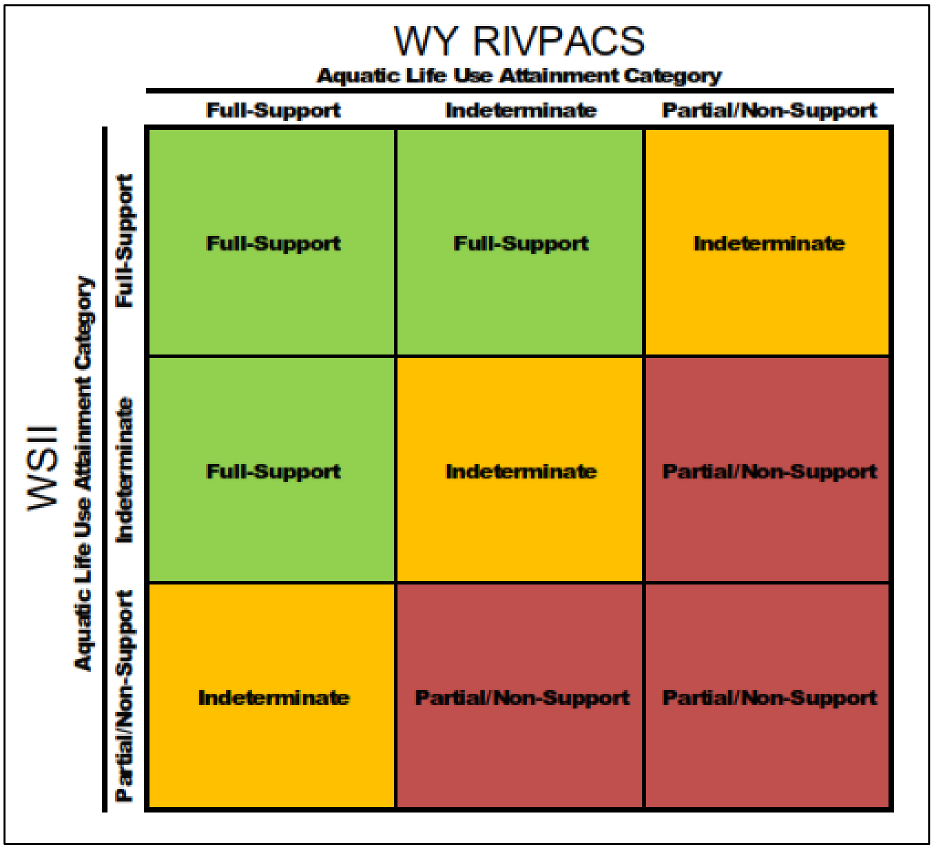
Game and Fish Department (WGFD). The Wyoming Stream Technical Team would like to develop additional parameters to describe biologic function in future versions of the tool, including amphibians, mussels, or others, where data are available to determine performance standards.

4.10.a. Macroinvertebrates

Macroinvertebrates are an integral part of the food chain that support functioning river ecosystems, and are commonly used as indicators of stream ecosystem health. There are two biological models that use macroinvertebrate communities to assess biological condition of Wyoming streams: the multimetric Wyoming Stream Integrity Index (WSII) and the multivariate River Invertebrate Prediction and Classification System (RIVPACS). Both measurement methods for macroinvertebrates are stratified by bioregion. Both WSII and RIVPACS should be applied to most projects with a restoration potential of level 5. Both measurement methods are limited to analyzing samples collected from riffles using WDEQ's targeted riffle sampling method (WDEQ 2017). One or both measurement methods may be excluded if it can be demonstrated that the required WDEQ sampling method is not applicable to the project site, or the results are not representative of unique biological conditions found at the site (Hargett 2012, Hargett 2011). Exceptions to the use of both measurement methods are subject to IRT approval. It is important to keep in mind that RIVPACS requires predictor data (latitude, longitude, watershed area, bioregion, and alkalinity) and must be calculated by WDEQ. Practitioners should coordinate with WDEQ if RIVPACS is going to be applied at the project site.

In order to recognize the uncertainty and variability in stream ecosystems and maintain consistency with how WDEQ applies these models the decision matrix in Figure 31 was incorporated into parameter scoring when field values are entered for both models. This means that for a small range of values the parameter score will not be an average of the measurement method scores. However, for most field values the macroinvertebrate parameter score will simply average the measurement method index scores consistent with parameter scoring throughout the WSQT.

Figure 31. Decision Support Matrix from Hargett (2012).



1. WSII

The WSII is a statewide regionally-calibrated macroinvertebrate-based multimetric index designed to assess biological condition in Wyoming perennial streams (Hargett 2011). Index scores for the WSII are calculated by averaging the standardized values of selected metrics (composition, structure, tolerance, functional guilds) derived from the riffle-based macroinvertebrate sample. The selected metrics are those that best discriminate between reference and degraded waters. The assessment of biological condition is made by comparing the index score for a site of unknown biological condition to expected values that are derived from an appropriate set of regional reference sites that are minimally or least impacted by human disturbance.

Benthic macroinvertebrate sampling, processing, and identification should be conducted using methods outlined in the Manual of Standard Operating Procedures for Sample Collection and Analysis (WDEQ, 2015). Samples are generally collected from riffles with a Surber sampler (0.09 m2 =1 ft2) and 500-μm mesh. Once taxa are identified from the sample (generally to the genus level), WSII values can be calculated using the WSII report (Hargett 2011; Table 7). Laboratories providing taxonomic identification services may also calculate metrics required for the WSII upon request. Additional resources needed to calculate metric values for the WSII are described or cited in the WSII report. Contact WDEQ for questions on macroinvertebrate sampling and assistance with calculating WSII scores, if needed.

Once the WSII value is determined, the field value in the WSQT is a ratio of observed over expected. The expected value is the 75th percentile WSII value of the reference calibration dataset. These values are provided in Table 24.

$$Field\ Value = \frac{WSII_{Observed}}{WSII_{Expected}}$$

Table 24. Expected Values for WSII

Bioregion	$WSII_{Expected}$
Volcanic Mountains & Valleys	88.10
Southern Foothills & Laramie Range	85.30
NE Plains	95.80
Southern Rockies	82.20
Granitic Mountains	74.90
SE Plains	87.00
High Valleys	78.20
Bighorn Basin Foothills	80.80
Sedimentary Mountains	70.80
Black Hills	65.70
Wyoming Basin	64.50

2. RIVPACS

RIVPACS is a statewide macroinvertebrate-based predictive model that assesses stream biological condition by comparing the riffle-based macroinvertebrate community observed at a site of unknown biological condition with that expected to occur under reference condition (Hargett 2012). The expected macroinvertebrate taxa are derived from an appropriate set of reference sites that are minimally or least impacted by human disturbance. The deviation of the observed from the expected taxa, a ratio known as the O/E value, is a measure of compositional similarity expressed in units of taxa richness and thus a community level measure of biological condition. O/E values near 1 imply high biological condition while values <1 imply some degree of biological degradation.

As with the WSII, benthic macroinvertebrate sampling, processing, and identification should be conducted using the methods outlined in the Manual of Standard Operating Procedures for Sample Collection and Analysis (WDEQ, 2015). Samples are generally collected from riffles with a Surber sampler (0.09 m2 =1 ft2) and 500-µm mesh. Taxa generally are identified to the genus level, and reported in a taxa-abundance matrix. Contact WDEQ for questions on macroinvertebrate sampling and assistance with calculating RIVPACS scores.

Once the RIVPACS value is determined, the field value in the WSQT is a ratio of observed over expected. The expected value is the 75th percentile RIVPACS value of the reference calibration dataset. These values are provided in Table 25.

$$Field\ Value = \frac{RIVPACS_{Observed}}{RIVPACS_{Expected}}$$

Table 25. Expected Values for RIVPACS

Bioregion	$RIVPACS_{Expected}$
Volcanic Mountains & Valleys	1.21
Southern Foothills & Laramie Range	1.20
NE Plains	0.98
Southern Rockies	1.18
Granitic Mountains	1.09
SE Plains	1.12
High Valleys	1.14
Bighorn Basin Foothills	0.92
Sedimentary Mountains	1.17
Black Hills	1.08
Wyoming Basin	1.18

4.10.b. Fish

Fish are an integral part of functioning river ecosystems. Three measurement methods for fish are included in the WSQT: Number of Native Fish Species (% of expected); Presence/Absence of Species of Greatest Conservation Need (SGCN); and Game Species Biomass. Measurement methods should be applied based on restoration project goals and targeted improvements to the fish community. These measurement methods could also be required for development projects that are likely to result in functional loss in priority conservation areas or other valuable fish habitats. In developing project goals, a practitioner should consider whether their project reach falls within priority conservation areas identified in the Wyoming State Wildlife Action Plan (SWAP; WGFD 2017). In addition, project specific consultation should occur with a Regional Fish Biologist from the WGFD who can provide local information on potential limiting factors to improving fish communities, or indicate whether project goals should center on native fish restoration or game fish species based on the management objectives within a specific sub-basin.

1. Number of Native Fish Species (% of expected)

This parameter is intended to document the diversity of the native fish community in comparison to reference expectations. Reference expectations are derived from the expected species assemblages within the six major river basins in Wyoming based on differences in stream temperature (cold, transitional, warm) and gradient. These assemblages are based on the 2017 SWAP and can be found in Appendix C.

Expected Fish Community

Users should first review the species assemblage list included in Appendix C for a preliminary estimate of the expected native fish assemblage at a site. Recognizing that each fish species' distribution varies naturally within any basin due to underlying factors such as geology, flow regime and duration, water temperatures, or natural barriers, the list of expected species in a project area reflects a subset of the assemblage list for the entire basin and may require further refinements based upon local knowledge. There may also be anthropogenic factors outside of a restoration practitioner's control that influence the number of species present, including flow alteration, barriers to movement, etc. While these anthropogenic factors may limit the restoration potential at a site, they should not be considered in estimating the "expected" fish community. Therefore, the "expected" community consists of the fish that should be naturally present in the absence of anthropogenic influence. Once a preliminary estimate of the number of native fish species is made, the practitioner should coordinate with a regional fish biologist at WGFD to further refine the expected species assemblage. The regional fish biologist will also be able to advise the practitioner whether improvements to the native fish community at a given site are possible or whether native fish species restoration is an appropriate project goal.

Observed Fish Community

Fish community data may be available from the Wyoming Natural Resources and Energy Explorer (NREX)[14], and these data may serve as a preliminary estimate of the number of native species present. The publicly accessible data is programmed to yield species lists of all species ever sampled from the closest fish sampling station. At this time, it is not possible for the public user to identify the sampling history or distance to WGFD sampling sites to judge whether the species list is current or derived from a nearby site. Therefore, the practitioner should coordinate with the Regional Fish Biologist at the WGFD to evaluate these questions. If representative data has not been collected within the previous 3 years, detailed fish surveys should be conducted on the site using standard methods (Bonar et al. 2009). Because of inter- and intra-annual variability in native fish communities, at least two sampling events occurring in different seasons (at least 60 days between sampling occurrences) or ideally different years are needed to establish the observed fish community. To verify fish identification, practitioners must collect and preserve voucher specimens of each fish species identified.

2. Presence/Absence of SGCN

Species of Greatest Conservation Need (SGCN) are identified in the State Wildlife Action Plan (2017) as those species whose conservation status warrants increased management attention, and funding, as well as consideration in conservation, land use, and development planning in Wyoming. For any project where this measurement method is used, the practitioner should consult with the Regional Fish Biologist at WGFD to determine whether there is natural potential at the site for SGCN to be present. Note, the natural potential is not limited by anthropogenic factors like culverts or flow alteration that may limit the existing distribution of a SGCN. For an initial site review the SWAP can be consulted to determine the potential for SGCN species to be present within the project reach.

SGCN species are classified into tiers where tier 1 species have the highest conservation need while tier 3 species have less of a conservation need than tier 1 or 2 species. The number of species with natural potential to occur at the site in each tier is used to calculate the field value for the WSQT. Therefore, once the list of SGCN species with natural potential at the site is determined, sort the list by tiers and report the number of SGCN in each tier for the site.

[14] https://nrex.wyo.gov/

To determine if SGCN are present in a reach, conduct at least two sampling events at the site using standard methods (Bonar et al. 2009). Sampling events should occur a minimum of 60 days apart or ideally in different years. From this sampling, report the number of species from the site's SGCN list that are absent in each tier. The field value is the number of species absent but the tiers are weighted. Tier 1 species are valued 3 times as much as tier 3 species while tier 2 species are valued at twice as much as tier 3 species (Table 26). Note that if there are no species in a tier for the site then there are no species absent for that tier.

Table 26. How to Determine the Field Value for SGCN measurement method

Column A	Column B	Column C
# Tier 1 Species Absent	3	$C_1 = A_1 * B_1$
# Tier 2 Species Absent	2	$C_2 = A_2 * B_2$
# Tier 3 Species Absent	1	$C_3 = A_3 * B_3$
Field Value for the WSQT =		$C_1 + C_2 + C_3$

The weighted number of SGCN species absent is the field value to be entered into the WSQT.

For example, for a project occurring in a transitional system in the Bear River Basin, two SGCN species (Bonneville cutthroat trout, tier II and Northern leatherside chub, tier II) may be expected in the stream if the stream was in pristine condition. Upon coordination with the Regional Fish Biologist, it is determined that only the Bonneville cutthroat trout has the natural potential to occupy that catchment. The practitioner would then determine if Bonneville cutthroat trout are present by sampling using standard methods over a least two sampling events. If no Bonneville cutthroat trout were detected, the field value in the WSQT would be 2 since there was 1 tier 2 SGCN species expected that was absent.

3. Game Species Biomass (% Increase)

This measurement method focuses on native or non-native game fish species determined to be a management priority following consultation with the WGFD. This measurement method is not applicable to functional loss or impact projects.

This method measures the increase in game fish biomass following a restoration project relative to the change observed at a control site. Fish baseline data from a nearby control reach is required to account for variability. The control reach should be at a similar elevation and be roughly similar to the project reach in all other aspects. A control reach can be located upstream or downstream from the project reach, or in a separate catchment within the same river basin as the project reach. The control reach should not be immediately adjacent to the project reach. A control reach that is geographically in close proximity to the project reach but outside the influence of the project actions is preferred.

In order to calculate the Game Species Biomass percent increase for the WSQT:

1. Conduct at least two sampling events (Bonar et al. 2009) at both the project reach and a control reach to establish baseline pre-project biomass estimates.

2. Conduct at least two sampling events in different years at both the project reach and the control reach post-construction.
3. For each post-construction sampling event, calculate the percent change in biomass for the project site and the percent change in biomass at the control site.
4. Subtract the percent change in biomass at the control site from the percent change in biomass at the project site.
5. The average post-construction percentage difference is the field value to be entered into the WSQT.

Subtracting the change in biomass at the control site helps account for inter and intra-annual variability inherent in fish populations, and reduces the influence of climactic or other external factors in determining increases in biomass associated with a restoration project.

Sampling events should occur a minimum of 60 days apart or ideally in different years. Example data and calculations are provided in Tables 27 and 28 for a yellow ribbon trout stream where data is collected in different years. WSQT field values for this example data are provided in Table 29. Recall that if a value is entered for a measurement method in the Existing Condition Assessment, a value must also be entered for the same measurement method in all subsequent condition assessments (e.g. proposed, as-built, and monitoring). Since the measurement methods for the fish parameter recommend multiple years of monitoring, if condition assessments are performed for sequential years post-construction, then the average value will be used for both monitoring events. If an As-Built condition assessment is performed, then the average of the year 1 and year 2 monitoring should be used for the As-Built Condition Assessment as well (as shown in Table 29).

Table 27. Example Baseline Data for Game Species Biomass in a Yellow Ribbon Trout Stream

Monitoring Event	Sampling Event Yield (lbs/mile)	
	Project Site	**Control Site**
Baseline Year 1	65	90
Baseline Year 2	85	110
Pre-Project Average	75	100

Table 28. Example Monitoring Data for Game Species Biomass in a Yellow Ribbon Trout Stream

Monitoring Event	Sampling Event Yield (lbs/mile)		Percent Increase		Difference
	Project Site	**Control Site**	**Project Site**	**Control Site**	
Baseline (From Table 28)	75	100			
Post Construction Year 1	100	115	$\frac{100-75}{75} = 33\%$	15%	18%
Post Construction Year 2	90	105	20%	5%	15%
Average					**16.5%**

Table 29. Example Field Values for Game Species Biomass in a Yellow Ribbon Trout Stream

Condition Assessment	Game Species Biomass Field Value
Existing	0
Proposed	30
As-Built	16.5
Monitoring Year 1	16.5
Monitoring Year 2	16.5

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APPENDIX A

DRAFT

Rapid Data Collection Methods for the Wyoming Stream Quantification Tool (WSQT)

Table of Contents

1. Introduction and Purpose

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

The rapid method will typically take three to six hours to complete per project reach. Recommended pyramid-level 2 (hydraulic) and 3 (geomorphology) parameters are quantitatively measured; however, standard surveying equipment like laser levels or a total station are not used. Instead, survey tapes and stadia rods are used to simply take measurements in the field. Keep in mind that cross sections and profiles cannot be plotted using this method. The rapid method does not include guidance on collecting physicochemical and biological data, as only detailed methods are provided for these parameters (Chapter 4).

This appendix compiles instructions from Chapter 4 of the user manual so that all rapid measures can be read in one place. Few measurements are unique to the WSQT, and data collection procedures are often detailed in other instruction manuals or literature. Where appropriate, this appendix will reference the original methodology to provide technical explanations and make clear any differences in data collection or calculation methods needed for the WSQT.

Rapid method forms are included in Section 6 of this appendix that can be used with these instructions to collect field data. The Wyoming Stream Quantification Tool Rapid Method Form (rapid method form) is the primary rapid method form described in this appendix. Additional rapid method forms are provided for riparian vegetation and lateral stability assessments. These three rapid method forms are also available as Microsoft Excel Workbooks where data can be entered upon returning from the field.[1]

2. Rapid Method Parameter List

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

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

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

- Floodplain Connectivity
  - Bank Height Ratio (2)
  - Entrenchment Ratio (2)
- Large Woody Debris
  - Piece Count (2)
- Lateral Stability
  - Dominant BEHI / NBS (2)
  - Percent Stream Erosion (2)
- Bedform Diversity
  - Pool Spacing Ratio (2)
  - Pool Depth Ratio (2)
  - Percent Riffle (2)
  - Aggradation (2)
- Sinuosity (1)
- Riparian Vegetation
  - Riparian Width Ratio (2)
  - Woody Vegetation Cover (2)
  - Herbaceous Vegetation Cover (2)
  - Non-native Vegetation Cover (2)

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

3. Desktop Component

Certain desktop tasks must be completed prior to collecting field data while a second portion of the desktop tasks can be completed after the fieldwork. The tasks that must be completed first are described below, followed by those that can be completed later.

Before Fieldwork:

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

The WSQT is a reach based tool and requires one Excel Workbook for each reach contained within the project. For long homogenous reaches, a sub-reach can be assessed to represent the overall reach. Refer to section 4.2 of the user manual for detailed guidance on reach delineation.

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

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

This background data will help in understanding and interpreting the field data. Enter values for the ecoregion, bioregion, river basin and predominant riparian soil texture into the Site Information and Stratification section of the WSQT and on the rapid method form for each reach. Delineate the catchment for each reach.

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

3. Complete the catchment assessment worksheet in the WSQT.

Methods and links to relevant online data sources for each category in the catchment assessment are provided in Section 4.3 of the user manual. The catchment assessment is used to: 1) calculate the catchment hydrology parameter; and 2) identify possible constraints and conditions that limit the restoration potential of the reach. This background data will also help in understanding and interpreting field data. A catchment assessment should be completed for every reach within a project although values may be similar for reaches located on the same stream. For each reach:

- Use categories 1 – 3 to select a field value for catchment hydrology (Section 4.6.a of the user manual). Enter this value into the Existing Condition Assessment of the Quantification Tool worksheet in the WSQT.
- Use all responses in the catchment assessment to determine the restoration potential of the reach (Section 2.2.a of the user manual). Enter this value into the Site Information and Performance Standard Stratification section of the Quantification Tool worksheet in the WSQT.

4. Obtain bankfull regional curves.

Bankfull regional curves that apply to the project site should be obtained if they're available. For Wyoming, established curves are available only for the Rocky Mountain Hydrologic Region (Wyoming Basin, Southern Rockies, Middle Rockies; Foster 2012).

5. Calculate regional curve dimensions.

This data is used to verify the bankfull indicators observed in the field. The regional curve dimensions should be entered into Section III of the rapid method form (Lines E., F., and G.). Bankfull verification is discussed in more detail in Section 4.4 of the user manual.

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

Determine the valley type (unconfined alluvial, confined alluvial, or colluvial) for each reach in the WSQT and the rapid field form. Guidance on identifying valley type is provided in Section 4.5 of the user manual. The entrenchment ratio and riparian width ratio measurement methods vary with valley width. Mark locations where valley width changes and valley measurements will need to be taken on maps that will be taken into the field.

Instructions for measuring the sinuosity of a reach are provided in both the desktop and fieldwork components of the rapid method. Given the prevalence and quality of aerial imagery, sinuosity can most often be measured from the office. For small streams and/or streams with significant canopy cover it may be difficult to determine sinuosity in the office and it should be noted to measure or confirm sinuosity in the field. Procedures for measuring the sinuosity of a reach using recent orthoimagery are provided in Section 3.2 below.

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

Desktop components that can be completed after fieldwork:

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

Curve number is a measurement method for the reach runoff parameter that requires characterizing the land use of the area that drains laterally to each reach. Procedures for calculating the Curve Number measurement method field value for the WSQT are provided in the following section.

3.1. Curve Number (CN) – Reach Runoff

The curve number measurement method characterizes the land use of the watershed draining laterally into the stream reach. To determine the field value:

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

This calculation will yield an existing condition curve number; an example is provided in Table 17 of the user manual. Further instructions are provided in section 4.6.b of the user manual.

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

Figure B.1: Lateral Drainage Area (Purple) Delineation Example (for comparison, the upstream drainage area is shown in green and blue)

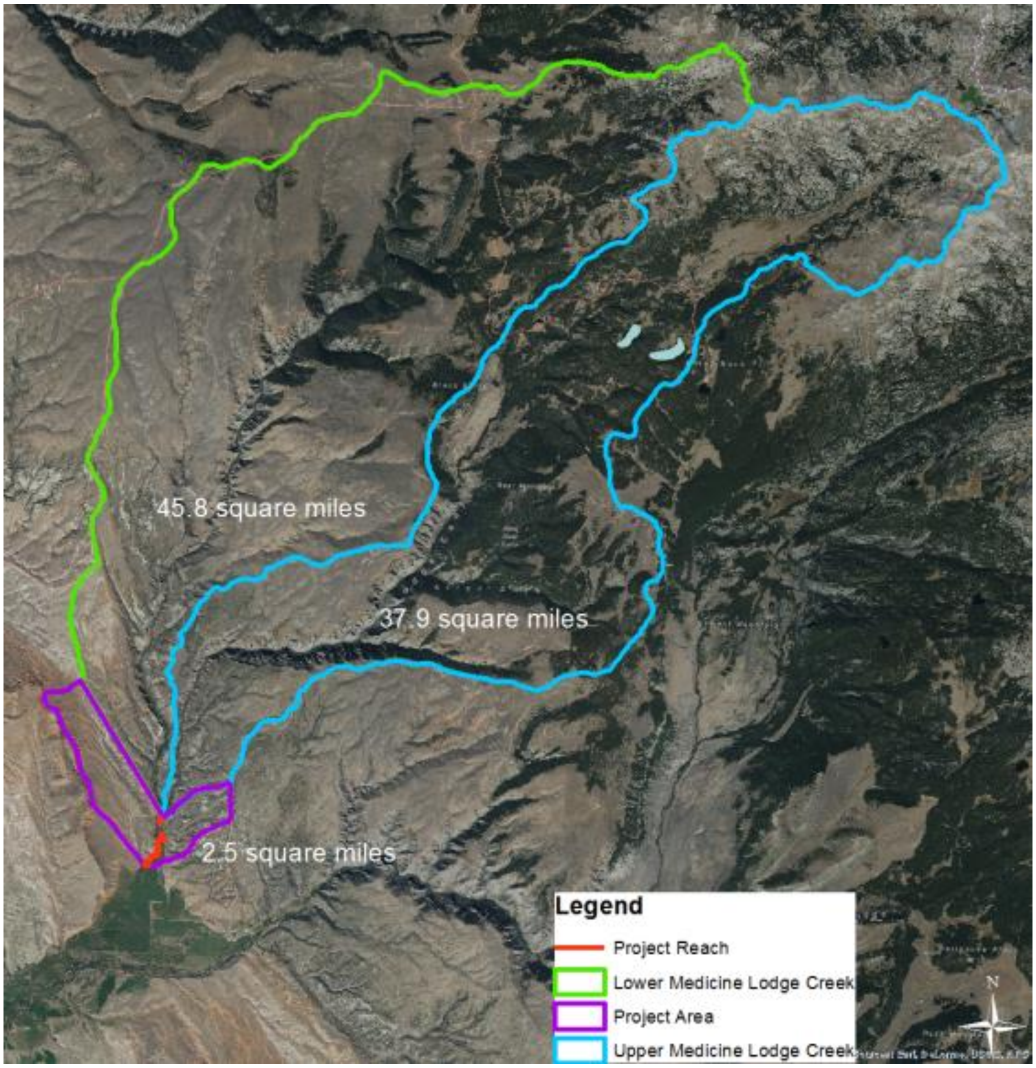

Table B.1. NRCS Land Use Descriptions

Land Use Description (From TR-55)	CN[3]
Semiarid Rangelands Land Uses	
[4] Pinyon-juniper – pinyon, juniper, or both; grass understory	41
Oak-aspen – mountain brush mixture of oak brush, aspen, mountain mahogany, bitter brush, maple, and other brush	30
[5] Sage brush with grass understory	35
[6] Herbaceous – mixture of grass, weeds, and low-growing brush, with brush the minor element	62
Desert shrub – major plants include saltbush, greasewood, creosotebush, blackbrush, bursage, palo verde, mesquite, and cactus	68
Urban Areas Land Uses	
Open Space (lawns, parks, golf courses, cemeteries, etc.)	61
Impervious areas	98
Gravel Roads	85
Dirt Roads	82
Natural desert landscaping (pervious areas only)	77
Commercial and business districts	92
Industrial districts	88
Residential districts by average lot size:	
1/8 acre or less (town houses)	85
¼ acre	75
1/3 acre	72
1/2 acre	70
1 acre	68
2 acres	65
Agricultural Lands	
Pasture, grassland, or range – continuous forage for grazing	61
Meadow – continuous grass, protected from grazing and generally mowed for hay	58
Brush – brush-weed-grass mixture with brush major element	48
Woods – grass combination (orchard or tree farm)	58
Woods	55
Farmsteads – buildings, lanes, driveways, and surrounding lots	74

3.2. Sinuosity

Sinuosity is measured from the plan form of the stream reach. The sinuosity of a stream is calculated by dividing the stream centerline distance by the straight-line valley length between two common points. Sinuosity should be assessed over a length that is 40 times the bankfull width (Rosgen 2014).

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[3] Representative CN selected for lands in good condition on HSG B.
[4] Reference land use for forested cover type
[5] Reference land use for scrub-shrub cover type
[6] Reference land use for herbaceous cover type

The rapid way to measure sinuosity is from recent orthoimagery if it is available.[7]

1. Download recent orthoimagery available for the site.
2. Determine the minimum length required using the bankfull width from the regional curve.
3. Trace out the path on the recent orthoimagery for at least the distance determined in Step 2.
4. Measure the straight-line valley distance between the beginning and the end of the traced stream path.
5. Calculate sinuosity by dividing the stream length by the valley length. This is the field value for the plan form measurement method in the Quantification Tool worksheet of the WSQT.

If recent orthoimagery is not available or the stream channel is not visible in the imagery, then sinuosity must be measured in the field. Field instructions are provided in Section 4.9 of this appendix.

4. Fieldwork Component

This chapter follows the rapid method form provided in Section 6. Details on each section of the rapid method form and entering the field data into the WSQT are provided in the following sections.

There is a shading key for the rapid method form indicating which cells of the workbook are intended to be filled out in the office versus the field, and which sections are for performing calculations. The calculation cells are blank and can be filled out on a printed rapid method form; however, in the workbook version, these cells will automatically calculate values from provided field data.

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

1. Fill out any desktop values on the rapid method form for each reach and print. This includes data in sections I and III of the rapid method form.
    a. Print the following for each reach: rapid method form, the BEHI/NBS field form, and two copies of the riparian vegetation field form.
2. Walk the reach. (Section II of the rapid method form)
    a. Determine assessment segment (segment roughly 20 times the bankfull width or two meander wavelengths) and representative riffle cross section locations.
    b. Measure difference between bankfull stage and water surface elevation at bankfull features throughout the reach.
    c. Count concentrated flow points.
3. Survey representative riffle.
    a. Collect bankfull dimensions for bankfull verification. (Section III of rapid method form)
    b. Determine stream type. (Section IV of the rapid method form)

[7] Recent orthoimagery for WY is available for download from http://geospatialhub.org/imagery

4. Stretch a tape along the centerline of the assessment segment. Start and end the assessment segment at the head of a riffle. (Sections V through VIII of the rapid method form)
    a. Record assessment segment length.
    b. Estimate the slope of the reach.
    c. Working from upstream to downstream, take measurements at every riffle and pool within the assessment segment.
    d. Identify 100 meters within assessment segment with highest number of pieces of large wood and count the number of pieces.
    e. Perform a BEHI/NBS assessment for all eroding banks and banks with the potential to erode within the assessment segment.
5. Assess riparian vegetation for the entire stream reach.
    a. Measure expected and observed riparian area width (Section V of the rapid method form) to calculate the riparian width ratio.
    b. Measure woody, herbaceous, and non-native plant cover in sample plots along the reach using the riparian vegetation field form.

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

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

4.1. Site information and Stratification

The Site Information and Performance Standard Stratification section consists of general site information and information necessary to determine what performance standards are applied in the WSQT for calculating index values of some measurement methods. All values in this section should be filled in prior to printing the form to complete the fieldwork component.

4.2. Reach Walk

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

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

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

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

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

3. Count concentrated flow points.

The number of concentrated flow points is a measurement method for the reach runoff parameter. The measurement method assesses the number of concentrated flow points caused by anthropogenic impacts that enter the project reach per 1,000 linear feet of stream. Anthropogenic causes of concentrated flow include agricultural drainage ditches, impervious surfaces, storm drains, land clearing, and others.

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

4.3. Bankfull Verification

Multiple parameters in the WSQT require bankfull dimensions. These include: floodplain connectivity, lateral stability, and bed form diversity. Prior to making field measurements for these parameters, the practitioner should identify and verify the bankfull stage and associated dimensions. Methods for identifying the bankfull stage and calculating the bankfull dimensions can be found in Rosgen (2014). Lines E, F, and G of Section III of the rapid method form should be populated with the bankfull area, width, and mean depth as calculated from regional curves before going out in the field.

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

These dimensions are compared to the bankfull regional curve data to verify bankfull indicators. The field data for the site should fall within the range of scatter of the regional curve in order for the site to be verified. If the field data are drastically different than the regional curve, the practitioner will need to determine if the wrong indicator was selected or if the regional curve represents a different hydro-physiographic region than the field site. More detail on bankfull verification is provided in Section 4.4 of the user manual.

4.4. Stream Classification

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

Selection of the representative riffle is critical; the criteria below can aid in the selection of a suitable riffle:

- Stable width and depth, no signs of bank erosion or headcutting. The bank height ratio is near 1.0.
- Cross sectional area plots within the range of scatter used to create the regional curve. More information is provided in the following paragraphs.
- The bankfull width/depth ratio is on the lower end of the range for the reach.
- Note: In a highly degraded reach, a stable riffle cross section may be used from an adjoining upstream or downstream reach. If a stable riffle is still not identified, the bankfull width and mean depth from the regional curve should be used.

Width Depth Ratio (WDR)

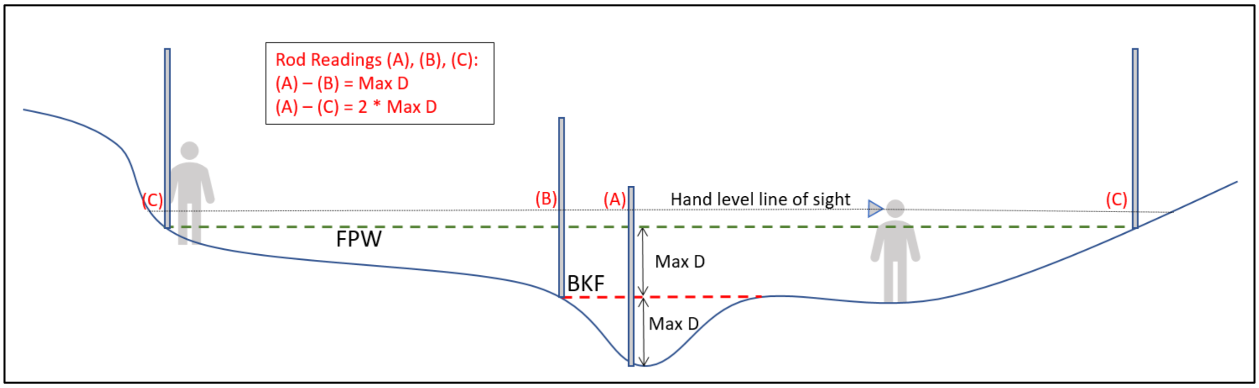
The WDR is calculated by dividing the bankfull width by the bankfull mean depth. These values were collected or calculated in Section III of the rapid method form.

Entrenchment Ratio (ER)

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

At the representative riffle cross section location, locate and flag the point along the cross section in the floodplain where the difference in stadia rod readings between the thalweg and that point is twice that of the difference measured in the previous step (refer to Figure B.2). Procedures for measuring and calculating the ER are provided on pages 5-15 through 5-21 of Rosgen (2014).

Figure B.2: Surveying Entrenchment Ratio



Reach Slope

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

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

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

Channel Material

Visually estimate the channel material for the reach. Measurements can be taken of representative particles if necessary. Table B.2 below provides the size class descriptions and particle size ranges for different channel materials.

Table B.2: Channel Material Size Classification Data

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

Use the data collected to determine the Rosgen stream type of the existing channel and enter the stream type into Section IV.G of the rapid method form.

4.5. Riffle Data (Floodplain Connectivity and Bed Form Diversity)

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

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

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

- Low bank height – Measure at every riffle
- Bankfull max depth – Measure at every riffle
- Bankfull width – Measure at every riffle
- Length of riffle (including the length of the run if present) – Measure at every riffle

- Bankfull mean depth – Measure at any riffle with aggradation features and/or the widest riffle in the assessment segment.
- Flood prone area width – Measure only if the valley width changes or if the BHR is greater than 1.8.
- Expected and observed riparian area width – Measure if the valley width, existing riparian vegetation width, or land uses in the expected riparian area changes.
- Slope – Measure across multiple riffles within a line of sight.

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

Bank Height Ratio (BHR)

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

To improve consistency and to reduce the potential for “cherry picking” riffles that create artificially high existing conditions or artificially low proposed conditions, the WSQT requires BHR to be measured at every riffle within the assessment segment. The BHR should be measured at the midpoint of the riffle, half way between the head of the riffle and the head of the run or pool if there isn’t a run. Using this data set, a weighted BHR is calculated as follows.

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

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

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

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

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

Entrenchment Ratio (ER)

Field methods for measuring the ER are covered in the Stream Classification section of this appendix. Unlike the BHR, the ER does not necessarily have to be measured at every riffle, as long as the valley width is fairly consistent. For valleys that have a variable width or for channels that have BHR's that range from 1.8 to 2.2, it is recommended that the ER be measured at all riffles and to calculate the weighted ER. Locations where valley width changes in the reach were noted during the desktop component of the rapid method.

The ER should be measured at the midpoint of the riffle, i.e. half way between the head of the riffle and the head of the run or pool if there isn't a run. Using this data set, a weighted ER is calculated as follows:

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

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

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

Aggradation Ratio

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

At candidate riffle features:

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

The maximum WDR ratio observed at a riffle within the assessment segment is then divided by a reference width to depth ratio (WDR) based on stream type (Table B.3).

Table B.3: Reference Bankfull WDR Values by Stream Type

Stream Type	Reference WDR
B	16
C	13
E	9

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

Percent Riffle

The percent riffle is the total length of riffles and runs within the assessment segment divided by the total assessment segment length. Riffle length is measured from the head (beginning) of the riffle downstream to the head of the pool. Run features are included within the riffle length.

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

4.6. Pool Data (Bed Form Diversity)

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

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

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

Pool Spacing Ratio

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

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

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

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

Pool Depth Ratio

The pool depth ratio is calculated by dividing the maximum bankfull pool depth by the mean bankfull riffle depth. The mean bankfull riffle depth is from a representative riffle cross section (Section III of the rapid method form) rather than measured at each riffle.

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

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

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

4.7. Large Woody Debris

For the rapid method, all pieces of LWD within a 100-meter segment are counted. 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. In a debris jam, the number of pieces of large wood within the dam should be counted. The 100-meter assessment reach should be within the same reach limits as the other assessment segments and should represent the length that will yield the highest score. The number of pieces should be tallied on line VII.A of the rapid method form.

4.8. Lateral Stability

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

Dominant BEHI/NBS

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

For banks throughout the assessment segment:

1. Determine whether the bank has the potential to erode or is actively eroding.
2. Determine the BEHI/NBS rating for each bank identified as actively eroding or that has a strong potential to erode. Record the rating in Section VIII.A of the rapid method form.
    a. A field form for BEHI/NBS measurements is included in Section 6 of this appendix to assist in determining BEHI/NBS ratings.
3. Measure and record the length of each bank assessed in Section VIII.A of the rapid method form. Bank lengths can be paced in the field or measured back in the office if a GPS unit is used to map assessed banks.

Using the data recorded in Section VIII.A of the rapid method form, the dominant BEHI/NBS rating can be determined and entered in to the WSQT for the field value of this measurement method. The dominant BEHI/NBS is the single category that describes the longest length of the banks assessed. For example, if an assessment segment evaluated 6 banks with scores and lengths shown in Table B.4 the dominant BEHI/NBS rating would be High/High (H/H).

Table B.4: Example BEHI/NBS Data

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

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

Percent Streambank Erosion

The percent streambank erosion is measured as the length of streambank that is actively eroding divided by the total length of bank (left and right) in the project reach. The total length of stream bank is not equal to the stream length. Instead, the total length of bank is the sum of the left and right bank lengths, or approximately twice the centerline stream length. The total assessment segment bank length can be paced, delineated with a GPS or estimated as twice the centerline stream length.

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

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

Using the data collected in Section VIII.A of the rapid method form, determine the length of eroding bank and enter it in Section VIII.C of the rapid method form. Enter the total bank length for the assessment segment, estimated as twice the centerline stream length, in Section VIII.D. of the rapid method form. The percent bank erosion is calculated by dividing the eroding bank length by total bank length in the assessment reach. This value is entered in Section VIII.E of the rapid method form and is automatically calculated in the workbook version of the rapid method form.

4.9. Sinuosity

Sinuosity is also covered in the desktop component, Section 3.3 of this appendix, as the rapid-based method to measure sinuosity is from recent orthoimagery if it is available. If recent orthoimagery is not available or the stream channel is not visible in the imagery, then sinuosity must be measured in the field.

Field measurements of sinuosity are best accomplished using a GPS unit to map the stream centerline along a length that is at least 40 times the bankfull width. The stream length and valley length can then be measured in the office using the GPS data and used to calculate sinuosity and enter the value in the WSQT. As this method does not require the lengths to be measured in the field, no space is provided for this alternative on the rapid method form.

4.10. Riparian Vegetation

Four measurement methods for the riparian vegetation parameter are included in the rapid method: Riparian Width Ratio, Woody Vegetation Cover, Herbaceous Vegetation Cover, and Non-Native Vegetation Cover. The riparian width ratio can be recorded on the rapid method form, while the cover measurements can be recorded on the riparian vegetation field form.

Riparian Width Ratio

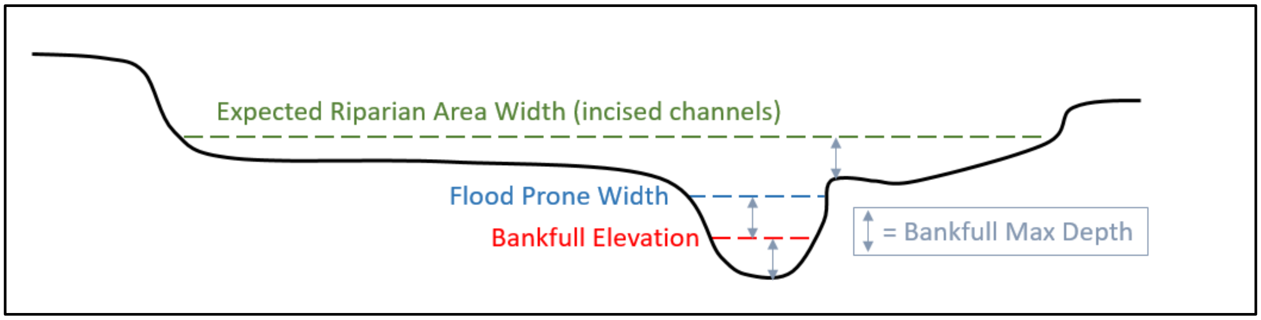
The riparian width ratio is the portion of the expected riparian area width that currently contains riparian vegetation and is free from utility-related, urban, or otherwise soil disturbing land uses and development.

This measurement compares the observed extent of the riparian area to an expected riparian area width. The expected width of the riparian area can be determined using the flood prone width or the meander width ratio. Each is described below. Measurements of both the observed and expected riparian area widths can be based on aerial imagery and verified in the field. Field measurements should be collected at the midpoint of riffles within the reach. If the valley width, riparian community, and extent of development is fairly consistent throughout the reach, the expected riparian area width field value can be estimated at the midpoint of the representative riffle. If valley width, impacts, restoration, ownership, protection level, or management vary throughout the reach then sufficient measurements should be taken to determine an average observed and expected riparian area width value for the reach.

<u>Determining Riparian Area Width using the Flood Prone Width</u>

In non-incised channels, the flood prone width can be used as a stand-in for riparian area width. Flood prone width is measured as the cross-section width at an elevation two times the bankfull max depth. This measurement is part of the entrenchment ratio measurement method described in section 4.4. However, in incised channels, the riparian area width should be measured as the cross-sectional width at an elevation equal to one bankfull max depth above the top of bank. For incised channels, this ensures that the riparian area is assessed, see Figure B.3.

Figure B.3. Riparian Area Width Example for Incised Channels



Determining Riparian Area Width using the Meander Width Ratio

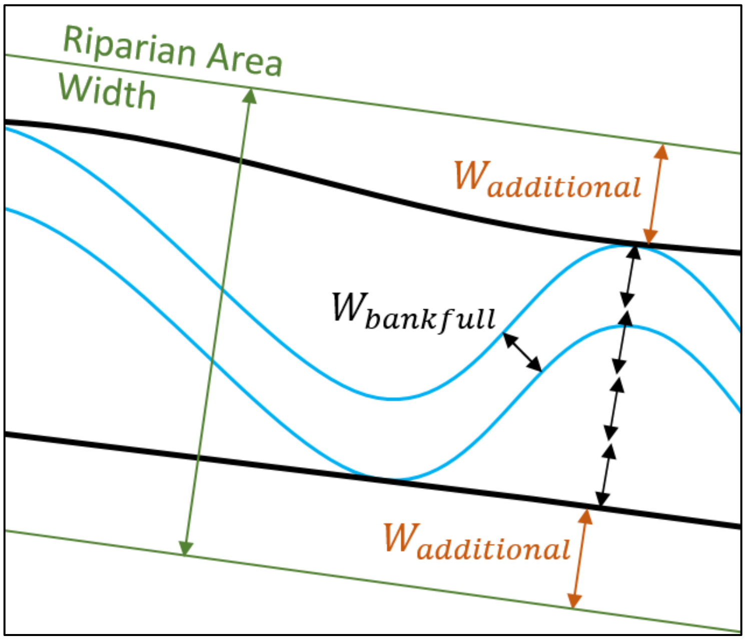
The meander width ratio (MWR) method may be preferred in wide, flat valleys where the flood prone width method will yield widths that exceed the 50-year flood mark. The MWR is the belt width of a meandering stream in its valley, divided by the bankfull width (Rosgen 2014). This option does not require the MWR to be measured; instead, a typical MWR is applied based on the valley type (Table B.5). To determine the riparian area width using this method, multiply the bankfull width of the channel by a selected MWR for the given valley type and add an additional width for outside meander bends.

$$Riparian\ Area\ Width = W_{Bankfull} * MWR + W_{additional}$$

Table B.5. How to Determine MWR using Valley Type (Adapted from Rosgen (2014) and Harman et al. (2012))

Valley Type	MWR	Additional Width $W_{additional}$
Alluvial Valley	4	25
Confined Alluvial	3	15
Colluvial	2	10

Figure B.4. Riparian area width example for alluvial valleys



On the rapid method form, the user should record the expected riparian area width, determined above, and the observed riparian area width. The observed riparian width is the area that contains riparian vegetation and is free from urban, utility-related, or intensive agricultural land uses and development. Riparian areas have one or both of the following characteristics: 1) distinctly different vegetation species than adjacent areas, and 2) species similar to adjacent areas but exhibiting more vigorous or robust growth forms (USFWS 2009). Riparian areas are usually transitional between wetland and upland and can be limited by stream incision, human development or detrimental land use. The riparian width ratio is the ratio of the observed riparian area width to the expected riparian area width, recorded and entered into the WSQT as a percentage.

$$Riparian\ Width\ Ratio = \frac{Observed\ Riparian\ Area\ Width}{Expected\ Riparian\ Area\ Width} * 100$$

Woody, Herbaceous, and Non-Native Vegetation Cover

The collection of data for the woody and herbaceous vegetation cover measurement methods rely on sampling plots. The methods are a combination of techniques borrowed from the Corps' Hydrogeomorphic (HGM) Approach (Hauer et al. 2002), USEPA National Rivers and Streams Assessment (USEPA 2007), Bureau of Land Management AIM (BLM 2016), and the Corps' Arid West Regional Supplement (USACE 2008). Instructions for setting up and monitoring sampling plots is described below, though greater detail can be found in section 4.6.c of the user manual.

Sampling Plot Procedures – Plot Locations

The minimum number of plots for a representative sample of each reach is determined using the sampling reach length as shown in Table B.6. Plots will be systematically distributed along each bank such that the minimum number of plots are evenly spaced along the known length of the representative reach.

Table B.6. Minimum Number of Sampling Plots Per Sampling Reach

Sampling Reach Length	Minimum Number of Plots per Riparian Area Side	Minimum number of plots for the reach
300-400 ft	3 plots	6 plots
400-600 ft	4 plots	8 plots
600-900 ft	6 plots	12 plots
900 -1300 ft	8 plots	16 plots

Random systematic riparian vegetation sampling (Elzinga et al. 1998) will begin at the top of the reach on the left-hand side (looking downstream) by selecting a random starting point within the first 20 feet. The lower left-hand corner of each plot will be placed at that location where it intersects the bankfull stage. The spacing interval (reach length/# of plots) may be measured using calibrated paces or a measuring tape. After the last plot is collected on the left side, cross the stream and place the first plot on the right side and move upstream collecting data on the remaining number of evenly spaced plots.

All vegetation sampling is conducted within the reach's expected riparian area width (see riparian width ratio discussion above), and in degraded systems may involve sampling dryland (upland) vegetation as part of the larger plots. In narrower or colluvial valleys, square plots may need to be reshaped (to a rectangular plot of the same area) to keep the plots within the expected riparian area width of the reach.

Sampling Plot Procedures – Measurements

Within each sampling plot for the reach, visually estimate the percent aerial cover of three different layers of vegetation (groundcover, understory and canopy) to determine vegetation structure and complexity (USEPA 2007, BLM 2016). Vegetative complexity is assessed across all vegetative types. Aerial cover is an estimate of the amount of shadow that would be cast by a particular category of vegetation if the sun were directly over the plot area.

The following procedure should be followed at each sampling plot location within the reach:

1. The lower left-hand corner of the first plot will be placed at that location where it intersects the edge of the bankfull stage. At each plot location:
    a. Confirm the bankfull location with geomorphic data for the reach;
    b. Identify the existing primary cover type and the proposed primary cover type (if applicable) as herbaceous, scrub-shrub, forested, mixed, or unknown;
    c. Note the geomorphic location as inside meander, outside meander, or straight/riffle.

2. The ground cover layer (< 0.5 m) is measured at every plot location as the percent aerial coverage within a 1-m by 1-m plot.
    a. Visually estimate herbaceous cover, woody cover, bare ground/litter, and embedded rock (> 15 cm diameter) in the ground cover layer.
    b. Record the dominant herbaceous and/or woody plant species present. Dominance is defined as the most common single species or each species with >30% cover within any layer.

3. The understory layer (0.5 to 5 m) is measured as the percent aerial coverage within a 5 m by 5 m nested plot.
    a. Pace out the bounds of the plot from the lower left starting point and mark corners with pin flags.
    b. Visually estimate herbaceous cover and woody cover in the understory layer.
    c. Record the dominant woody plant species within the understory.

4. The canopy layer (> 5 m) (USEPA 2007, BLM 2016) is measured as the percent aerial coverage within a 10-m by 10-m plot.
    a. Pace out the bounds of the plot from the lower left starting point and mark corners with pin flags.
    b. Visually estimate woody cover in the canopy layer.
    c. Record the dominant woody species within the canopy.

5. For measuring non-native plant cover:
    a. Identify the non-native species present in each vegetation layer when performing ground, understory, and canopy layer cover plots.
    b. Consider each layer independently and estimate the percent aerial cover of the plot provided by non-native vegetation (herbaceous and woody combined).

Below are a few notes on sampling procedure.

- Areal cover estimates within each layer cannot be greater than 100%.
- Areal estimates among different layers are independent of each other (absolute cover by layer), so the sum of the aerial cover for the three layers combined could add up to 300%.
- Total areal cover for the canopy and understory layers can be less than 100%, but percent cover for the ground cover layer must equal 100% coverage.
- Plants over-hanging the plot do not need to be rooted in the plot to be counted as areal cover.
- Standing dead shrubs/trees should be included in areal cover estimates.
- Both riparian and non-riparian species can be counted as cover.

<u>WSQT Vegetation Cover Measurement Methods</u>

The field value for woody vegetation cover used in the WSQT is the sum of percent woody plant cover from the canopy, understory, and ground cover layers.

$$Woody\ vegetation\ cover = Woody_{Ground\ Cover} + Woody_{Understory} + Woody_{Canopy}$$

The field value for herbaceous vegetation cover used in the WSQT is the sum of percent herbaceous plant cover from the understory and ground cover layers. Note: The value is stratified in the workbook by colluvial or alluvial valley type.

$$Herbaceous\ vegetation\ cover = Herbaceous_{Ground\ Cover} + Herbaceous_{Understory}$$

The field value for non-native plant cover used in the WSQT is the sum percent of non-native plant cover from the canopy, understory and ground cover layers.

$$Non-Native\ Plant\ Cover = Non-Native_{Ground\ Cover} + Non-Native_{Understory} + Non-Native_{Canopy}$$

5. References

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Date:
Investigators:

Wyoming Stream Quantification Tool
Rapid Method Form

I. Site Information and Stratification

Project Name:	
Reach ID:	
Drainage Area (sq. mi.):	
Stream Reach Length (ft):	
Ecoregion:	
Bioregion:	
Valley Type:	

Shading Key
Desktop Value
Field Value
Calculation

II. Reach Walk

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

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

III. Bankfull Verification and Representative Riffle Cross Section

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

Cross Section Measurements Depth measured from bankfull			
Station	Depth	Station	Depth

Date:
Investigators:

Wyoming Stream Quantification Tool
Rapid Method Form

IV. Stream Classification

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

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

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

B. Bank Height & Riffle Data

	R1	R2	R3	R4	R5	R6	R7	R8
Low Bank Height (ft)								
Bankfull Max Depth (ft)								
Bankfull Mean Depth (ft)								
Bankfull Width (ft)								
Flood Prone Area Width (ft)								
Riffle Length (ft) *Including Runs*								
Riparian Width Ratio (%)								
Bank Height Ratio (BHR) Low Bank H / Bankfull Max D								
BHR * Riffle Length (ft)								
Entrenchment Ratio (ER)								
ER * Riffle Length (ft)								

WDR BKF Width / BKF Mean Depth								
WDR_Riffle / WDR_Reach								

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

VI. Pool Data (Bed Form Diversity)

A. Pool Data

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

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

Date:
Investigators:

Wyoming Stream Quantification Tool
Rapid Method Form

VII. Large Woody Debris

A.	Number of Pieces per 100m	

VIII. Lateral Stability

A. Bank Data

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

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

IX. Riparian Width Ratio

A. Riparian Width Using Floodprone Width

Width (ft)	R1	R2	R3	R4	R5	R6	R7	R8
Observed Width (ft)								
Expected Width (ft)								
Ratio: Observed / Expected								
Average Ratio								

B. Riparian Width Using Meander Width Ratio

Legend:	**Check Valley Type**	Expted. MWR	Addtl. Width
Alluvial Valley		4	25
Confined Alluvial		3	15
Colluvial		2	10

	R1	R2	R3	R4	R5	R6	R7	R8
Observed Width (ft)								
Expected Width (ft) *Expted. MWR * BKF W + Addtl.*								
Ratio: Observed / Expected								
Average Ratio								

Date:
Investigators:

Wyoming Stream Quantification Tool
Riparian Vegetation Field Form

LEFT / RIGHT (Circle One)

Reach Length:	

# of Plots per side:		Plot spacing:		Random # (1-20 ft):	

	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	**Most Common**
Primary Cover Type (H, S, F, M, U)									
Geomorphic Position (IM, OM, S)									

	Ground Cover Layer (< 0.5m h;, 1 x 1m plot)	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	**Average**
a	Herbaceous Cover									
b	Woody Cover									
c	Bareground/litter/gravel									
d	Embedded rock									
	Total (a+b+c+d ≤ 100%)									-
	Non-native Cover									

	Understory Cover Layer (0.5m to 5m ht; 5 x 5m plot)	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	**Average**
a	Herbaceous Cover									
b	Woody Cover									
	Total (a+b ≤ 100%)									-
	Non-native Cover									

Canopy Cover Layer (> 5m ht; 10 x 10m plot)	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	**Average**
Tree Cover (0-100%)									
Non-native Cover									

H = Herbaceous, S= Scrub-shrub, F= Forested, M = Mixed, U = Unknown

IM = inside meander, OM = outside meander, S = straight

Date:
Investigators:

Wyoming Stream Quantification Tool
Riparian Vegetation Field Form

LEFT / RIGHT (Circle One)

Dominant Species (or >30%)	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot6	Plot 7	Plot 8	**Most Common**
Ground Layer									
Understory Layer									
Canopy Layer									

Herbaceous Vegetation Cover	
(Ground Layer + Understory Layer)	

Woody Vegetation Cover	
(Ground Layer+ Understory Layer + Canopy Layer)	

Non-native Plant Cover	
(Ground Layer+ Understory Layer + Canopy Layer)	

Date:
Investigators:

Wyoming Stream Quantification Tool
Riparian Vegetation Field Form

LEFT / RIGHT (Circle One)

Reach Length:			# of Plots per side:		Plot spacing:		Random # (1-20 ft):	

	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	**Most Common**
Primary Cover Type (H, S, F, M, U)									
Geomorphic Position (IM, OM, S)									

	Ground Cover Layer (< 0.5m h;, 1 x 1m plot)	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	**Average**
a	Herbaceous Cover									
b	Woody Cover									
c	Bareground/litter/gravel									
d	Embedded rock									
	Total (a+b+c+d ≤ 100%)									-
	Non-native Cover									

	Understory Cover Layer (0.5m to 5m ht; 5 x 5m plot)	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	**Average**
a	Herbaceous Cover									
b	Woody Cover									
	Total (a+b ≤ 100%)									-
	Non-native Cover									

Canopy Cover Layer (> 5m ht; 10 x 10m plot)	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	**Average**
Tree Cover (0-100%)									
Non-native Cover									

H = Herbaceous, S= Scrub-shrub, F= Forested, M = Mixed, U = Unknown

IM = inside meander, OM = outside meander, S = straight

Date:
Investigators:

Wyoming Stream Quantification Tool
Riparian Vegetation Field Form

LEFT / RIGHT (Circle One)

Dominant Species (or >30%)	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot6	Plot 7	Plot 8	**Most Common**
Ground Layer									
Understory Layer									
Canopy Layer									

Herbaceous Vegetation Cover	
(Ground Layer + Understory Layer)	

Woody Vegetation Cover	
(Ground Layer+ Understory Layer + Canopy Layer)	

Non-native Plant Cover	
(Ground Layer+ Understory Layer + Canopy Layer)	

Stream Name: **Stream Type** **Bed Material** **Date:**

Data Collected By:

Valley Type

			Bank Erosion Hazard Index								
Station ID	**Bank Length (Ft)**	**Study Bank Height (ft)**	**Bankfull Height (ft)**	**Root Depth (ft)**	**Root Density (%)**	**Bank Angle (degrees)**	**Surface Protection (%)**	**Bank Material Adjustment**	**Stratification Adjustment**	**BEHI Total/Category**	**NBS Ranking**

BEHI/NBS and associated measurements are described fully in
Rosgen, D.L. 2014. River Stability Field Guide, Second Edition. Wildlands Hydrology Books, Fort Collins, Colorado.

APPENDIX B

Frequently Asked Questions about the Stream Quantification Tool

Why does the Hydraulics functional category come before the Geomorphology category?

This is directed more towards the Stream Functions Pyramid Framework (SFPF) than the Stream QT. However, since the Stream QT is organized from the SFPF the question is relevant here. The question is often asked from the perspective of a practitioner changing hydraulics by changing the geometry of a channel. With this perspective, geomorphology should be listed below hydraulics. For example, one way to reduce the average bankfull velocity (hydraulics) is to increase the sinuosity of the channel (geomorphology), which will reduce the average slope and thereby the average velocity. To increase sinuosity, construction equipment is typically used to re-build the channel.

The SFPF shows that hydraulics is before geomorphology because the framework is built on the premise that natural processes are supporting and effecting functional change. The use of heavy equipment is not a natural process. If we remove heavy equipment from the process, then sinuosity would be increased by the quantity of water produced by the watershed (hydrology) flowing in the channel and on the floodplain (hydraulics) to move sediment and adjust the channel (geomorphology).

Are performance standards also design standards?

Performance standards are used in the Stream QT to determine the functional capacity of a given measurement method and then rolled up to the parameter level. The terms performance standards and functional capacity come from the Federal Mitigation Rule (see glossary for definitions). In the Stream QT, a performance standard is scaled from 0 to 1 with a 0 representing no function and a 1.0 representing 100% function of reference condition. A reference condition of 100% is an undisturbed, natural condition. Therefore, the performance standard quantifies the quality of each metric relative to an undisturbed condition.

This is related to but not exactly equal to a design standard. The performance standards inform the design process by quantifying not functioning through functioning conditions. This could be considered a design target for each parameter. However, there are many things to consider within the design process about what approaches and techniques will work best for the site. It is highly unlikely that a project could achieve a 1.0 for every parameter, even though that is what would yield a maximum score. To do this, the practitioner would have to restore the stream to essentially a pristine condition. The practitioner must use appropriate assessment and design methods to develop the design, and much of this is completed outside of the Stream QT.

In addition, the stratification process creates options for meeting performance standards. For example bed form diversity is stratified by stream type, and a meandering stream has different performance standards than a step-pool channel. Based on site constraints, goals, and more, the practitioner can choose one approach over the other and thereby the appropriate performance standard curve. The Stream QT does not dictate the design approach.

The Stream QT is a tool that can inform the design; however, the design includes many more parameters. For example, sediment transport is a major design element, but it is not explicitly in the Stream QT. Rather, the effects of sediment transport are assessed. If the design is degradational (vertical instability), it will show up in the floodplain connectivity and possibly the bedform diversity and lateral stability parameters. If the project is aggradational, it will show up in bedform diversity and lateral stability.

Why are performance standards established using an undisturbed reference condition rather than a best attainable condition?

This question is often asked by mitigation providers who recognize that it's typically not possible to return a degraded stream reach back into a pristine or undisturbed condition. The thought is that they won't get credit if they can't achieve a near-perfect score. First, it is important to remember that the Stream QT is primarily a delta tool. This means that the focus is on quantifying the difference between an existing condition and a restored condition (or an impacted condition on the debit side). A minimum quality must be achieved before the delta can be used to create mitigation credit or to even justify the project, but once the minimum quality is met, the score is the delta.

The focus on the delta should alleviate concerns about reaching a reference condition. A provider will not be punished for not returning a stream to a reference condition. However, practitioners that can return a heavily degraded stream to a highly functional stream will create the most lift (delta) and receive the most credit. Conversely, practitioners who take a "good" stream and make it "great," will quantify a smaller amount of lift and generate less credit. It's all about the lift, after a minimum stability threshold has been met.

Comparing all stream reaches to an undisturbed condition supports the logic of the SFPF. The SFPF logic is that lower-level functions (hydrology, hydraulics, and geomorphology) must be functioning in order to achieve functioning levels in physicochemical and biology. If these lower-level functions were scored against best attainable rather than undisturbed reference condition, the logic would break. A best attainable hydrology score may still not support aquatic biology needs. So, to keep the logic intact, it's critical to compare against natural/undisturbed reference condition.

Finally, by measuring every stream reach against its reference condition, the condition scores can be compared across sites. For example, a 0.65 (if measured through level 5) always means that the reach is functioning at 65% of a natural/unaltered system within the same environmental setting. If a 1.0 was set to be best attainable, the results would have little condition/quality meaning. A 0.65 would simply mean 65% of the best that the practitioner could do (best attainable). A 0.65 or even a 1.0 in this case may still not support a healthy aquatic ecosystem. In fact, it could be highly degraded.

How are performance standard curves created?

All performance standards are listed in the List of Metrics Microsoft Excel Workbook, which is provided on the _[Corps?]______ and Stream Mechanics web pages. The Workbook shows how each measurement method is stratified and the relationship between field values and index values. A field value is the score of a given measurement method before it has been converted into an index value. For example, the pool spacing ratio of 4.0 is a measurement method field value. This field value is converted into an index value from 0 to 1. For example, a field value of 4.0 yields an index value of 1.0 for C, Cb, and Bc stream types and a 0.7 for B and Ba stream types.

Performance standards are typically created from field data or existing manuscripts. The performance standard example above for pool spacing came from an extensive data set from the U.S. Forest Service and the WY Game and Fish Department. The workbook provides references to the source of the performance standards, but it does not explain how the team translated the field values (from the references) into index values. In broad terms, this was typically done collaboratively with a team of subject-matter experts. The process and logic explaining how field values were converted into index values will be explained in an upcoming report. Check the web pages listed above for updates.

Channel evolution is a function-based parameter in the SFPF, why is it not in the Stream QT?

Channel evolution is a function-based parameter listed in the SFPF. Two measurement methods are provided: the Simon Channel Evolution Model and the Rosgen Stream Type Succession Scenarios. Performance standards are provided for each measurement method.

An early version of the Stream QT did include channel evolution, first within the tool and then as an "add on" after a final score had been calculated. During the beta-testing phase, it was quickly determined that channel evolution should be removed from the tool because it predicts a future condition whereas the Stream QT is meant to score the condition at the time of the assessment. For mitigation and other purposes, adjusting a score based on what might happen in the future does not align well with the purpose of using the Stream QT to inform debits or credits.

This does not mean that channel evolution isn't important or that it should not be used as part of a stream restoration project. Channel evolution assessments are a great compliment to the Stream QT, especially during the site-selection process and the design phase. During site selection, the Stream QT can provide the existing condition score to determine its level of impairment. Channel evolution can then be used to explain how the condition may change over time. For example, the stream is trending towards a worse condition and restoration solutions are imperative. It can also be used to develop the restoration approach. In the example above, heavy equipment may be needed to alter the channel evolution. Conversely, channel evolution may show that the stream is trending towards stability and better function; perhaps only land use management changes are needed for further recovery. In both cases, channel evolution is used outside the Stream QT to make better-informed decisions about how to proceed with a project.

Why doesn't the Stream QT use more sophisticated methods for the roll-up scoring?

The Stream QT uses simple averaging to roll up scores to the functional category level. Measurement method scores are averaged to create parameter scores, which are then averaged to create a functional category score. For the overall reach condition score, the functional category scores are weighted and then summed. The original NC Stream QT weighted each category equally at 0.2; each of the five categories represents 20% of the total score. The category-level weighting supports the restoration potential concept, e.g., a project with a level 3 restoration potential is not required to monitor higher levels, but the score caps out at 0.6. Note, the WY Stream QT modified the functional category weights. See the roll-up scoring section for more information.

The Stream QT includes more parameters and measurement methods than will typically be assessed for any given project. When a measurement method is not assessed, it is simply removed from the tool, it does not count as a zero. The averaging and removal of measurement methods creates a simple and flexible architecture. States and regions using the tool can easily change the structure to meet their needs, as WY did. There is no coding or programming required.

There are other ways to create the score. Multivariate statistics, such as principal component analysis, could be used; however, a robust data set would be required for individual sites through biology (level 5). Once the weighting/scoring was established, the tool would lose its flexibility, i.e., it would be difficult to add and subtract metrics.

For now, it seems best to keep the architecture and scoring simple to allow for easy implementation. And, since it's primarily a delta tool, the method used to roll up the condition scores is less important than the difference between the overall existing and proposed condition.

What are "The Big Four" parameters and why are they important?

The Big Four parameters are floodplain connectivity, bedform diversity, riparian vegetation, and lateral stability. They are called the big four because they are arguably the four most important parameters to restore in any project across the country. (Note, stratification methods make this work, e.g., floodplain connectivity is stratified by alluvial versus colluvial systems. See the SFPF for more information). They are also parameters that can be directly manipulated by a restoration practitioner; they have a lot of control over the outcome as compared to biological metrics like macroinvertebrates or fish.

The Big Four are often used to establish the minimum condition score before functional lift can be counted. For example, floodplain connectivity, bedform diversity, and lateral stability should be functioning by the end of the monitoring period. Since it takes longer for newly established riparian vegetation to reach a functioning level, its score should be in the functioning-at-risk category. This is a general guide that can be adjusted on a case-by-case basis by the IRT.

The big four should be included in all stream assessments, but other metrics should be required that fit the region. For example, large woody debris should be included in forested regions and flow alteration should be included in regions where water withdrawal limits functional capacity. The regionalization process determines the final list of metrics beyond the Big Four and is provided in the user documents.

Can function-based parameters, measurement methods, and performance standards be added to the Stream QT?

Yes, new parameters, measurement methods, and/or performance standards can be added to the Stream QT by working with the IRT. The Stream QT is password protected, so users cannot make the changes themselves. Instead, users can propose changes to the IRT. If approved, they will update the Stream QT.

Are there data gaps within the Stream QT?

Yes, some parts of Wyoming have better data sets than others. The Stream QT is currently a perennial-stream centric tool. The most robust data sets for hydraulic and geomorphology parameters came from the Rocky Mountain Region. There are fewer data sets for grassland/prairie and desert regions, and ephemeral and intermittent flow regimes. Projects completed in these regions or flow regimes may need to assess reference condition streams and propose new performance standards.

APPENDIX C

Fish Community Assemblage Lists by Basin

Wyoming Game and Fish Department (WGFD). 2017. State Wildlife Action Plan. Wyoming Game and Fish Department, Habitat Program, Cheyenne, WY.

The following lists the fish community assemblages for three stream types in each Wyoming River Basin. The idea behind this list is that they could represent the expected community assemblage in a pristine or even best-attainable system. Assemblages are included for coldwater-high gradient systems, transitional systems (either transitional in slope or temperature), and warmwater-low gradient systems. The species lists are derived from the 2017 Draft State Wildlife Action Plan (WGFD 2017). These species were assigned to cold, transitional or warm assemblages based on professional judgment. Fish species that normally exist in lakes and only occasionally occur in flowing water (and do not depend on flowing water) in Wyoming (lentic species) are not included. Those species include: Black Crappie, Bluegill, Emerald Shiner, Freshwater Drum, Gizzard Shad, Green Sunfish, Goldfish, Golden Shiner, Golden Trout, Grass Carp, Grayling, Kokanee Salmon, Lake Trout, Largemouth Bass, Northern Pike, Pumpkinseed, Rock Bass, Smallmouth Bass, Spottail Shiner, Walleye, White Crappie, and Yellow Perch.

Table C.1. Wyoming stream fish species occurrence in major basins (SWAP 2017). "N" denotes native to the basin and "P" indicates present but not native to the basin. An "E" indicates a fish species that has been historically extirpated from the basin. Extirpated species should not be included in assembling the best attainable fish community assemblage.

Species	Tier	Cold	Transitional	Warm	Bear	Green	Platte	Snake/Salt	Yellowstone	NE Missouri
Bigmouth Shiner	III		X	X			N			
Black Bullhead				X			N		P	N
Bluehead Sucker	I		X	X	N	N		N		
Bonneville Cutthroat	II	X	X		N	P	P	P	P	
Brassy Minnow	III		X	X			N		N	N
Brook Stickleback			X	X			P		P	P
Brook Trout		X	X		P	P	P	P	P	P
Brown Trout			X		P	P	P	P	P	P
Burbot	II					P			N	
Central Stoneroller			X	X			N			N
Channel Catfish			X	X		P	N		N	N
Colorado Pikeminnow				X		E				
Colorado River Cutthroat	II	X				N	P		P	
Common Carp			X	X	P	P	P		P	P
Common Shiner	III		X	X			N			
Creek Chub			X	X		P	N		N	N
Fathead Minnow			X	X	P	P	N	P	N	N
Finescale Dace	II									N
Flannelmouth Sucker	I		X	X		N				
Flathead Chub	III		X	X			N		N	N
Goldeye	II			X			N		N	N
Greenback Cutthroat		X					E			
Hornyhead Chub	I		X				N			
Iowa Darter	II		X	X		P	N			N

Species	Tier	Cold	Transitional	Warm	Bear	Green	Platte	Snake/Salt	Yellowstone	NE Missouri
Johnny Darter			X	X			N		P	
Kendall Warm Springs Dace	I		X			N				
Lake Chub			X	X		P	N		N	N
Longnose Dace		X	X		N	P	N	N	N	N
Longnose Sucker		X	X	X		P	N		N	P
Mottled Sculpin		X	X		N	N		N	P	
Mountain Sucker		X	X		N	N	N	N	N	N
Mountain Whitefish			X		N	N		N	N	
Northern Leatherside Chub	II		X		N	P		N		
Northern Plains Killifish	II		X	X			N		P	P
Northern Pearl Dace	II			X						N
Orangethroat Darter	II			X			N			
Paiute Sculpin		X	X		N			N		
Plains Minnow	II			X			E		N	N
Plains Topminnow	II			X			N			N
Quillback				X			N			
Rainbow Trout		X	X		P	P	P	P	P	P
Redside Shiner			X	X	N	P		N		
Red Shiner			X	X			N			N
River Carpsucker				X			N		N	N
Roundtail chub	I		X	X		N				
Sand Shiner			X	X		P	N		N	N
Sauger	II		X	X			N		N	
Shorthead Redhorse				X			N		N	N
Shovelnose Sturgeon	II			X			E		N	
Speckled Dace			X	X	N	N		N		
Snake River Cutthroat [1]	II	X	X		P	P	P	N	P	P
Stonecat			X	X			N		N	N
Sturgeon Chub	II			X			E		N	
Suckermouth Minnow	II			X			N			
Utah Chub			X	X	N	P		N		
Utah Sucker			X	X	N	P		N		
Western Silvery Minnow	II			X					N	N
Western Mosquitofish				X			P			
White Sucker			X	X		P	N	P	N	N
Yellowstone Cutthroat [1]	II	X	X			P	P	N	N	

[1] Snake River Cutthroat trout and Yellowstone cutthroat trout are managed separately but considered variants of the same subspecies in Wyoming.

APPENDIX D

List of Metrics for the

Wyoming Stream Quantification Tool

Functional Category	Function-Based Parameters	Measurement Method/Units	Measurement Method Notes
Hydrology	Catchment Hydrology	Catchment Assessment	Poor (P), Fair (F) or Good (G) designations
	Reach Runoff	Curve Number	Characterizes land use. Area weighted curve number for land draining directly to project reach.
		Concentrated Flow Points	Number observed in the field per 1,000 linear feet of channel.
		Soil Compaction	Representative soil bulk density value for area draining directly to project reach measured in field.
	Flow Alteration	Baseflow Alteration - Q_Low, Measured / Q_Low, Expected	Observed over Expected August mean flow
Hydraulics	Floodplain Connectivity	Bank Height Ratio (ft/ft)	Low bank height / bankfull depth
		Entrenchment Ratio (ft/ft)	Floodprone area width / bankfull width
Geomorphology	Large Woody Debris	LWD Index (Dimensionless)	Index score
		# Pieces	
	Lateral Stability	Erosion Rate (ft/yr)	Lateral erosion rate from monitoring.
		Dominant BEHI/NBS	From BANCS model
		Percent Streambank Erosion (%)	Eroding bank length / total bank length
	Riparian Vegetation	Riparian Width Ratio	% floodprone area width or % MWR derived corridor width
		Woody Vegetation Cover	
		Herbaceous Vegetation Cover	
		Non-native Plant Cover	
		Hydrophytic Vegetation Cover	
		Stem Density	
		Greenline Stability Rating	
	Bed Material Characterization	Size Class Pebble Count Analyzer (p-value)	Determine whether the difference between the project reach a local reference reach is statistically significant
	Bed Form Diversity	Pool Spacing Ratio	P-P Spacing / Bankfull Width
		Pool Depth Ratio	Max Pool Depth / Mean Riffle Depth
Geomorphology	Bedform Diversity	Percent Riffle	Includes runs. Stream reach to be divided between pools (pools and glides) and riffles (riffles and runs).
		Aggradation Ratio	Maximum riffle WDR/ Expected WDR. Expected WDR based on stream type.
	Plan Form	Sinuosity	Channel length / valley length

Functional Category	Function-Based Parameters	Measurement Method/Units	Measurement Method Notes
Physicochemical	Temperature	Daily Maximum (ºC)	
		MWAT 7-day Average (ºC)	Mean weekly average temperature, calculated on a rolling 7-day basis.
	Nutrients	Chlorophyll (mg/m2)	
Biology	Macros	WSII	Observed over Expected WSII value.
		RIVPACS	Observed over expected RIVPACS value.
	Fish	Number Native Fish Species (% of expected)	
		SGCN Absent Score	
		Game Species Biomass (% Increase)	

Function-Based Parameters	Measurement Method/Units	Performance Standard Stratification		Not Functioning		Functioning-At-Risk		Functioning		Performance Standard Notes
		Type	Description	Min (index = 0)	Max (index ≤ 0.29)	Min (index ≥ 0.3)	Max (index ≤ 0.69)	Min (index ≥ 0.7)	Max (index = 1)	
Catchment Hydrology	Catchment Assessment			P1	P3	F1	F3	G1	G3	
Reach Runoff	Curve Number	Cover type	Forested	>71		71	61.2	61.1	<=44	TR-55 Pinyon-juniper values, good condition, BCD HSG
		Cover type	Scrub-Shrub	>=59.5	55.1	55	47.2	47	<=35	TR-55 Sage brush with grass understory values, good condition, BCD HSG
		Cover type	Herbaceous	>85		84.9	74.2	73.9	<=62.2	TR-55 Herbaceous values, good condition, BCD HSG
	Concentrated Flow Points			>3		3	1		0	
	Soil Compaction	Riparian Soil Texture	Sandy	> 1.94	1.81	1.80	1.60	1.59	< 1.45	Shaded values are derived from linear extrapolation of known values.
		Riparian Soil Texture	Silty	> 1.83	1.66	1.65	1.40	1.39	< 1.21	Shaded values are derived from linear extrapolation of known values.
		Riparian Soil Texture	Clayey	> 1.74	1.48	1.47	1.10	1.09	< 0.82	Shaded values are derived from linear extrapolation of known values.
Flow Alteration	Baseflow Alteration - Q_Low, Measured / Q_Low, Expected			<=0.6 >=2	0.68 1.78	0.69 1.77	0.82 1.43	0.83 1.42	>=1 <=1.1	
Floodplain Connectivity	Bank Height Ratio (ft/ft)			> 1.6	1.6	1.5	1.3	1.2	<= 1	
	Entrenchment Ratio (ft/ft)	Reference Stream Type	C or E	< 2.0		2.0	2.3	2.4	>= 5	
		Reference Stream Type	A, B or Bc	< 1.2		1.2	1.3	1.4	>= 2.2	
Large Woody Debris	LWD Index (Dimensionless)			< 37	198	201	299	300	>=595	
	# Pieces			<1	9	10	14	15	>=30	
Lateral Stability	Erosion Rate (ft/yr)			> 0.70	0.41	0.40	0.20	0.19	<= 0.10	
	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	
	Percent Streambank Erosion (%)			> 48	26	25	10	9	<=5	
Riparian Vegetation	Riparian Width Ratio	Valley Type	Unconfined Alluvial	<30		30	59	60	100	
		Valley Type	Confined Alluvial	<60		60	74	75	100	
		Valley Type	Colluvial/V-Shaped	<80		80	89	90	100	
	Woody Vegetation Cover	Ecoregion/Cover Type	Mountains/Forested, Scrub-Shrub	<2	35	36	65	66	>=90	
		Ecoregion/Cover Type	Basin/Forested, Scrub-Shrub	<1	30	31	60	61	>=90	Shaded values are derived from linear extrapolation of known values.
		Ecoregion/Cover Type	Plains/Forested, Scrub-Shrub	<3	25	26	45	46	>=69	Shaded values are derived from linear extrapolation of known values.
	Herbaceous Vegetation Cover	Cover Type	Herbaceous	<30		30	74	75	100	
		Cover Type/Valley Type	Forested, Scrub-Shrub/Colluvial	100	76	0 75	15 56	16	55	
		Cover Type/Valley Type	Forested, Scrub-Shrub/Alluvial	0 100	10 86	11 85	30 71	31	70	
	Non-native Plant Cover			>96	50	49	19	18	0	
	Hydrophytic Vegetation Cover			<1	24	25	69	70	100	
	Stem Density			0 >=50	10 45	11 44	19 41	20 40	25 - 36	
	Greenline Stability Rating			<2.7	4.9	5	6.9	7	9	
Bed Material Characterization	Size Class Pebble Count Analyzer (p-value)	Bed Material	Gravel or Cobble Bed	<= 0.01	0.05	0.06	0.1		> 0.1	
Bed Form Diversity	Pool Spacing Ratio	Reference Stream Type	C	>= 9.4 <= 3.0	8.4 3.2	8.3 3.3	7.1 3.6	7.0 3.7	4.0 - 6.0	Shaded values are derived from extrapolation of known values.
		Reference Stream Type	Cb	>= 7.6 <= 2.4	7.1 2.5	7.0 2.6	6.1 2.9	6.0 3.0	3.7 - 5.0	Shaded values are derived from extrapolation of known values.
		Reference Stream Type	B & Ba	>= 7.5 <= 0.1	6.1	6.0	4.1	4	<= 3	Shaded values are derived from extrapolation of known values.
		Reference Stream Type	Bc	> 9.2 <= 0.1	8.1	8.0	6.1	6	<= 4	Shaded values are derived from extrapolation of known values.
	Pool Depth Ratio			<= 1.10	1.19	1.20	2.09	2.10	>= 2.50	
	Percent Riffle	Slope	S < 3%	> 73 < 37	71 39	70 40	66 44	65 45	50 - 60	Shaded values are derived from extrapolation of known values.
		Slope	S >= 3%	> 88 < 57	85 60	84 61	81 65	80 66	70 - 76	Shaded values are derived from extrapolation of known values.
		Bioregion	Volcanic Mountains & Valleys	> 95 < 58	59	95 60	86 64	85 65	73 - 80	Shaded values are derived from extrapolation of known values.
	Aggradation Ratio	Reference Stream Type	C or E	>= 1.6	1.41	1.4	1.2	1.19	1	Only applicable to aggrading streams.

Function-Based Parameters	Measurement Method/Units	Performance Standard Stratification		Not Functioning		Functioning-At-Risk		Functioning		Performance Standard Notes
		Type	Description	Min (index = 0)	Max (index ≤ 0.29)	Min (index ≥ 0.3)	Max (index ≤ 0.69)	Min (index ≥ 0.7)	Max (index = 1)	
Plan Form	Sinuosity	Reference Stream Type	B	> 1.40		1.40 1.00	1.31 1.09	1.30 1.10	1.15 - 1.25	
		Reference Stream Type	C	>1.50 <1.15		1.50 1.15	1.41 1.19	1.40 1.20	1.25 - 1.35	
		Reference Stream Type	E	>2.00 <1.20		2.00 1.20	1.81 1.29	1.80 1.30	1.60 - 1.70	
Temperature	Daily Maximum (^oC)	Steam Temperature	Tier 1 (Cold)	>=24.6	22	21.9	18.4	18.3	<=15.6	
		Steam Temperature	Tier 2 (Cold-Cool)	>=27.7	24.2	24.1	19.4	19.3	<=15.7	
		Steam Temperature	Tier 3 (Cool)	>=32.4	28.2	28.1	22.4	22.3	<=17.8	
		Steam Temperature	Tier 4 (Cool-Warm)	>=34.6	30.4	30.3	24.6	24.5	<=20.2	
		Steam Temperature	Tier 5 (Warm)	>=35.4	32.3	32.2	28	27.9	<=24.6	
	MWAT 7-day Average (^oC)	Steam Temperature	Tier 1 (Cold)	>=19.3	18.2	18.1	16.7	16.6	<=15.5	
		Steam Temperature	Tier 2 (Cold-Cool)	>=21	19.5	19.4	17.3	17.2	<=15.6	
		Steam Temperature	Tier 3 (Cool)	>=24	22.2	22.1	19.7	19.6	<=17.8	
		Steam Temperature	Tier 4 (Cool-Warm)	>=28.8	26.3	26.2	22.8	22.7	<=20	
		Steam Temperature	Tier 5 (Warm)	>=31	29.2	29.1	26.6	26.5	<=24.5	
Nutrients	Chlorophyll (mg/m2)	Ecoregion	Mountains	>= 97	55	54	25	24	< 14	
		Ecoregion	Plains or Basin	>= 150	94	93	40	39	<= 20	
Macros	WSII	Bioregion	Volcanic Mountains & Valleys	< 0.35	0.53	0.54	0.79	0.80	> 0.98	
		Bioregion	Granitic Mountains	<= 0.44	0.57	0.58	0.81	0.82	> 0.98	
		Bioregion	Sedimentary Mountains	<= 0.23	0.46	0.47	0.76	0.77	1	
		Bioregion	Southern Rockies	<= 0.06	0.32	0.33	0.69	0.7	> 0.96	
		Bioregion	S. Foothills & Laramie Range	< 0.30	0.5	0.51	0.78	0.79	1	
		Bioregion	Bighorn Basin Foothills	<= 0.10	0.38	0.39	0.76	0.77	1	
		Bioregion	Black Hills	<= 0.20	0.43	0.44	0.74	0.75	> 0.98	
		Bioregion	High Valleys	<= 0.22	0.40	0.41	0.71	0.72	> 0.94	
		Bioregion	SE Plains	<= 0.19	0.39	0.4	0.71	0.72	> 0.95	
		Bioregion	NE Plains	<= 0.20	0.42	0.43	0.71	0.72	> 0.94	
		Bioregion	Wyoming Basin	<= 0.25	0.41	0.42	0.71	0.72	> 0.94	
	RIVPACS	Bioregion	Volcanic Mountains & Valleys	<=0.21	0.44	0.45	0.76	0.77	1.00	
		Bioregion	Granitic Mountains	< 0.50	0.63	0.64	0.83	0.84	> 0.98	
		Bioregion	Sedimentary Mountains	< 0.36	0.53	0.54	0.78	0.79	> 0.97	
		Bioregion	Southern Rockies	< 0.26	0.47	0.48	0.77	0.78	1.00	
		Bioregion	S. Foothills & Laramie Range	< 0.28	0.48	0.49	0.78	0.79	1.00	
		Bioregion	Bighorn Basin Foothills	< 0.48	0.64	0.65	0.87	0.88	1.00	
		Bioregion	Black Hills	< 0.36	0.54	0.55	0.80	0.81	1.00	
		Bioregion	High Valleys	< 0.38	0.55	0.56	0.80	0.81	> 0.98	
		Bioregion	SE Plains	< 0.33	0.50	0.51	0.76	0.77	> 0.95	
		Bioregion	NE Plains	< 0.35	0.52	0.53	0.78	0.79	> 0.98	
		Bioregion	Wyoming Basin	< 0.34	0.51	0.52	0.77	0.78	> 0.96	
Fish	Number Native Fish Species (% of expected)			>=58	75.6	75.7	99	99.4	100	Shaded values extrapolated from known values
	SGCN Absent Score			>=3			2		1	
	Game Species Biomass (% Increase)	Stream Productivity Rating	Blue Ribbon and non-trout game fish	<5		5	24.7	24.8	>=40	Shaded values extrapolated from known values
		Stream Productivity Rating	Red Ribbon	<10		10	49.4	49.5	>=80	Shaded values extrapolated from known values
		Stream Productivity Rating	Yellow Ribbon	<15		15	74.1	74.2	>=119	Shaded values extrapolated from known values
		Stream Productivity Rating	Green Ribbon	<20		20	98.0	99.0	>=159	Shaded values extrapolated from known values

Functional Category	Function-Based Parameters	Measurement Method	Reference
Hydrology	Catchment Hydrology	Catchment Assessment	Developed by Stream Mechanics & WY IRT.
	Reach Runoff	Curve Number	Natural Resources Conservation Service (NRCS), 1986. Urban Hydrology for Small Watersheds, Tech. Release 55, Washington, DC. http://www.wcc.nrcs.usda.gov/water /quality/common/tr55/tr55.pdf
		Concentrated Flow Points	Developed by Stream Mechanics.
		Soil Compaction	NRCS, 1999. Soil Quality Test Kit Guide. U.S. Department of Agriculture, NRCS, Soil Quality Institute. Washington D.C. http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044790.pdf NRCS, 2008. Soil Quality Indicators Bulk Density. U.S. Department of Agriculture NRCS. Washington D.C. http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_053256.pdf
	Flow Alteration	Q_Low, Measured / Q_Low, Expected	Lowham, H. W. 1988. Streamflows in Wyoming. Water-Resources Investigations Report 88-4045, U.S. Geological Survey, Cheyenne, WY. Miselis, D. V., T. A. Wesche and H. W. Lowham. 1999. Development of hydrologic models for estimating streamflow characteristics of Wyoming=s mountainous basins. Wyoming Water Resource Center Report, University of Wyoming, Laramie, WY. Lowham, H.W., et al. 2009. Estimating Streamflow from Concurrent Discharge Measurements. Wyoming Water Development Commission. Lander, Wyoming.
Hydraulics	Floodplain Connectivity	Bank Height Ratio	Rosgen, D.L., 2008. River Stability Field Guide. Wildland Hydrology, Fort Collins, CO.
		Entrenchment Ratio	
Geomorphology	Large Woody Debris	LWD Index	Davis, Jeffrey C., G. Wayne Minshall, Christopher T. Robinson, Peter Landres. Monitoring Wilderness Stream Ecosystems. USDA Forest Service General Technical Report RMRS-GTR-70 (January 2001). http://www.fs.fed.us/rm/pubs/rmrs_gtr070.pdf
	Lateral Stability	Erosion Rate (ft/yr)	Rosgen, D. 2014. River Stability Field Guide (Second Edition). Wildland Hydrology, Fort Collins, CO. Harrelson, C.C., C.L. Rawlins, and J.P. Potyondy, 1994. Stream Channel Reference Sites: An Illustrated Guide to Field Technique. General Technical Report RMRS-GTR-245. US Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.
		Dominant BEHI/NBS	Rosgen, D. 2014. River Stability Field Guide (Second Edition). Wildland Hydrology, Fort Collins, CO. Harman, W., R. Starr, M. Carter, K. Tweedy, M. Clemmons, K. Suggs, C. Miller. 2012, A Function-Based Framework for Stream Assessment and Restoration Projects. US Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Washington, DC EPA 843-K-12-006.
		Percent Streambank Erosion (%)	Developed by Stream Mechanics.
	Riparian Vegetation	Riparian Width Ratio	Developed by Stream Mechanics & WY IRT.
		Woody Vegetation Cover	U.S. Environmental Protection Agency. 2010. National Rivers and Streams Assessment 2008-2009 (data and metadata files). Available from U.S. EPA website: https://www.epa.gov/national-aquatic-resource-surveys/data-national-aquatic-resource-surveys Bureau of Land Management. 2016. AIM National Aquatic Monitoring Framework: Field Protocol for Wadeable Lotic Systems. Tech Ref 1735-2. U.S. Department of the Interior, Bureau of Land Management, National Operations Center, Denver, CO. Hauer F.R., B.J. Cook, M.C. Gilbert, E.J. Clairain, Jr., R. D. Smith. 2002. A Regional Guidebook for Applying the Hydrogeomorphic Approach to Assessing Wetland Functions of Riverine Floodplains in the Northern Rocky Mountains. U.S. Army Corps of Engineers Research Report ERDC/EL TR-02-21. U.S. Department of the Interior. 2011. Riparian area management: Multiple indicator monitoring (MIM) of stream channels and streamside vegetation. Technical Reference 1737-23. BLM/OC/ST-10/003+1737+REV. Bureau of Land Management, National Operations Center, Denver, CO. 155 pp
		Herbaceous Vegetation Cover	
		Non-native Plant Cover	
		Hydrophytic Vegetation Cover	
		Stem Density	Hauer F.R., B.J. Cook, M.C. Gilbert, E.J. Clairain, Jr., R. D. Smith. 2002. A Regional Guidebook for Applying the Hydrogeomorphic Approach to Assessing Wetland Functions of Riverine Floodplains in the Northern Rocky Mountains. U.S. Army Corps of Engineers Research Report ERDC/EL TR-02-21.

Functional Category	Function-Based Parameters	Measurement Method	Reference
Geomorphology	Riparian Vegetation	Greenline Stability Rating	Winward, Alma H. 2000. Monitoring the Vegetation Resources in Riparian Areas. Gen. Tech. Rep. RMRS-GTR-47. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. https://www.treesearch.fs.fed.us/pubs/5452 U.S. Department of the Interior. 2011. Riparian area management: Multiple indicator monitoring (MIM) of stream channels and streamside vegetation. Technical Reference 1737-23. BLM/OC/ST-10/003+1737+REV. Bureau of Land Management, National Operations Center, Denver, CO. 155 pp
	Bed Material Characterization	Size Class Pebble Count Analyzer (p-value)	Size Class Pebble Count Analyzer Developed by John Potyondy and Kristin Bunte. Available from: https://www.fs.fed.us/biology/nsaec/products-tools.html Bevenger, G.S. and R.M. King, 1995. A Pebble Count Procedure for Assessing Watershed Cumulative Effects. Research Paper RM-RP-319. US Department of Agriculture Forest Service Research Paper RM-RP-319. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.
	Bedform Diversity	Pool-Pool Spacing Ratio	Rosgen, D. 2014. River Stability Field Guide (Second Edition). Wildland Hydrology, Fort Collins, CO. Harman, W., R. Starr, M. Carter, K. Tweedy, M. Clemmons, K. Suggs, C. Miller. 2012, A Function-Based Framework for Stream Assessment and Restoration Projects. US Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Washington, DC EPA 843-K-12-006.
		Pool Depth Ratio	
		Percent Riffle	
		Bankfull WDR	
	Plan Form	Sinuosity	Rosgen, D. 2014. River Stability Field Guide (Second Edition). Wildland Hydrology, Fort Collins, CO. Lowther, Brian Christopher. Stream Channel Geomorphology Relationships for North Carolina Piedmont Reference Reaches. (Under the direction of Gregory Jennings).
Physicochemical	Temperature	Mean Daily Aug Temp (^oC)	Peterson, Caitlin M., Development of thermal tiers and regulatory criteria for Wyoming stream fishes., M.S., Wyoming University Department of Zoology and Physiology, May 2017.
		MWAT 7-day Average	
	Nutrients	Chlorophyll	Dataset and performance standard guidance provided by Wyoming Dept. of Environmental Quality Water Quality Division
Biology	Macroinvertebrates	RIVPAC	Hargett, Eric, 2012. Assessment of Aquatic Biological Condition Using WY RIVPACS with Comparisons to the Wyoming Stream Integrity Index (WSII). Wyoming Department of Environmental Quality, Water Quality Division, Cheyenne, Wyoming.
		WSII	Hargett, Eric, 2011. The Wyoming Stream Integrity Index (WSII) – Multimetric indices for Assessment of Wadeable Streams and Large Rivers in Wyoming. Wyoming Department of Environmental Quality, Water Quality Division, Cheyenne, Wyoming.
	Fish	Number Native Fish Species (% of expected)	Developed in consultation with Wyoming Game and Fish
		SGSN Absent Score	
		Game Species Biomass (% Increase)	