US Army Corps of Engineers
Omaha District

Wyoming Stream Quantification Tool User Manual (Version 1.0)

Wyoming Stream Quantification Tool

User Manual

Version 1.0

July 2018

Lead Agency:

U.S. Army Corps of Engineers, Omaha District, Wyoming Regulatory Office

Contractors:

Stream Mechanics

Ecosystem Planning and Restoration

Contributing Agencies:

U.S. Environmental Protection Agency

Wyoming Game and Fish Department

Wyoming Department of Environmental Quality

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Acknowledgements

The Wyoming Stream Quantification Tool (WSQT) is the collaborative result of agency representatives on the Wyoming Interagency Review Team, Stream Technical Workgroup; Stream Mechanics; and Ecosystem Planning and Restoration, which make up the Wyoming Stream Technical Team (WSTT). Contributing authors include:

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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.

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Preface

Document History:

- The Wyoming Stream Quantification Tool (WSQT), Beta Version was released for testing and public comment by the Omaha District Wyoming Regulatory Office in August 2017 for 120 days.
- The Wyoming Stream Technical Team gratefully received technical comments from 4 agencies and 6 practitioners. The WSTT reviewed and responded internally to technical comments received; and revised and updated the WSQT accordingly. Larger revisions included simplification of the tool; consideration of other methods, approaches, parameters and metrics; and the development of a separate scientific support document to document the scientific rationale of the WSQT.
- The WSQT v1.0 was released for program implementation in Wyoming in July 2018.

Updates and Revisions:

The WSQT can be updated and revised as necessary in the future. Field data supporting refinement of reference curves and evaluation of metrics are appreciated. Technical feedback may be submitted to the Wyoming Regulatory Office at 2232 Dell Range Boulevard, Suite 210, Cheyenne, Wyoming 82009, or contact the office at (307) 772-2300; an email address can be provided on request.

Disclaimer:

The Wyoming Stream Quantification Tool (WSQT) is intended for the evaluation of impact sites and compensatory mitigation projects and their departure from a reference standard. In part, or as a whole, the function-based parameters, metrics, and index values are not intended as engineering design criteria and do not serve as the basis of engineering design. The U.S. Army Corps of Engineers assumes no liability for engineering designs based on the WSQT. Designers should evaluate evidence from hydrologic and hydraulic monitoring, modeling, nearby stream morphology, existing stream conditions, sediment transport requirements, and site constraints to determine appropriate restoration design variables and specifications.

Availability:

A copy of the WSQT and associated documents can be obtained on the Regulatory In-lieu fee and Bank Information Tracking System (RIBITS) website under Assessment Tools for State: Wyoming:
https://ribits.usace.army.mil/ribits_apex/f?p=107:27:2897195223512::NO::P27_BUTTON_KEY:20

Or at the Stream Mechanics website:
https://stream-mechanics.com/stream-functions-pyramid-framework/

Or a copy may be requested from the USACE Wyoming Regulatory Office.

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

FF – Functional Feet

NRCS – Natural Resource Conservation Service

PCS – Proposed Condition Score

RH&H – Reach Hydrology and Hydraulics

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

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 (USACE 2018)

WSQT – Wyoming Stream Quantification Tool

WSTT – Wyoming Stream Technical Team

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 – Metric-based index values are averaged to characterize condition for each parameter, functional category, and overall project reach.

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

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

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

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

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

Functional Category – The organizational levels of the stream quantification tool: Reach Hydrology and Hydraulics, Geomorphology, Physicochemical, and Biology. Each category is defined by functional statement(s).

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

Function-Based Parameter – A structural measure or function (expressed as a rate) that describes and supports the functional statement of each functional category.

Index Values: Dimensionless values between 0.00 and 1.00 that express the relative condition of a metric field value compared with reference standards. These values are derived from reference curves for each metric. Index values are combined to create parameter, functional category, and overall reach condition scores.

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 – A specific tool, equation or assessment method used to inform a metric. Where a metric is informed by a single data collection method, metric and measurement method are used interchangeably (see Metric).

Metric – A specific tool, equation, measured values or assessment method used to qualify or quantify a function-based parameter. Some metrics can be derived from multiple measurement methods. Where a metric is informed by a single data collection method, metric and measurement method are used interchangeably (see Measurement Method).

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

Project Reach – A homogeneous stream reach within the project area, i.e., a stream segment with similar valley morphology, stream type (Rosgen 1996), stability condition, riparian vegetation type, and bed material composition. Multiple project reaches may exist in a project area where there are variations in stream physical characteristics and/or differences in project designs.

Reference Aquatic Resources – A set of aquatic resources that represent the full range of variability exhibited by a regional class of aquatic resources as a result of natural processes and anthropogenic disturbances. (see 33 CFR 332.2)

Reference Curves – A relationship between observable or measurable metric field values and dimensionless index values. These curves take on several shapes, including linear, polynomial, bell-shaped, and others, to best represent the degree of departure from a reference standard for a given field value. These curves are used to determine the index value for a given metric at a project site.

Reference Standard – The subset of reference aquatic resources that are least disturbed and exhibit the highest level of function. In the WSQT, this condition is considered functioning for the metric being assessed, and ranges from minimally impacted to unaltered or pristine condition.

Representative Sub-Reach – A length of stream within the Project Reach that is selected for field data collection of parameters and metrics. Sub-reach length and relative location within the Project Reach will vary by parameter.

Riparian Area Width – The percentage of the historic or expected riparian corridor that currently contains riparian vegetation and is free from utility-related, urban, or otherwise soil disturbing land uses. The riparian corridor corresponds to (Merritt et al. 2017):

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 plants known to be adapted to shallow water tables and fluvial disturbance, and
3) Hydrologic attributes -- the area of the valley bottom flooded at the stage of the 100-year recurrence interval flow.

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

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, metrics (measurement methods), and performance standards to assess the functional categories of the Stream Functions Pyramid (Harman et al. 2012).

Stream Restoration – The manipulation of the physical, chemical, or biological characteristics of a site with the goal of returning natural/historic functions to a former or degraded aquatic resource (33 CFR 332.2). The term is used in this document to represent stream compensatory mitigation methods including re-habilitation, re-establishment, and enhancement.

Threshold Values – Criteria used to develop the reference curves and index values for each metric. These criteria differentiate between three condition categories: functioning, functioning-at-risk, and not functioning and relate to the Performance Standards defined in Harman et al. (2012).

Wyoming Stream Quantification Tool (WSQT) – The WSQT is a spreadsheet-based calculator that scores the difference in stream condition and functional feet 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 (WSTT) – Group tasked with developing function-based parameters, measurement methods, and reference standards for the WSQT. Members include Paige Wolken with the Wyoming Regulatory Office in the Omaha District of the U.S. Army Corps of Engineers (USACE), Julia McCarthy with the U.S. Environmental Protection Agency (EPA) Region 8, Paul Dey with the Wyoming Game and Fish Department (WGFD), and Jeremy ZumBerge with the Wyoming Department of Environmental Quality (WDEQ).

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 in the context of aquatic functions (33 CFR 332.2). The regulations further emphasize 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).

The Wyoming Stream Quantification Tool (WSQT) is a spreadsheet-based calculator designed to inform permitting and compensatory mitigation decisions within the CWA 404 program. This Microsoft Excel Workbook has been developed to characterize stream ecosystem functions by evaluating a suite of indicators that represent structural or compositional condition attributes of a stream and its underlying processes. The WSQT is an application of the Stream Functions Pyramid Framework (SFPF; Harman et al. 2012) and uses function-based parameters and metrics to assess four functional categories: reach hydrology and hydraulics, geomorphology, physicochemical and biology. The WSQT integrates multiple indicators from these functional categories into a reach-based condition score that is used to calculate the change in condition before and after a project. This change in condition can be used to draw inferences about the amount of lift or loss of aquatic resource functions related to various impacts or restoration efforts. Restoration refers to the manipulation of the physical, chemical, or biological characteristics of a site with the goal of returning natural/historic functions to a former or degraded aquatic resource (33 CFR 332.2). The term is used in this document to represent compensatory mitigation methods including re-habilitation, re-establishment, and enhancement.

The main goal of the WSQT is to produce objective, verifiable and repeatable results by consolidating well-defined procedures for objective and quantitative measures of defined stream variables. The WSQT allows users to tailor their data collection to their particular site or project by selecting from 13 parameters and 28 metrics included in the WSQT. Metrics included in the WSQT represent parameters that are often impacted by authorized projects or affected (e.g. enhanced or restored) by mitigation actions undertaken by restoration providers. While there are metrics and parameters available in the WSQT that can be tailored to particular sites and projects, there is a base-set of metrics and parameters in the WSQT that should be assessed for all projects to provide consistency between impacts and compensatory mitigation and allow for more consistent accounting of functional change.

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, metrics and reference curves are unique to this region. Other stream quantification tools and user manuals are being developed for use in other states and regions.

This manual describes the WSQT and how to collect and analyze data used in the WSQT. The companion document, the Wyoming Stream Mitigation Procedure (WSMP) v2, provides policy direction for how and when the WSQT will be used for the CWA 404 regulatory program and how WSQT results are translated into credits and debits. The Scientific Support for the WSQT is a companion document that provides rationale for scoring in the WSQT and describes how measured stream conditions were converted into dimensionless index scores (WSTT, 2018).

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. The tool is a 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 3). On the impact side, functional loss can be estimated using the WSQT or the Debit Tool (Chapter 4). Estimates of functional lift (Chapter 3) and functional loss (Chapter 4) can inform CWA 404 permitting and mitigation decisions. This tool can also be used to develop monitoring plans and set performance standards. Application of the WSQT in the CWA 404 Regulatory Program in Wyoming is outlined in the Wyoming Stream Mitigation Procedure v2 (USACE 2018). The WSMP is the regulatory program policy document that provides instruction on how the WSQT will be implemented and used to fulfill documentation requirements for CWA 404 permit actions and mitigation. Users are encouraged to contact the Corps to obtain project-specific direction. Debit and credit determination methods are not included in this manual but are outlined in the WSMP. Not all portions of the WSQT will be applicable to all projects. Figure 1 can assist in navigating the user manual for specific project types.

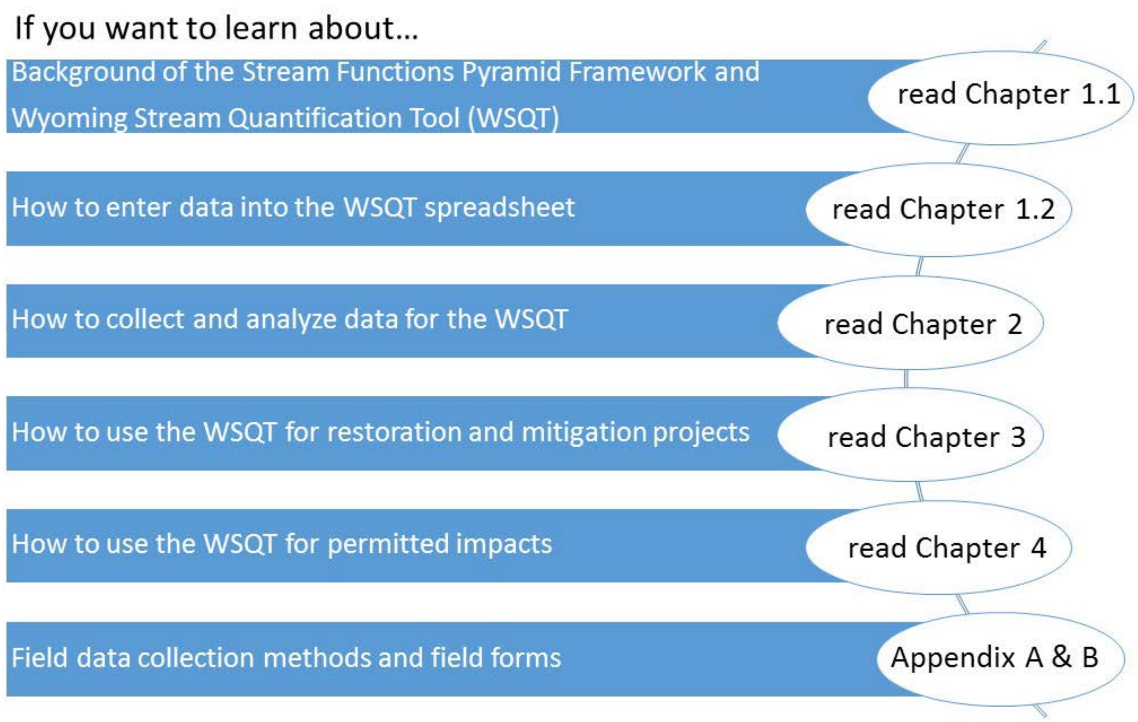


Figure 1. Manual Directory

In addition, the WSQT **can assist** in site selection, setting project specific function-based goals and objectives, understanding the restoration potential of a site, and developing a monitoring plan. The WSQT can help determine if a proposed site has the potential to be considered for a stream restoration or mitigation project. The catchment assessment and restoration potential process accompanying the WSQT (described in Chapter 3) can be used to help determine factors that limit the potential lift achieved by a stream restoration or mitigation project. This information can be used to develop project goals that match the restoration potential of a site. Quantifiable objectives and performance standards can be developed that link restoration activities to measurable changes in stream functional categories and function-based parameters assessed by the tool.

Key Considerations

The WSQT and supporting documentation have been developed to respond to specific regulatory and policy requirements and program needs. They have been tailored to meet the function-based approaches set forth in the 2008 Compensatory Mitigation for Losses to Aquatic Resources; Final Rule (2008 Rule), as well as the needs of the WGFD and WDEQ for their stream monitoring and restoration programs. As such, there are several considerations which are critical in understanding the applicability and limitations of the tool:

- The parameters and metrics in the tool were, in part, selected due to their sensitivity in responding to reach-scale changes associated with the types of activities commonly encountered in the CWA 404 program and commonly used in stream restoration. These parameters do not comprehensively characterize all structural measures or processes that occur within a stream.
- The WSQT is designed to assess the same metrics at a site over time, thus providing information on the degree to which the condition of the system changes following impacts or restoration activities. We refer to the WSQT as a delta tool for this reason – it is intended to detect change at a site over time. Unless the same parameters and metrics are used across all sites, it would not be appropriate to compare scores across sites.
- The WSQT itself does not score or quantify watershed condition. Watershed condition reflects the external elements that influence functions within a project reach. Watershed condition is an important consideration when selecting a project site, determining the restoration potential of a site, and informing project design. Chapter 3 of this manual describes how watershed condition is used to inform site selection and restoration potential.
- The WSQT is not a design tool. Many function-based parameters are critical to a successful restoration design but sit outside of the scope of the WSQT. For example, hydrologic characterization/modeling and sediment transport competency/capacity are critical to understanding what designs are appropriate, and limitations in site potential. These analyses are often necessary in project design. The WSQT does not include these approaches, but instead measures the hydraulic, geomorphological, and ecological responses or outcomes at a reach scale.

Chapter 1. Background and Introduction

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 an overview of the elements included in the WSQT Workbook.

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). 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 technical 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.

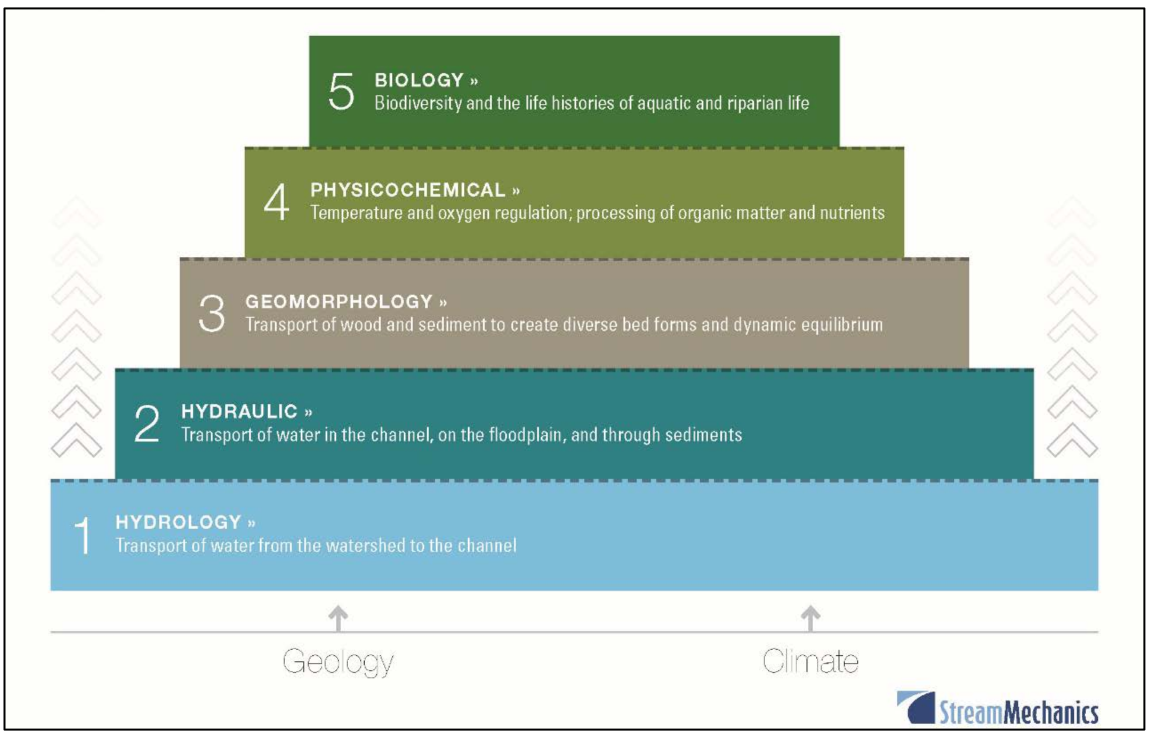


Figure 2. Stream Functions Pyramid (Image from Harman et al. 2012)

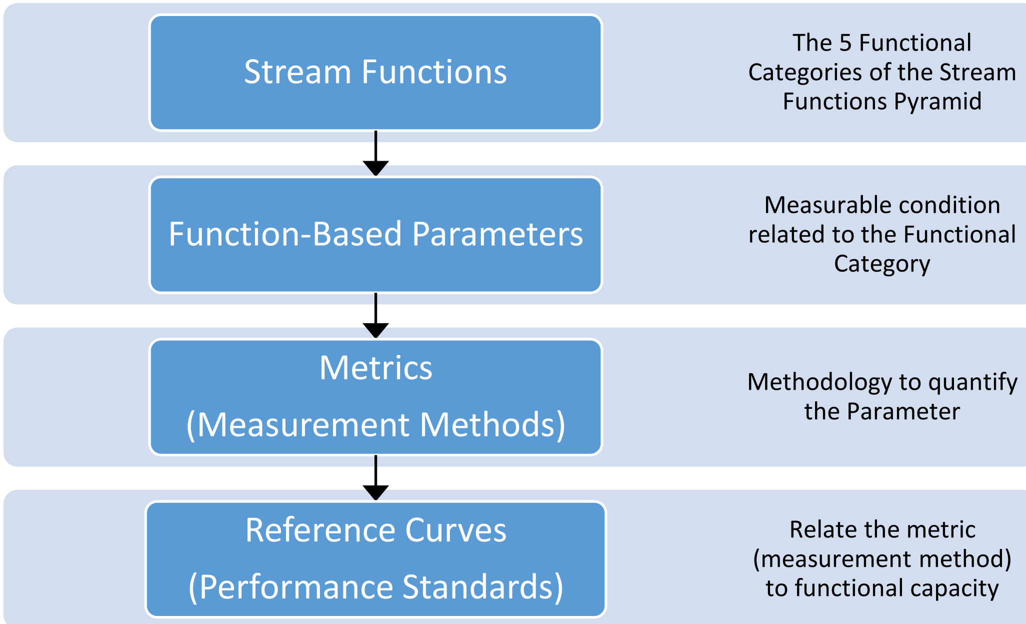


Figure 3. Stream Functions Pyramid Framework

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.

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 metrics (measurement methods) are specific tools, equations, and/or assessment methods that are used to characterize site condition and inform function-based parameter scores. Performance standards are measurable or observable end points of stream restoration.

The SFPF forms the basis of the Stream Quantification Tool concept. The Stream Quantification Tool concept was originally developed for stream restoration projects completed as part of a compensatory mitigation requirement under the CWA 404 regulatory program. However, the tool is also more broadly applicable to stream restoration projects, regardless of the purpose or funding driver. Reasons for developing the tool include:

1. Develop a 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. It is related to, and could be part of, a credit determination method, as defined by the 2008 Rule.
2. Link restoration activities to changes in stream functions and processes by primarily selecting function-based parameters and metrics 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.

1.2. Wyoming Stream Quantification Tool (WSQT)

Following the SFPF, function-based parameters and metrics were selected to quantify stream condition across the ecoregions and stream types found in Wyoming. Each metric is linked to reference curves that relate measured field values to a regional reference condition. In the WSQT, field values for a metric are assigned an index value (0.00 – 1.00) using the applicable reference curves. The numeric index value range was standardized across metrics by determining how field values relate to functional capacity, i.e., functioning, functioning-at-risk and non-functioning condition (Table 1). The reference curves in the WSQT are tied to specific benchmarks (thresholds) that represent the degree to which the aquatic resources are functioning and/or the degree to which condition departs from reference standard. Additional detail on function-based parameters and metrics, along with specific information on stratification and reference curve development is provided in the Scientific Support for the WSQT (WSTT, 2018).

Table 1. Functional Capacity Definitions Used to Define Threshold Values and Develop Reference Curves for the WSQT

Functional Capacity	Definition	Index Score Range
Functioning	A functioning score means that the metric 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 standard condition. The reference standard concept used here aligns with the definition laid out by Stoddard, et al. (2006) for a reference condition for biological integrity. A score of 1.00 does not represent the best attainable condition, but an unaltered or minimally impacted system. A score of 0.70 represents a system that is attaining a high level of functioning but may no longer be pristine.	0.70 to 1.00
Functioning-at-risk	A functioning-at-risk score means that the metric 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 metric, is between functioning and not functioning.	0.30 to 0.69
Not functioning	A not functioning score means that the metric is quantifying or describing one aspect of a function-based parameter in a way that **does not support** a healthy aquatic ecosystem. A score of 0.29 represents a condition that is impaired, and a score of 0.00 represents a condition that is indicative of no functional capacity.	0.00 to 0.29

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)
- Reference Curves (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 Reference Curves 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 project reach, the proposed project, and its effect on the stream within the project area. This worksheet is used for all projects. If the purpose of the proposed project is restoration, 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 thus multiple workbooks), the project information on this worksheet may be the same across workbooks except for a unique reach-specific description. Information on delineating project reaches is provided in Chapter 2.

For users proposing on-site compensatory mitigation for CWA 404, in most cases the impacted area and mitigation area will be located on different project reaches within the overall project area. The functional loss at the impacted reach should be evaluated consistent with the instructions provided in Chapter 4, and the functional lift at the mitigation reach should be evaluated within a separate workbook consistent with the instructions provided in Chapter 3. 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. The user would have another WSQT workbook to calculate the functional lift for the stream reach that is restored to offset those impacts. In the unique circumstance that the impacts and mitigation are proposed within the same project reach, 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. A drop-down menu is provided with the following options: Mitigation – Credits, Mitigation – Debits, TMDL, Grant, or Other.

Reach Description (all projects) – Space is provided to describe the project reach, including the individual reach ID, location (latitude/longitude) and reference stream type. If there are multiple project reaches within the project area, this section should include a description of the characteristics that separate it from other reaches. Guidance on identifying project reaches and selecting reference stream type is provided in Chapter 2.

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 area boundaries or easement, and any important features within the project site.

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 project reach functions and parameters should be explained.

Restoration Approach (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 (see example 1).

The connection between the restoration potential and the programmatic goals should be explained in the second text box. The restoration potential can be classified as partial or full restoration, and this is entered on the Catchment Assessment worksheet (see below).

The third text box in this section provides space to describe the function-based goals and objectives of the project. These goals should match the restoration potential. More information on restoration potential and developing goals and objectives is provided in Chapter 3.

Example 1: Restoration Approach

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 partial restoration, then the second text box would explain how bringing geomorphology to a functioning condition would create the necessary credits and identify whether there are constraints that may limit restoration of physicochemical and biological functions to a reference standard.

The goals of the project would match the restoration potential, e.g., target reference standard habitat condition and partial restoration of biological condition. Accompanying objectives could identify parameters to be restored and which metrics will be used to monitor restoration progress.

1.2.b. Catchment Assessment Worksheet

One of the goals of the WSQT is to link goals and objectives to the restoration potential of a site given its watershed context. The WSQT includes a catchment assessment to identify stressors that may limit and inform restoration potential of the project reach (Chapter 3).

The Catchment Assessment includes descriptions of processes and stressors that exist outside of the project reach that may limit functional lift. It also highlights factors necessary to consider or address during the project design to maximize the likelihood of a successful project. Most of the categories describe potential stressors upstream of the project reach since the contributing catchment has the most influence on the project reach's hydrology, water quality, and biological condition. 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 Section 2.3.

1.2.c. Quantification Tool Worksheet

The Quantification Tool worksheet is the main calculator of the WSQT where users enter data describing the existing and proposed conditions of the project reach and the resulting change in condition scores are calculated. The Quantification Tool worksheet contains three areas for data entry: Site Information and Reference 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 Reference Stratification

The Site Information and Reference Stratification section consists of general site information and classifications to determine which reference curves to apply in calculating index values for relevant metrics (Figure 4). Information on each input field and guidance on how to select values is provided in Chapter 2, Section 2.5.

Site Information and Reference Selection	
Project Name:	
Reach ID:	
Restoration Potential:	0
Existing Stream Type:	
Reference Stream Type:	0
Ecoregion:	
Bioregion:	
Drainage Area (sq.mi.):	
Proposed Bed Material:	
Project Reach Stream Length - Existing (ft):	
Project Reach Stream Length - Proposed (ft):	
Stream Slope (%):	
River Basin:	
Stream Temperature:	
Reference Vegetation Cover:	
Stream Productivity Rating:	
Valley Type:	

Figure 4. Site Information and Reference Stratification Input Fields

2. Existing and Proposed Condition Assessment Data Entry

Once the Site Information and Reference 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 metrics associated with each applicable function-based parameter (Figure 5). The function-based parameters and metrics are listed by functional category, starting with Reach Hydrology and Hydraulics. A user will rarely input data for all metrics or parameters within the tool. Guidance on parameter selection is provided in Chapter 2. Parameter selection guidance for CWA 404 projects is also provided in the WSMP v2 or through consultation with the Corps.

The Existing Condition Assessment field values are derived from data collection and analysis methods outlined in Chapter 2 and Appendix A. An existing condition score relies on baseline data collected from the project reach 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 and calculations, reports, and best available science. 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. More detail on how to determine and document reasonable values for proposed condition scores are described in the Functional Lift (Chapter 3) and Functional Loss (Chapter 4) chapters.

Functional Category	Function-Based Parameter	Metric	Field Value
Reach Hydrology & Hydraulics	Reach Runoff	Land Use Coefficient Concentrated Flow Points	
	Flow Alteration	Q_Low, Measured / Q_Low, Expected	
	Floodplain Connectivity	Bank Height Ratio Entrenchment Ratio	
Geomorphology	Large Woody Debris	LWD Index No. of LWD Pieces/ 100 meters	
	Lateral Migration	Greenline Stability Rating Dominant BEHI/NBS Percent Streambank Erosion (%) Percent Armoring (%)	
	Bed Material Characterization	Size Class Pebble Count Analyzer (p-value)	
	Bed Form Diversity	Pool Spacing Ratio Pool Depth Ratio Percent Riffle (%) Aggradation Ratio	
	Plan Form	Sinuosity	
	Riparian Vegetation	Riparian Width (%) Woody Vegetation Cover (%) Herbaceous Vegetation Cover (%) Percent Native Cover (%)	
Physicochemical	Temperature	MWAT (°C)	
	Nutrients	Chlorophyll (mg/m2)	
Biology	Macroinvertebrates	WSII RIVPACS	
	Fish	Native Fish Species Richness (% of Expected) SGCN Absent Score Game Species Biomass (% Change)	

Figure 5. Field Value Data Entry in the Condition Assessment Table

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 metric. Where more than one metric is used per parameter, these index values are averaged to calculate parameter scores. Similarly, multiple parameter scores within a functional category are averaged to calculate functional category scores. Functional category scores are weighted and summed to calculate overall condition scores that are used to calculate lift.

<u>Index Values</u> – The reference curves available for each metric are visible in the Reference Curves worksheet. Documentation on how reference curves were developed is provided in the

Scientific Support for the WSQT (WSTT, 2018). When a field value is entered for a metric on the Quantification Tool worksheet, these reference curves are used to calculate an index value between 0.00 and 1.00.

As a field value is entered in the Quantification Tool worksheet, the neighboring index value cell should automatically populate with an index value (Example 2a). If the index value cell returns FALSE instead of an index value, the Site Information and Reference Stratification section may be missing data (Example 2b).

Example 2: Populating Index Values in WSQT

(a) Index values automatically populate when field values are entered.

Metric	Field Value	Index Value
Pool Spacing Ratio	5	1.00
Pool Depth Ratio		
Percent Riffle (%)	60	1.00
Aggradation Ratio		

(b) If FALSE, check the Site Information and Reference Stratification section of the worksheet.

Metric	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 Reference Stratification for data entry errors and then check the stratification for the metric in the Reference Curve worksheet or the Scientific Support for the WSQT (WSTT, 2018) to see if there are reference curves applicable to the project. Incorrect information in the Site Information and Reference Stratification section may result in applying reference curves that are not suitable for the project.

<u>Roll Up Scoring</u> – Metric index values are averaged to calculate parameter scores; parameter scores are averaged to calculate category scores (Figure 6). The category scores are then weighted and summed to calculate overall condition scores (Table 2). The reach hydrology and hydraulics category provides 30% of the overall score, geomorphology provides 30%, and physicochemical and biology each provide 20% of the overall score. Additional discussion of and rationale for roll up scoring is provided in the Scientific Support for the WSQT (WSTT, 2018).

Table 2. Functional Category Weights

Functional Category	Weight
Reach Hydrology and Hydraulics	0.30
Geomorphology	0.30
Physicochemical	0.20
Biology	0.20

Functional Category	Function-Based Parameter	Parameter	Category	Category
Reach Hydrology & Hydraulics	Reach Runoff	0.54	0.56	Functioning At Risk
	Flow Alteration			
	Floodplain Connectivity	0.57		
Geomorphology	Large Woody Debris	0.16	0.54	Functioning At Risk
	Lateral Migration	0.54		
	Bed Material Characterization			
	Bed Form Diversity	1.00		
	Plan Form	0.30		
	Riparian Vegetation	0.72		
Physicochemical	Temperature	0.68	0.68	Functioning At Risk
	Nutrients			
Biology	Macroinvertebrates	0.54	0.69	Functioning At Risk
	Fish	0.85		

Figure 6. Roll Up Scoring Example

<u>Calculating Functional Feet</u> – The WSQT estimates the change in condition at an impact or mitigation site by calculating the difference between existing (pre-project) and proposed (post-project) overall condition. This change in condition is referred to as the delta. Existing and proposed condition scores are multiplied by stream length to calculate the change in functional feet. In a pristine stream with an existing condition score of 1.00, one functional foot would equal one linear foot of stream. When condition is less than 1.00, the functional feet are no longer equivalent to stream length.

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

1. $Existing\ FF = ECS * Existing\ Stream\ Length$
2. $Proposed\ FF = PCS * Proposed\ Stream\ Length$
3. $\Delta FF = Proposed\ FF - Existing\ FF$

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. The change in functional feet, or the delta, can serve as the basis for calculating debits and credits (WSMP v2).

Color Coding – When index values are populated in the Quantification Tool worksheet, cell colors will automatically change to communicate where on the reference curve the field value lies (Figure 6). Green represents field values and index scores that represent a functioning (reference standard) range of condition; yellow represents field values and index scores that represent a functioning-at-risk range of condition; and red represents field values and index scores that represent a non-functioning range of condition (see Table 1 for definitions). This color-coding is provided as a communication tool to illustrate the relative condition of the various metrics and parameters assessed. This is particularly useful when comparing existing to proposed condition, as well as reviewing the summary tables and monitoring data included in the tool (both are described in greater detail below). Note that color coding is not provided for the overall condition score, as the overall score is not representative of an overall site condition unless parameters within all categories are evaluated. For example, if only Reach Hydrology & Hydraulics and Geomorphology parameters are evaluated, the maximum overall score will be 0.60. A maximum overall score of 1.00 is possible only when parameters within all four categories are evaluated.

4. Functional Lift and Loss Summary Tables

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

Functional Change Summary – This summary (Figure 7) provides the overall scores from the Existing Condition Assessment and Proposed Condition Assessment sections, calculates the functional change occurring at the project site, and incorporates the length of the project to calculate the overall change in functional feet (FF).

The change in condition is the difference between the proposed condition score (PCS) and the existing condition score (ECS). The summary includes the existing and proposed stream lengths to calculate and communicate functional feet (FF). A functional foot is the product of a condition score and the stream length (see equations in Calculating Functional Feet above). Since the condition score is 1.00 or less, the functional feet of a stream reach are always less than or equal to the actual stream length.

The change in functional feet (ΔFF; equation 3 above) 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 (see WSMP v2). Functional change can also be expressed as the percent change in functional feet for a project reach:

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

FUNCTIONAL CHANGE SUMMARY	
Existing Condition Score (ECS)	0.54
Proposed Condition Score (PCS)	0.79
Change in Functional Condition (PCS - ECS)	0.25
Existing Stream Length (ft)	1000
Proposed Stream Length (ft)	1100
Change in Stream Length (ft)	100
Existing Functional Foot Score (FF)	540
Proposed Functional Foot Score (FF)	869
Proposed FF - Existing FF	329
Percent Change in FF (%)	61%

Figure 7. Functional Change Summary Table

Mitigation Summary –This summary also reports the change in functional feet (ΔFF). If this value is a positive number, then functional lift is occurring at the project site. A negative number represents a functional loss. For projects that include multiple reaches, the results from the Mitigation Summary for each reach can be summed to calculate the total change in functional feet for an entire project.

Functional Category Report Card – This summary presents a side-by-side comparison of the functional category scores based on the existing and proposed condition scores from the Condition Assessment sections of the worksheet (Figure 8). This table provides a general overview of the functional changes pre- and post-project to illustrate where the change in condition is anticipated. The color coding within this table is described in Section 1.2.c.3 above.

FUNCTIONAL CATEGORY REPORT CARD			
Functional Category	**ECS**	**PCS**	**Functional Change**
Reach Hydrology & Hydraulics	0.53	0.90	0.37
Geomorphology	0.37	0.82	0.45
Physicochemical	0.68	0.68	0.00
Biology	0.69	0.69	0.00

Figure 8. Functional Category Report Card

Function-Based Parameters Summary – This summary also provides a side-by-side comparison, but for individual parameter scores (Figure 9). 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 functional category score is low in the physicochemical category (Figure 8), the parameter summary table illustrates that only temperature was assessed, and no information was provided on nutrients (Figure 9). This table is a useful quality control check to see if a parameter was assessed for both the existing and proposed condition assessments. The color coding within this table is described in Section 1.2.c.3 above.

FUNCTION BASED PARAMETERS SUMMARY			
Functional Category	**Function-Based Parameters**	**Existing Parameter**	**Proposed Parameter**
Reach Hydrology & Hydraulics	Reach Runoff	0.62	0.85
	Flow Alteration		
	Floodplain Connectivity	0.44	0.94
Geomorphology	Large Woody Debris	0.16	0.32
	Lateral Migration	0.54	1.00
	Riparian Vegetation	0.31	0.77
	Bed Material		
	Bed Form Diversity	0.55	1.00
	Plan Form	0.30	1.00
Physicochemical	Temperature	0.68	0.68
	Nutrients		
Biology	Macros	0.54	0.54
	Fish	0.85	0.85

Figure 9. Function-Based Parameters Summary Table

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 (described in Chapter 4). It is recommended that a user coordinate with the Corps and refer to WSMP v2 for information on 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 includes space to enter the project name, reach ID, and existing and proposed stream lengths (measured in feet). The Impact Severity Tier section includes a drop-down menu to select the Impact Severity Tier (1-5) and space to describe the proposed project impacts. This worksheet also includes a table describing the impact severity tiers, an Existing Condition Scores (ECS) table, a PCS Calculator, and a Functional Loss Summary like 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 5, page 15). 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 date and year at the top of each condition assessment table, i.e. 1 for the first year post project. The methods for calculating index values and scoring are identical to the Quantification Tool worksheet (Section 1.2.c). The color coding within these tables is described in Section 1.2.c.3 above. If a value is entered for a metric in the Existing Condition Assessment, a field value should also be entered for the As-Built condition and for all monitoring events in the Monitoring Data worksheet. In cases where some values are monitored every year while others are monitored every other year, or more, it is recommended to fill in values from the previous monitoring event. For a final WSQT submittal with all monitoring events, the user can interpolate values between two monitoring events.

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. Reference Curves Worksheet

The Reference Curves worksheet contains the reference curves used to convert metric field values into index values in the Quantification Tool and Monitoring Data worksheets. *This worksheet is included for information purposes and does not require any data entry.*

The numeric index value range (0.00 to 1.00) was standardized across metrics by determining how field values relate to functional capacity, i.e., functioning, functioning-at-risk and non-functioning condition (Table 1, page 11). The reference curves in the WSQT are tied to specific benchmarks (thresholds) that represent the degree to which the aquatic resources are functioning and/or the degree to which condition departs from reference standard as described in Section 1.2. Additional detail on how reference curves were developed is provided in the Scientific Support for the WSQT (WSTT, 2018).

The Reference Curves worksheet is locked to protect the calculations used to convert field values to index values. The Corps will review the WSQT and reference curves and provide updates as new data and information become available. There may be instances where better data are available for a particular project, and the Corps can approve an exception to using the reference curves within the WSQT. More detail on this process is provided in Section 2.1. Examples of factors that may indicate the need for alternative reference curves include geographic or ecoregion differences, local reference reach data, or better modeling, depending on the parameter and metric.

On this worksheet, reference curves are organized into columns based on functional category and appear in the order they are listed on the Quantification Tool worksheet. One metric can have multiple curves depending on how the reference curves were stratified. For example, the woody vegetation cover metric is stratified by ecoregion. All reference curves and their stratification are described in the Scientific Support for the WSQT (WSTT, 2018).

Chapter 2. Data Collection and Analysis

This chapter provides instruction on how to collect and analyze data used in the WSQT. Individuals collecting and analyzing these data should have experience and expertise in botany, ecology, hydrology, and geomorphology. Interdisciplinary teams with a combination of these skillsets are beneficial to ensuring consistent and accurate data collection and analysis. Field trainings in the methods outlined herein, as well as the Stream Functions Pyramid Framework, are recommended to ensure that the methods are executed correctly and consistently.

This chapter includes a summary of field methods, as well as data analysis and methods for metrics that can be evaluated in the office. Detailed field procedures are provided in Appendix A. Few metrics are unique to the WSQT, and data collection procedures are often consistent with other instruction manuals or literature. Where appropriate, this chapter and Appendix A will reference the original methodology to provide technical explanations and make clear any differences in data collection or calculation methods needed for the WSQT.

The parameters and metrics in the tool were, in part, selected due to their sensitivity in responding to reach-scale changes associated with the types of activities commonly encountered in the CWA 404 program and commonly used in stream restoration. Where a 404 permit is required, users should coordinate early in the project planning stages with the Corps to determine the parameters, metrics, and field methods appropriate for a proposed project. A user would rarely, if ever, enter field values for all metrics included in the WSQT. The parameters included in the WSQT do not comprehensively characterize all structural measures or processes that occur within a stream. Additionally, the WSQT is designed to assess the same metrics at a site over time, providing information on the degree to which the condition of the system changes following impacts or restoration activities. We refer to the WSQT as a delta tool for this reason – it is intended to detect change at a site over time. Unless the same parameters and metrics are used across all sites, it would not be appropriate to compare scores across sites.

2.1. Parameter and Metric Selection

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). For CWA 404 projects, the Corps has discretion over which field methods, metrics, and parameters are used for a project; therefore, users should consult with the Corps prior to data collection on a particular project.

The WSQT includes 13 parameters and 28 metrics used to quantify the parameters. Some of these metrics can be calculated in the office, but the majority rely on field data collection. Some parameters have metrics that are redundant, while other metrics complement each other. For example, the Large Woody Debris Index (LWDI) and large wood piece count metrics are redundant and vary in their level of field effort. A user would select the LWDI or piece count, but not both. The bank height ratio and entrenchment ratio metrics are complimentary, as each of these metrics contributes differently to an overall understanding of floodplain connectivity; therefore, both should be used to inform the floodplain connectivity parameter. A parameter selection checklist is included in Appendix A and should accompany the WSQT for each project.

The following four parameters must always be evaluated: **floodplain connectivity, lateral migration, 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**.

The WSQT can be tailored to a specific project through the selection of additional parameters that tie to the project's landscape setting, 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. General recommendations for additional parameters is provided below:

- Flow alteration (RH&H) – this parameter should be evaluated where the user is proposing to modify baseflows within the project reach.
- Bed Material Characterization (Geomorphology) – this parameter is recommended for stream reaches with potentially altered sediment transport processes. For example, streams where there is potential to coarsen the bed if fine-grained sediment supply is reduced.
- Aggradation ratio (Geomorphology) – this bedform diversity metric is only recommended for projects where symptoms of aggradation are present, such as mid-channel or transverse bars.
- Large Woody Debris (Geomorphology) – this parameter is recommended where the upstream watershed or adjacent land area naturally supported trees large enough to produce LWD. This metric is not applicable to streams without forested catchments, riparian gallery forests, or other streams that naturally have a limited supply of LWD.
- Sinuosity (Geomorphology) – this parameter is recommended for most projects located in alluvial valleys with Rosgen C and E stream types. This parameter may also be used for B stream types to ensure that practitioners do not propose sinuosity values that are too high. This parameter may not be necessary for short project reaches and is not applicable in braided systems.
- Temperature and Nutrients (Physicochemical) – these parameters are recommended for projects with goals and objectives related to water quality improvements or projects where improvements to these parameters is anticipated based on restoration potential.
- Macroinvertebrates (Biology) – this parameter is recommended for projects with goals and objectives related to biological improvements or projects where improvements in biological condition is anticipated based on restoration potential.
- Fish (Biology) – this parameter is recommended for projects with goals and objectives related to fisheries improvements. Selection of this parameter requires coordination with a WGFD Regional Fish Biologist.

The WSQT has been primarily designed for application within perennial, wadeable, single-thread stream systems. Other stream situations, such as braided systems, large rivers, or streams with side channels should always be noted and considered in selecting applicable parameters and metrics. Data collection methods may vary in these reaches; discuss proposed sampling plan with the Corps prior to performing the field work. Additional discussion on the limitations of applying the WSQT in these systems is provided in the Scientific Support for the WSQT (WSTT, 2018). General recommendations for other stream situations include:

- Intermittent and Ephemeral Streams: relevant parameters may include riparian vegetation, reach runoff, flow alteration, floodplain connectivity, lateral migration, bed material characterization, and large woody debris. NOTE: Reference curves have been developed from reference sites within perennial systems, and thus these systems may not attain high index scores even if they are considered a reference standard for this stream type.
- Perennial and intermittent braided (D stream type) or anastomosing (DA stream type) systems: relevant parameters include riparian vegetation, reach runoff, flow alteration, bed material characterization, large woody debris, temperature, nutrients, macroinvertebrates, and fish. Note: Reference curves have not been developed specifically for these streams. Additionally, modifications to sampling methods would need to be made to accommodate these types of streams.
- Non-wadeable streams: Some metrics may be difficult to sample in these systems or may require alternate field methodologies. Sampling plans in these systems should be discussed with the Corps prior to data collection efforts.

The tool architecture is flexible and can accommodate additional parameters and metrics that are accompanied by specific and defensible reference curves and index values. Any additional parameters or metrics should be provided in a written proposal to the Corps for consideration.

<u>Important notes on parameter and metric selection:</u>

- The same metrics must be used in the existing condition and all subsequent condition assessments (e.g. proposed, as-built, and monitoring), otherwise the relative weighting between metrics and parameters changes and the overall condition scores are not comparable.
- For metrics that are not assessed (i.e., a field value is not entered), the metric is not included in the scoring. It is NOT counted as a zero.
- When the suite of parameters and metrics varies between project sites, the overall condition scores should not be compared or contrasted between sites. To evaluate multiple sites, the same suite of parameters and metrics would need to be collected at all sites. In cases where metrics are evaluated at different frequencies (ex. some metrics are monitored every year while others are monitored every other year) it is recommended to fill in missing values from the previous monitoring event. For a final WSQT submittal with all monitoring events, the user can interpolate values between monitoring events.
- The WSQT Quantification Tool worksheet will display a warning message above the Functional Category Report Card reading “WARNING: Data are not provided for Floodplain Connectivity, Lateral Migration, Riparian Vegetation, and Bed Form Diversity Parameters.” if data are not entered for these parameters.

2.2. Reach Delineation and Representative Sub-Reach Selection

Stream impact and restoration projects can vary substantially in length. For example, restoration projects may extend several miles and include main-stem channels and tributaries. Some headwater restoration projects can even encompass all or many stream channels within a catchment. Alternatively, projects such as culvert placement or removal, are short and may encompass less than a hundred linear feet, not several miles.

The WSQT is a tool that is informed by reach-based assessment methods, and each reach is input into the tool separately. A large project may be subdivided into multiple project 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 is a need to separate the project area into multiple reaches based on variations in stream physical characteristics and/or differences in project designs. Once project reaches are determined, the user selects a representative sub-reach to assess various metrics. The processes to define project reaches and representative sub-reaches are described in detail below in Sections 2.2.a and 2.2.b respectively.

2.2.a. Delineation of Project Reach(es)

The user should determine whether their project area encompasses a single homogeneous stream reach, or multiple potential 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 (see Example 3).

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 streams, i.e. tributaries vs. main stem, are considered separate project reaches.
- A tributary confluence should lead to a reach break. Where a tributary enters the main stem, the main stem should be split into two project reaches - one upstream and one downstream of the confluence. Small tributaries, as compared to the drainage area of the main stem channel, may not require a reach break.
- Reach breaks should occur where there are diversion dams or other flow modification structures on the stream, with one project reach upstream of the structure and one downstream of the structure.
- 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. For example, a culvert's footprint would be evaluated as a separate project reach from the reaches immediately up and downstream of the culvert.

- Multiple project 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.

2.2.b. Representative Sub-Reach Determination

Some parameters, such as armoring, sinuosity, and concentrated flow points, will be evaluated along the entire project reach, but other parameters will only be evaluated within a representative sub-reach (Figure 10). 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 small projects, the representative sub-reach may encompass the entire project reach. Guidelines are provided below for each functional category.

Reach Hydrology & Hydraulics Functional Category:

- Reach runoff parameters are evaluated within the entire project reach.
- The flow alteration parameter is evaluated at the downstream extent of the project reach.
- Floodplain connectivity is assessed within a representative 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 project reach should be assessed.

Geomorphology Functional Category:

- Riparian vegetation, lateral migration, bed material characterization, and bed form diversity are assessed within the same representative sub-reach as floodplain connectivity.
- Large woody debris (LWD) is assessed within a 328-foot (100 meter) segment located, whenever possible, within the same representative sub-reach as floodplain connectivity. If the project reach is less than 328 feet, the LWD assessment should extend proportionally into the adjacent upstream and downstream reaches to achieve the required stream length.
- Sinuosity is assessed over the entire project reach. Where the project reach is short, it may not be appropriate to evaluate this parameter.

Physicochemical and Biology Functional Categories:

- Sampling locations vary by metric, and are described in the metric sections in this Chapter and in Appendix A.

Note: Use of a reference or control reach is required for the bed material characterization and fish biomass parameters. The user may choose to assess other parameters at a reference reach in addition to the project reach, to compare the project site with an upstream or nearby condition. If a reference reach is located at the upstream end of the project reach, this would provide an upstream to downstream comparison in addition to showing changes pre- and post-project at a site.

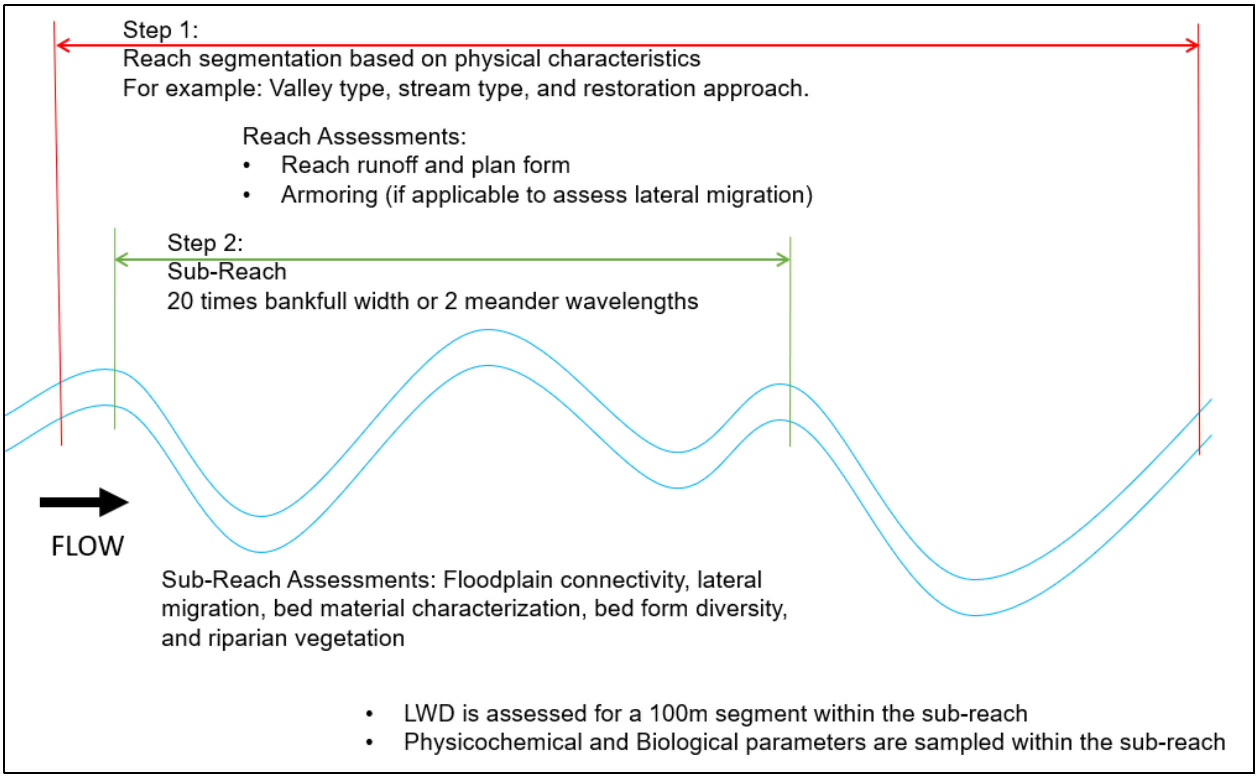
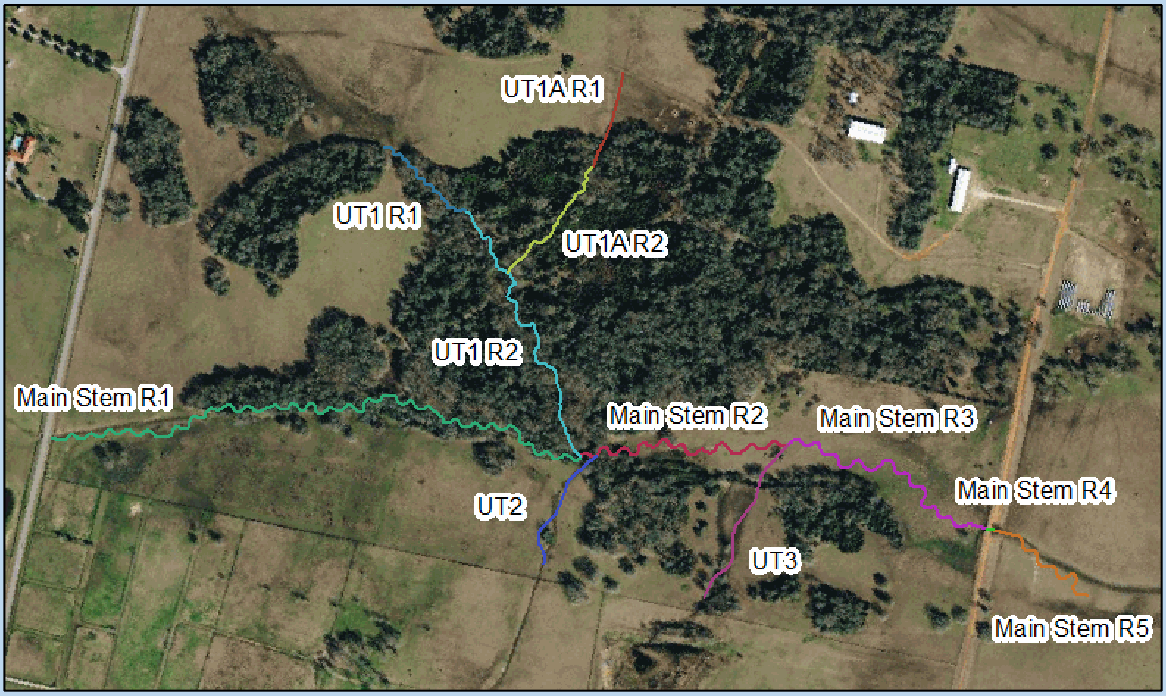


Figure 10. Reach and Sub-Reach Segmentation

Example 3: Project Reach Delineation

The following is an example showing how project reaches are identified based on physical observations. Work was proposed on five streams. The main-stem channel was delineated into five reaches, two unnamed tributaries (UT) were delineated into two reaches each, and the remaining two UTs as individual project reaches. This project has a total of 11 project reaches and an Excel Workbook would need to be completed for each.



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. Bed material is finer and bedform diversity is impaired below 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.

2.3. Catchment Assessment

The primary purpose of the catchment assessment is to assist in determining restoration potential for restoration and mitigation projects (described in Section 3.2.a.). The Catchment Assessment worksheet includes descriptions of processes and stressors that exist outside of the project reach and may limit functional lift. 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. Instructions for collecting data and describing each process and stressor are provided in this section. *The Catchment Assessment does not need to be completed for impact-only projects.*

2.3.a. Catchment Assessment Worksheet Categories

The catchment assessment relies on spatial data available from various online or local resources and site-specific 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 are three choices to describe the catchment condition for each category: Good, Fair and Poor. Data needed to assess each category are described below along with good, fair, and poor descriptions. Data needed to support each selection should be documented.

1. Impoundments

Impoundments are structures that can impede longitudinal (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 to achieve 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 longitudinal connectivity, impact catchment hydrology, alter sediment and temperature regimes, 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 then the catchment may be in good condition. An impoundment that has an adverse effect on the project area and fish passage may result in a poor condition score.

The location of dams or other impoundments within the catchment can be determined through field walks, recent aerial imagery, 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 be less 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 catchment hydrology and stream physicochemical and aquatic habitat conditions. Examples of flow alteration include diversion dams withdrawing water for irrigation or municipal/industrial use, water storage reservoirs, hydroelectric operations, large 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 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. Users should also consider the timing, magnitude, frequency, duration, and rate of change, as compared with the natural flow regime.

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. A fair or poor rating may also occur where more than one aspect of the flow regime is altered, or where a single aspect of the natural flow regime is substantially modified.

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 aerial imagery 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.

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 sources described in the flow alteration and 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

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

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 from inhabiting areas 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 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 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 Fisheries and Aquatic Life Uses

The Wyoming Department of Environmental Quality (WDEQ), Water Quality Division (WQD) maintains a list of impaired waterbodies (category 5 waters; the 303(d) list) as part of its biennial Integrated Report to EPA. Category 5 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 category 5 and placed in category 4A (TMDL completed but not yet restored) until additional monitoring shows water quality standards are achieved. It is therefore important to check the State's most recent Integrated Report for both category 4A and category 5 (303(d) listed) waters in the catchment. Most stream restoration and compensatory mitigation 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. 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. This category addresses large scale land uses common to Wyoming that are often independent from urbanization. For example, roads or other infrastructure associated with energy development that is adjacent to or crossing a project reach is a design constraint that may limit the 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. Existing or planned development with 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 aerial imagery and/or spatial data. Spatial 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 data from this assessment includes mining density, road density, and road-stream crossing density.

8. WYPDES Permits

The Wyoming Pollutant Discharge Elimination System (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 (e.g. dissolved solids, conductivity, oil and grease), thus discharges may limit full restoration potential. A catchment in good condition would have no major and few minor 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. WYPDES stormwater and temporary discharge permits are excluded from consideration for this parameter. The WY DEQ hosts maps of the minor and major WYPDES permitted facilities.

9. 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

[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

anthropogenic disturbance. Rivers throughout the Medicine Bow and Big Horn Mountains, and the upper Wind River and Green River basins all had periods of tie drives. A catchment in which many of the streams experienced tie drives may today still be degraded, especially for channel complexity and large woody debris metrics.

10. 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 extending across the majority (e.g., more than 2/3) of the 100-year floodplain, and riparian corridors that are over 80% contiguous along the contributing catchment stream length. Catchments in poor condition will have limited natural plant communities (e.g., extending across less than 1/3 of the 100-year floodplain), and/or gaps in the riparian corridor that exceed 30% or more of the contributing catchment stream length. These numeric examples are approximate and based on best professional judgment of the Wyoming Stream Technical Team and select reviewers.

The 100-year floodplain can be estimated using available spatial data or Federal Emergency Management Agency delineated floodplains (Note: floodplain maps may not be reflective of the historic floodplain in urban or developed areas). The prevalence of riparian vegetation on streams draining to the project reach can be determined using recent aerial imagery 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, road density within the riparian zone, natural cover within the hydrologically active zone, and high intensity land cover in the riparian zone.

11. Sediment Supply

The sediment supply entering a restoration reach plays an important role in determining restoration potential. Unnaturally high sediment loads from upstream bank erosion, upland 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 addresses human-altered sediment regimes; systems with naturally high sediment supplies would not score poorly unless the natural sediment transport processes were altered.

Users should review recent aerial imagery of the catchment and walk as much of the upstream channel as possible looking for evidence of high sediment loads, including extensive bank erosion, mid-channel bars, lateral bars, sediment fans at mouths of tributaries and other evidence of excess human sources of sediment (see Example 4). If there are multiple lines of evidence of excess sediment then there is a high sediment supply – if this is unnatural, the catchment condition is poor. If there are only a few small sources of sediment or sediment sources are naturally occurring, then the catchment condition is good.

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

There are also tools available to estimate the sediment load from surrounding land use, including the Spreadsheet Tool for Estimating Pollutant Loads (STEPL v4.1; Tetra Tech, Inc. 2011) or the Watershed Assessment of River Stability and Sediment Supply (WARSSS; Rosgen, 2006). WARSSS is an intensive level of effort that is not necessary for this catchment assessment but could be used here if WARSSS was applied for other reasons in the project.

12. 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.

Example 4: Indicators of Human-Altered Sediment Regimes

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

2.5. Data Collection for Site Information and Reference Stratification

The WSQT quantifies functional lift and using reference curves to translate field values into index scores. For some metrics, these curves are stratified by physical stream characteristics like stream type, temperature, ecoregion, etc. The Site Information and Reference Stratification section consists of general site information and classifications to determine which reference curves are used to calculate index values for relevant metrics. Information on each and guidance on how to select values is described below. While it may not necessary to complete all fields (depending on parameter selection), some metrics will not be scored or may be scored incorrectly if 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 index values for that variable are not yet available for Wyoming. Additional information on how reference curves are stratified is included in the Scientific Support for the WSQT (WSTT, 2018).

<u>Project Name</u> – Enter the name of the project.

<u>Reach ID</u> – Each project reach within a project area should be assigned a unique identifier (see Section 2.2 for guidance on delineating project reaches).

<u>Restoration Potential</u> (restoration and mitigation projects only) – Restoration potential should be determined using the stepwise process described in Section 3.2.a. This cell is automatically populated by the restoration potential selected by the user on the Catchment Assessment worksheet.

Stream Type – The WSQT relies on the Rosgen Stream Type (Rosgen 1996) to stratify reference curves for some metrics, including entrenchment ratio, pool spacing ratio, aggradation ratio, and sinuosity. 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 and reference stream types must be determined and entered in the WSQT.

Existing Stream Type – The existing stream type is determined through a field survey of the project reach. Guidance on how to collect field data needed to determine the Rosgen Stream Type is provided in Appendix A (WDEQ/DWQ 2018). For mitigation and restoration projects, the existing stream type is not used to determine index values or scores but is provided for communication and to inform channel evolution scenarios (Cluer and Thorne 2013, Rosgen 2006).

Reference Stream Type – Reference stream type is the stream type that should occur in a given landscape setting given the hydrogeomorphic processes occurring at the watershed and reach scales. Channel evolution scenarios should be used to inform the reference stream type in the WSQT, and this information can be further supported with information from the design process, where available (see Example 5). The Rosgen Channel Succession Scenarios (Rosgen 2006) or other stream evolution models can be used as a guide for determining the reference stream type. This cell is automatically populated by the reference stream type selected by the user on the Project Assessment worksheet. Space is provided on the Project Assessment worksheet to describe the rationale used to select the reference stream type.

Example 5: Reference Stream Type Identification

Existing stream type: Gc

This stream type will often evolve into an F and then a C stream type (Table 3). If the reach is in a wide alluvial valley, the reference stream type would likely be a C, E, or DA. These are all common in wide, low gradient, alluvial valleys.

However, it may sometimes evolve into a Bc stream type if the forces resisting lateral migration are greater than the driving forces of water and sediment discharge.

Historic, geomorphic, and even stratigraphic evidence and research may be needed to determine reference stream type. For example, DA (stream/wetland) complexes were historically common in alluvial valleys with low energy and sediment supply while alluvial valleys with gravel/cobble bed streams and ample sediment supply were likely single-thread C or E stream types. It will require experience and expertise from a multi-disciplinary team to determine the reference stream type.

Information from the design process (e.g., fluvial landscape, historic channel conditions, watershed hydrology, sediment transport and/or anthropogenic constraints) can also be used to inform reference stream type. The design process is beyond the scope of this tool, 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), Roni and Beechie (2012), and Yochum (2018).

For impact projects (debits), the existing stream type is used to select the appropriate reference curve, so the existing stream type should be entered for both existing and reference stream type. Note: if the existing stream type is degraded (e.g., a G or F), a different reference stream type will need to be selected because reference curves are not currently available for degraded stream types.

Ecoregion – The WSQT uses the project's ecoregion to stratify reference curves for riparian vegetation and nutrients parameters. 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 is referred to as the 'Basins' ecoregion in the WSQT. The Great Plains ecoregion is referred to as the 'Plains'; and the Northwestern Forested Mountains is referred to as 'Mountains' in the WSQT.

Bioregion – Bioregions are defined by WDEQ to classify groups of streams with similar physical, chemical, and biological traits (Figure 11; Hargett and Zumberge 2013). Bioregions are delineated using a hybrid classification approach that uses integrated cluster analyses of reference site macroinvertebrate data, GIS, nonmetric multidimensional scaling (NMS), and best professional judgment. The boundaries of the eleven bioregions were constructed using USEPA Level IV Ecoregions, elevation contours, watershed boundaries, bedrock geology, and stream origins 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 reference curves for percent riffle and both macroinvertebrate metrics.

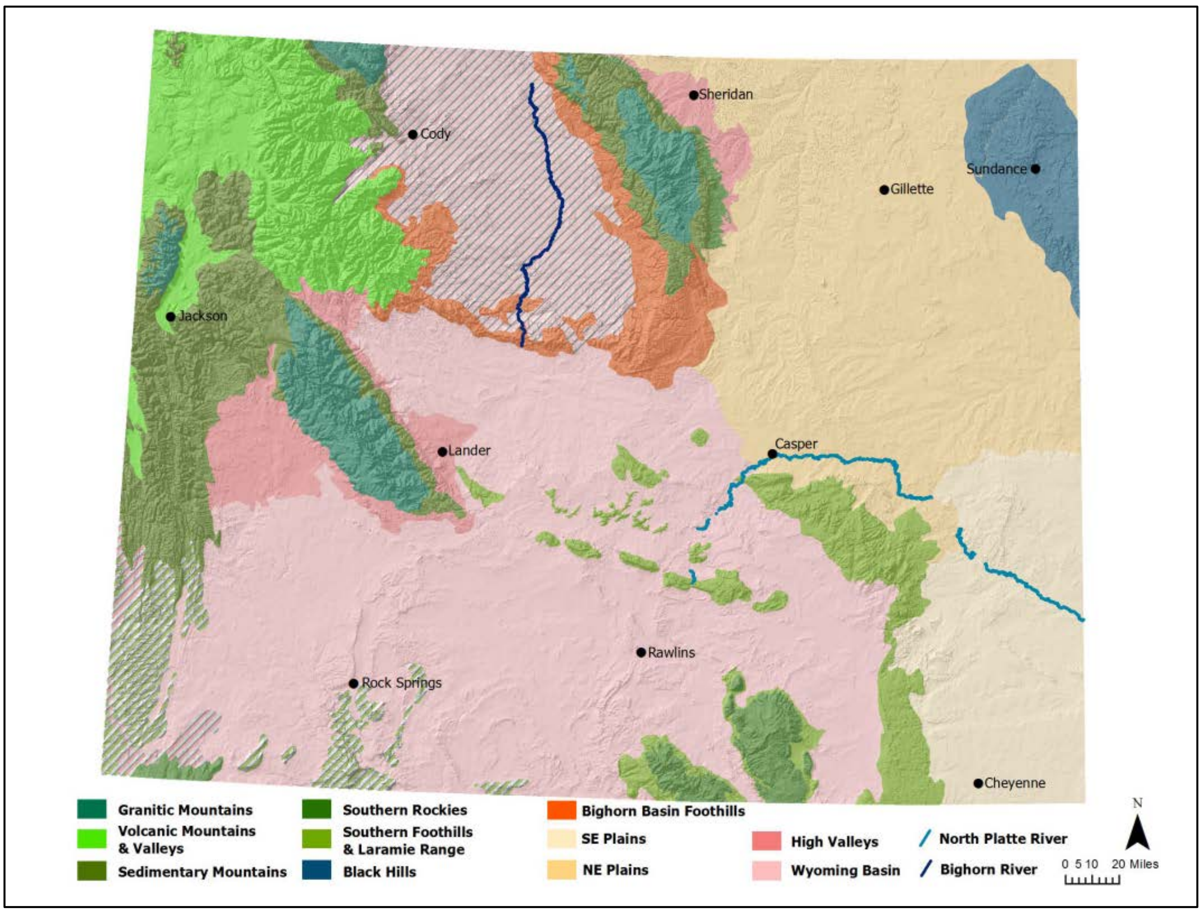


Figure 11. Wyoming Bioregions (reproduced from Hargett and Zumberge, 2013)

Drainage Area – The drainage area is the land area (in square miles) draining water to the downstream end of a project reach and is delineated using available topographic data (ex. USGS maps, LiDAR or other digital terrain data). The drainage area is not used to stratify any reference curves but is important information to include for a project site.

Proposed Bed Material – The bed material characterization metric in the WSQT is only applicable to gravel or cobble bed streams. Otherwise, the proposed bed material is not used to stratify any reference curves but is important information to include for a project site.

Project Reach Stream Length – Existing (ft) – Project reach stream length extends from the upstream to the downstream end of the project reach. This can be determined by surveying the profile of the stream, stretching a tape in the field, or remotely by tracing the stream centerline pattern from aerial imagery. Stream length is not used for reference curve stratification but is used to calculate functional feet.

Project Reach Stream Length – Proposed (ft) – Project reach stream length extends from the upstream to the downstream end of the project reach. The proposed length can be estimated from project design documents, and later verified using as-built conditions using the approaches described in Existing Project Reach Stream Length above. Where stream length does not change post-project, the same value can be entered for the Existing and Proposed Project Stream Length. Stream length is used to calculate the functional feet, so both existing and proposed stream length must be recorded.

Stream Slope (%) – The WSQT uses stream slope to select the correct reference curves for percent riffle. The stream slope is a reach average and not the slope of an individual bed feature, e.g., riffle. Field methods to determine stream slope are outlined in Appendix A.

River Basin – Wyoming is 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 metric. Appendix C contains fish assemblage lists for each river basin.

Stream Temperature Tier – The stream temperature tier is used to determine the correct reference curve 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). Use Table 3 to select the tier that corresponds with the mean modeled August Stream temperature (Peterson 2017).

Table 3. 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

Reference Vegetation Cover – Reference vegetation cover is used to determine the reference curve for the herbaceous vegetation cover metric. The user should select the reference vegetation cover as herbaceous, scrub-shrub, or forested. The reference vegetation cover is 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. The appropriate reference community type can be determined by locating a similar pristine or minimally altered reference site within the catchment area or watershed, researching historical and ecological descriptions of mature and undisturbed vegetation communities in the vicinity, and deduced through understanding the effects of land use practices and management on vegetation communities.

Stream Productivity Rating – The WSQT uses the stream productivity rating to select the correct reference curves for the game species biomass metric. The stream productivity rating is a classification determined by WGFD based on trout pounds/mile (Annear et al., 2006). 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 reference curves for riparian width. The valley type options are unconfined alluvial, confined alluvial or colluvial/v-shaped:

Unconfined Alluvial Valleys: wide, low gradient (typically less than 2% slope) valleys that support meandering stream types (e.g., C, E, DA). In alluvial valleys, rivers adjust pattern without intercepting hillslopes. These valleys typically have a valley width ratio greater than 7.0 (Carlson 2009) or a meander width ratio (MWR) greater than 4.0 (Rosgen 2014).

Confined Alluvial Valleys: valleys that support transitional stream types between step-pool and meandering or where meanders intercept hillslopes (e.g., C, Bc). These valley types typically have a valley width ratio less than 7.0 and a MWR between 3 and 4.

Colluvial/V-shaped Valleys: valleys that are confined and support straighter, step-pool type channels (e.g., A, B, Bc). These valley types typically have a valley width ratio less than 7.0 and a MWR less than 3.

2.6. Reach Hydrology and Hydraulics Functional Category Metrics

There are two function-based parameters to assess reach-scale hydrology functions: reach runoff and flow alteration, and one function-based parameter to assess hydraulic functions: floodplain connectivity. Each is discussed in the following sections.

2.6.a. 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 (Figure 12). The reach runoff parameter consists of two metrics that quantify different aspects of reach runoff: land use coefficient and concentrated flow points.

1. Land Use Coefficient

This metric, an area weighted land use coefficient, serves as an indicator of runoff potential from land uses draining into the project reach between the upstream and downstream ends.

Land use coefficients are based on the curve numbers (CN) developed by the NRCS in their manual Urban Hydrology for Small Watersheds (NRCS 1986), commonly known as TR-55. CN values can be used to link land use type to its potential for generating runoff and are determined based on soil type, land use, and surface condition. To focus on land use change rather than infiltration capacity of soils, land use coefficients for the WSQT were derived from CNs within hydrologic soil group B (Table 4). Higher CN values, nearer 100, indicate more runoff while lower values, nearer 0, indicate less runoff. Note that the WSQT does not require any runoff calculations using the CN methodology. Rather, the WSQT uses CN to draw inferences about land use within the lateral drainage area.

Table 4. NRCS Land Use Descriptions and Associated Land Use Coefficients

Land Use Description (From TR-55)	Land Use Coefficient
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) 1/4 acre 1/3 acre 1/2 acre 1 acre 2 acres	 85 75 72 70 68 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

<u>Data Collection Method:</u>

1. Delineate the lateral catchment area adjacent to the project reach and calculate the total lateral catchment area (see Figure 12).
2. Using the USGS National Land Cover Database (NLCD), delineate the different land use types within the lateral catchment area and calculate the area occupied by each type.
3. Using Table 4, assign each land use type a land use coefficient value.
4. Calculate an area-weighted land use coefficient. For each land use type, multiply the land use coefficient by the area of that land use type; sum all products and divide by the total lateral drainage area (see equation below).

$$Land\ Use\ Coefficient_{Area\ Weighted} = \frac{\sum(Area_i *\ Land\ Use\ Coefficient_i)}{Area_{total}}$$

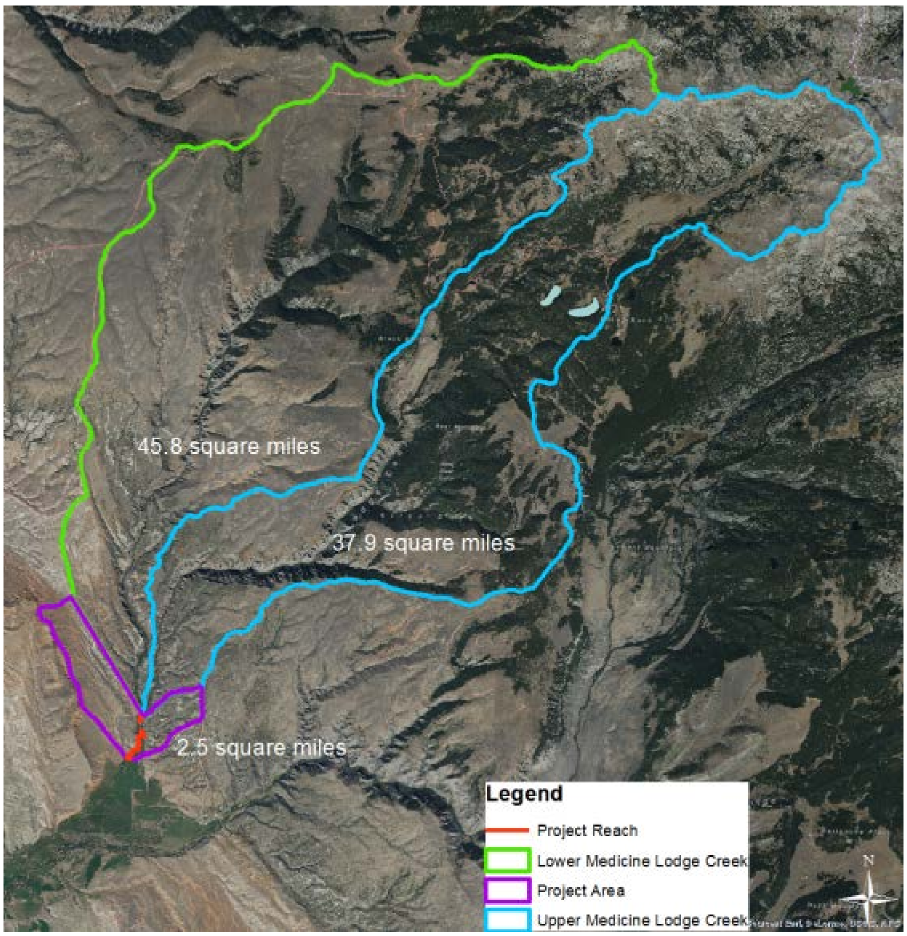


Figure 12. Lateral Drainage Area for Reach Runoff. The purple polygon (2.5 mi^2) delineates the land draining laterally to the project reach and is the lateral catchment area evaluated by the land use coefficient metric.

2. Concentrated Flow Points

Anthropogenic impacts can lead to concentrated flows that erode soils and transport sediment into receiving stream channels (Al-Hamdan et al., 2013). This metric assesses the number of concentrated flow points that enter the project reach per 1,000 linear feet of stream. For this metric, 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 may include agricultural drainage ditches, impervious surfaces, storm drains, and others (see Example 6).

Example 6: Concentrated Flow Points

An agricultural ditch draining water from an adjacent field into a project reach.

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

Data Collection Method:

Concentrated flow points are evaluated in the field; methods are outlined in Appendix A.

2.6.b. Flow Alteration

The flow alteration parameter evaluates the hydrologic impact of water withdrawals and/or augmentation within the project reach. There is currently one metric to evaluate this parameter; however, the Wyoming Stream Technical Team is interested in developing additional metrics that quantify other aspects of the flow regime in future versions of the tool.

The base flow alteration metric compares the observed low flow condition in the channel to the expected low flow condition. For this metric, low flow is defined as the monthly average flow for August. This metric 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). [7]

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

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

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

Data collection methods:

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 ($Qaug_{exp}$).

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

Observed low flow condition:

Two methods can be used to measure the observed low flow condition. 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 second option is to follow the concurrent-discharge methodology as outlined by Lowham (2009) and collect individual flow measurement(s) during August. Both of these methods are described in more detail in Appendix A.

2.6.c. Floodplain Connectivity

Floodplain connectivity is assessed using two metrics: Bank Height Ratio (BHR) and Entrenchment Ratio (ER).

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 metric 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, and the one used in the WSQT is 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 is taken at every riffle within the representative sub-reach and a weighted BHR is calculated and input into the WSQT. To calculate the weighted BHR, use the measurements for low bank height, thalweg depth, and riffle length for every riffle feature within the representative sub-reach and calculate using the weighted BHR equation below (also see Example 7). The weighted BHR should then be entered in the Quantification Tool spreadsheet.

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

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

Example 7: Weighted BHR 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>Data collection methods:</u>

BHR data are collected within the representative sub-reach using either longitudinal profile and cross-sectional surveys or the rapid survey method. Field methods are described in Appendix A.

2. Entrenchment Ratio (ER)

Floodplain connectivity and width vary naturally by stream and valley type, with some streams 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.

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

The ER should be measured at each riffle to calculate the weighted ER (see equation below and Example 8). 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. Where valley width is consistent throughout the representative sub-reach, fewer ER measurements may be needed. 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.

Example 8: Weighted ER Calculation in an assessment segment with four riffles

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			

Data collection methods:

ER data are collected within the representative sub-reach using either longitudinal profile and cross-sectional survey methods or the rapid survey method. Field methods are described in Appendix A.

2.7. Geomorphology Functional Category Metrics

The WSQT contains the following function-based parameters to assess the geomorphology functional category: large woody debris, lateral stability, bed material characterization, bed form diversity, plan form, and riparian vegetation. Not all geomorphic parameters will be evaluated for all projects. Refer to Section 2.1 of this manual for guidance on parameter and metric selection.

2.7.a. Large Woody Debris

There are two metrics to assess large woody debris (LWD), including an LWD piece count and a large woody debris index (LWDI). Either metric can be used to inform this parameter; both metrics should not be used at a site.

Large woody debris is defined as dead and fallen wood over 1m in length and at least 10 cm in diameter at the largest end.[8] The wood must be within the stream channel or touching the top of the streambank. Both metrics use data from an LWD assessment reach of 328 feet (100 meters). This reach should be located within the representative sub-reach and should represent the portion of the sub-reach 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. LWD that solely lies in the floodplain is not counted.

[8] Note: in willow-dominated systems, willow branches that form debris jams are included in the LWDI assessment even if they do not meet the minimum piece size. Additional discussion is provided in the LWDI manual.

This index was developed by the USDA Forest Service Rocky Mountain Research Station (Davis et al. 2001). Guidance on calculating the LWDI score is provided on the field form, available in Appendix B. The LWDI score is entered as the field value in the Quantification Tool worksheet.

<u>Data Collection Method:</u>

Data collection methods are provided in the *Application of the Large Woody Debris Index: A Field User Manual Version 1* (Harman et al. 2017).

2. Piece Count

For this metric, all pieces of LWD within the LWD assessment reach are counted. For debris dams, each piece within the dam that qualifies as LWD is counted as a piece. The number of pieces observed is the field value input for the WSQT. No additional calculation is required.

<u>Data Collection Method:</u>

The field procedure is outlined in Appendix A.

2.7.b. Lateral Migration

Lateral migration is a parameter that assesses the degree of streambank erosion relative to a stable reference condition and is recommended for all projects. There are four metrics for this parameter: dominant bank erosion hazard index (BEHI)/near bank stress (NBS), percent streambank erosion, armoring, and Greenline Stability Rating. When using the BEHI/NBS assessment, it is recommended to use percent eroding banks and dominant BEHI/NBS in combination; dominant BEHI/NBS characterizes the magnitude of bank erosion while percent eroding bank characterizes the extent of bank erosion within a reach. The Greenline Stability Rating may be used instead of the combined dominant BEHI/NBS and percent streambank erosion, while armoring is an optional metric that may be used where armoring is present.

1. Dominant Bank Erosion Hazard Index/Near Bank Stress (BEHI/NBS)

The Bank Erosion Hazard Index (BEHI) is a tool used to estimate the tendency of a given stream bank to erode based on factors such as bank angle, riparian vegetation, rooting depth and density, surface protection, and bank height relative to bankfull height. Near Bank Stress (NBS) is an estimate of shear stress exerted by flowing water on the stream banks. Together, BEHI and NBS are used to populate the Bank Assessment for Non-point source Consequences of Sediment (BANCS) model and produce cumulative estimates of stream bank erosion rates for surveyed reaches (Rosgen 2014). Here, the BEHI/NBS assessment is used to determine the dominant BEHI/NBS category within the representative sub-reach. Evaluation of BEHI/NBS should be completed for every bank that is actively contributing sediment, including, but not limited to, the outside of meander bends. Depositional zones, such as point bars, or other areas that are not actively eroding should not be evaluated (Rosgen, 2014). Additionally, riffle sections that are not eroding and have low potential to erode are excluded from the WSQT BEHI/NBS survey.

The dominant BEHI/NBS is calculated by summing the length of each bank and dividing that length by the assessed bank length. The total percent is calculated for each category by adding the percent of total for each assessed bank length within that category (see Example 9). The dominant BEHI/NBS is the category that represents the greatest cumulative bank length; it does not need to describe over 50% of the assessed banks. If there is a tie between BEHI/NBS categories, the category representing the highest level of bank erosion should be selected.

To enter the field value in the WSQT, a drop-down list of BEHI/NBS categories is provided in the Quantification Tool worksheet.

Example 9: Calculation of Dominant BEHI/NBS

In this example, data were collected in the field for 1100 feet of bank (including left and right banks). Actively eroding banks and those 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

There are four BEHI/NBS categories present. The length of each bank was summed and divided by the assessed bank length; the total percent is then calculated for each category (e.g., High/High = 8+20+20 = 48). The dominant BEHI/NBS category is High/High since that score is highest and describes 48% of the assessed banks.

<u>Data Collection Method:</u>

Field methods are included in Appendix A and datasheets in Appendix B. Additional resources to use in the field include: Appendix D of the *Function-Based Rapid Field Stream Assessment Methodology* (Starr et al. 2015), or *River Stability Field Guide, Second Edition* (Rosgen 2014).

2. 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 BEHI/NBS score indicating an actively eroding bank (Table 5) should be summed together to calculate this metric.

Table 5. BEHI/NBS Stability Ratings that Represent Actively Eroding and Non-eroding Banks

Non-eroding Banks	***Actively Eroding Banks***
L/VL, L/L, L/M, L/H, L/VH, L/Ex, M/VL, M/L	M/M, M/H, M/VH, M/Ex, H/L, H/M, H/H, H/Ex, VH/VL, Ex/VL, Ex/L Ex/M, Ex/H, Ex/VH, VH/VH, Ex/Ex

This metric is calculated by dividing the total length of eroding bank by the total length of streambank within the sub-reach. The total length of streambank is the sum of the left and right bank lengths within the sub-reach (approximately twice the channel length).

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

Data Collection Method:

Data from the BEHI/NBS assessment method is used to calculate percent erosion. Methods are included in Appendix A and datasheets in Appendix B. Additional resources to use in the field include: Appendix D of the *Function-Based Rapid Field Stream Assessment Methodology* (Starr et al., 2015), or *River Stability Field Guide, Second Edition* (Rosgen, 2014)

Example 10: Calculation of Percent Erosion

This example uses the same BEHI/NBS results as above. In the table below, actively eroding banks are identified in bold per Table 6. These bank lengths are added together (12+22+31+31) and divided by the total bank length (1100 feet including left and right banks). The total percent streambank erosion is 8.7%.

Bank ID (Left and Right)	BEHI/NBS	Length (Feet)
L1	Low/Low	50
L2	**High/High**	**12**
R1	**Mod/High**	**22**
R2	**High/High**	**31**
L3	Low/Mod	9
R4	**High/High**	**31**
	Total Length	**155**

3. Greenline Stability Rating (GSR)

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 in 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).

GSR becomes less valuable in monitoring steeper (greater than 4 percent gradient) streams or highly modified streams where natural and artificially hardened streams are less susceptible to vegetation influences; or in monitoring large rivers where landform features play the dominant role in regulating hydrologic influences (Winward 2000).

The GSR is calculated by multiplying the percent composition of each community type along the greenline by the stability class rating assigned to that type (per methods referenced below) and calculating the average value for the project reach.

Data Collection Method:

GSR can be used instead of or in addition to the BEHI/NBS. Data collection should occur throughout the representative sub-reach. The WSQT relies on either of two methods to measure the Greenline Stability Rating.

- The original greenline data collection procedures described in *Monitoring the Vegetation Resources in Riparian Areas* (Winward 2000)

- The Modified Winward Greenline Stability Rating procedures described in *Riparian Area Management: Multiple Indicator Monitoring (MIM) of Stream Channels and Streamside Vegetation* (USDOI 2011).

The Modified Winward Greenline Stability Rating integrates a more systematic approach to collecting data by using plots instead of paces and calculating stability ratings by key species rather than community types to improve precision. It also includes additional species stability ratings not identified in Winward (2000). Regardless of the GSR collection method selected, Table H1 of the USDOI (2011) MIM document outlines procedures for developing a relative stability value for other plant species.

4. Armoring

Literature shows that bank armoring can have positive and negative effects on aquatic functions (Fischenich 2003; Henderson 1986). An example of a positive impact from rip rap is the creation of localized fish habitat (pool and cover formation) and the reduction in excessive bank erosion and sediment supply (Fischenich 2003). Negative impacts to stream functions include overall loss of fish habitat, removal of riparian vegetation, and impacts to channel evolution by preventing natural rates of lateral migration (Fischenich 2003; Henderson 1986).

This metric should only be used if bank armoring is present or proposed in the project reach. Examples of armoring include rip rap, gabion baskets, concrete, and other engineered materials that prevent streams from meandering. If banks are not armored in the project reach, a field value should not be entered. To calculate the armoring field value, measure the total length of armored banks (left and right) and divide by the total length of bank (left and right). Multiply by 100 to report as a percentage of bank armoring. Enter the field value into the SQT.

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

Data Collection Method:

Collect along total reach length using the field method described in Appendix A.

2.7.c. 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; Potyondy and Bunte 2007).[9]

The field value for this metric is informed by a comparison between the project reach and a 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, the reference reach should be located upstream of the project reach and

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

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 metric cannot be calculated. The location of the reference and project reaches should be mapped and provided to the Corps.

Steps for calculating this metric:

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 at the project and reference reaches.
4. Enter the results for the reference and project 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 project reach is statistically different from the reference condition for the 4mm and 8mm size classes. Depending on the size of gravel in your project area 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 project reach.

<u>Data Collection Method:</u>

Bed material data should be collected using a standard Wolman Pebble Count procedure (Rosgen 2014, WDEQ/DWQ 2018). Note, only collect one bank sample every other transect per the instructions. This will ensure that bank material is not oversampled.

2.7.d. 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 metrics for this parameter: pool spacing ratio, pool depth ratio, percent riffle, and aggradation ratio.

1. Pool Spacing Ratio

Pool-to-pool spacing is essentially a measure of how many geomorphic pools are present within a given reach and can be indicative of the channel stability and geomorphic function. For this metric, pools should only be included if they are geomorphic pools; micro-pools within riffles are not counted using this metric. Geomorphic pools are associated with planform features that create large pools that remain intact over many years and flow conditions. Examples include pools associated with the outside of a meander bend and downstream of a large cascade or step. Micro pools are small, typically less than half the width of the channel, and may not last for a long period of time or after a large flow event. An example is a scour pool downstream of a single piece of large woody debris. It is important that users accurately characterize pools, and thus guidance for identifying pools in different valley types is provided below. Also, pool identification is slightly different for pool depth and percent riffle, so the user should read about pool identification for each metric.

Identifying Geomorphic Pools in Alluvial-Valley Streams

Pools should only be included if they are located along the outside of the meander bend. Figure 13 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 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.

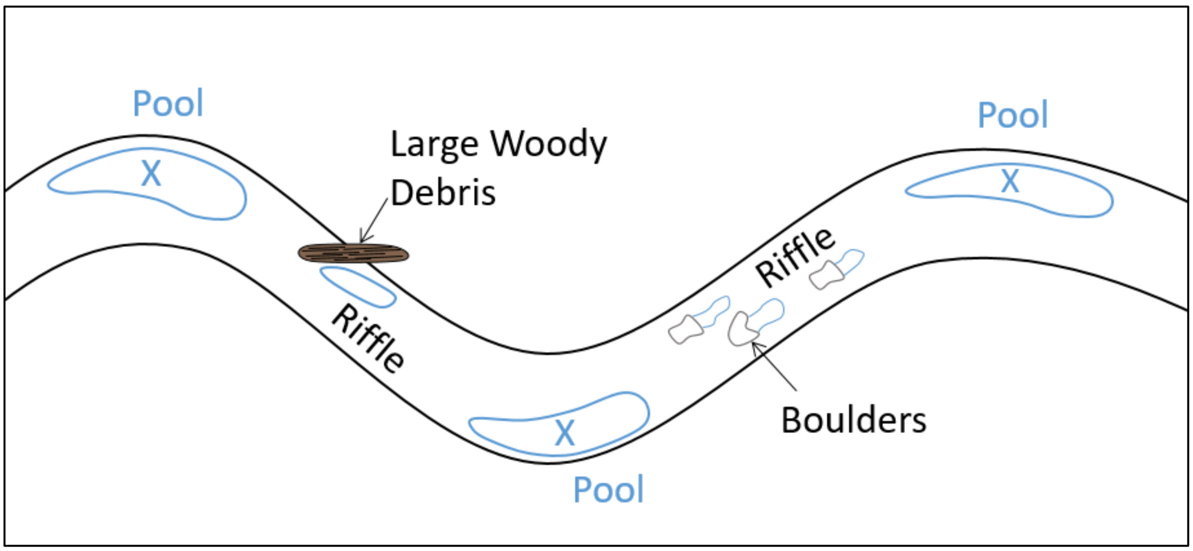


Figure 13. Pool Spacing in Alluvial Valley Streams

Identifying Geomorphic Pools in Colluvial and V-Shaped Valleys

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

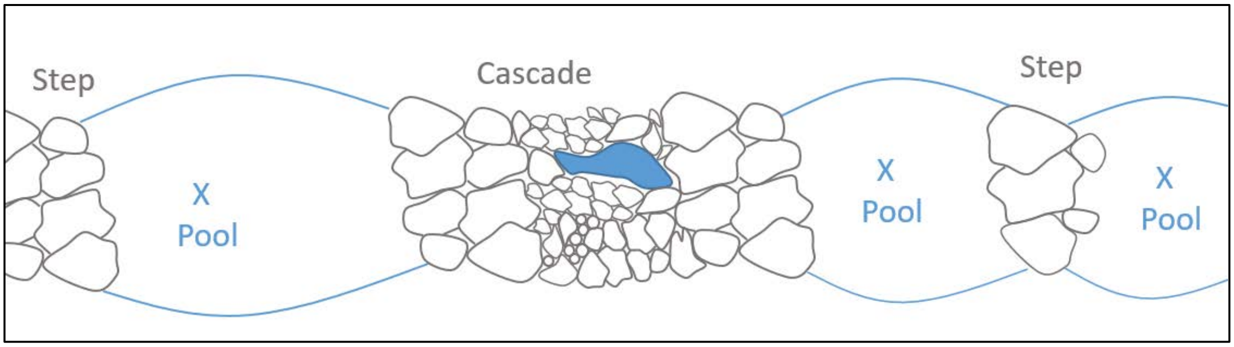


Figure 14. Pool Spacing in Colluvial and V-Shaped Valleys

The pool spacing ratio is the calculation of the pool spacing divided by the bankfull riffle width determined from the representative riffle cross section. 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.

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

The pool spacing ratio is calculated for each pair of sequential pools in the representative sub-reach. The field value entered in the WSQT should be a median value based on at least three pool spacing measurements.

<u>Data Collection Method:</u>

Field methods are described in Appendix A. Pool-to-pool spacing is the distance between the deepest point of two pools, and these data can be collected using either longitudinal profile and cross-sectional survey methods or the rapid survey method. Bankfull riffle width data is collected using the Representative Riffle Survey method.

2. Pool Depth Ratio

The pool depth ratio is a measure of pool quality with deeper pools scored higher than shallow pools. All significant pools (geomorphic and pools associated with wood, boulders, convergence, and backwater) are assessed. If a pool is not associated with a geomorphic or planform feature (ex. meander bend or cascade/step), it should still meet the following criteria to classify as a pool: the pool must be deeper than the riffle, have a concave shaped bed surface, have a water surface slope that is flatter than the riffle, and a width that is at least one-third the width of the channel. 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 by dividing the maximum bankfull pool depth by the mean bankfull riffle depth. The pool depth ratio is calculated for each pool in the representative sub-reach. The minimum, maximum, and average values are then calculated. However, only the average value is input into the WSQT.

Data Collection Method:

Field methods are described in Appendix A. Pool depth represents the elevational difference between the deepest points of each pool. These data can be collected using either longitudinal profile and cross-sectional survey methods or the rapid survey method. Mean bankfull riffle depth is calculated using the Representative Riffle Survey method.

3. Percent Riffle

The percent riffle is the proportion of the representative sub-reach containing riffle bedform features. 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. Glide features should be classified as pools. A run is a transitional feature from the riffle to the pool and the glide transitions from the pool to the riffle (Rosgen 2014). If the pools are not associated with a planform feature (ex. meander bend or cascade/step), it should still be large enough to qualify as a pool. The criteria used to classify a pool includes: the pool must be deeper than the riffle, concave shaped bed surface, water surface slope that is flatter than the riffle, and a width that is at least one-third the width of the channel. Percent riffle is calculated by dividing the total length of riffles within the representative sub-reach by the total sub-reach length.

Data Collection Method:

Field methods are described in Appendix A. Percent riffle data can be collected using either longitudinal profile and cross-sectional survey methods or the rapid survey method.

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 representative sub-reach divided by the mean bankfull riffle depth at that riffle. This ratio is then divided by a reference width to depth ratio (WDR). This metric is recommended mainly for C and E stream types but could also apply to some Bc and B stream types if the channel is exhibiting signs of aggradation.

$$Aggradation\ Ratio = \left. \frac{W_{max\ riffle}}{D_{mean\ riffle}} \middle/ Reference\ WDR \right.$$

Since the WDR can play a large role in the design process and is often linked to slope and sediment transport assessments, the reference WDR is selected by the practitioner. Statistics from a compiled geomorphic reference dataset are shown in Table 6 to provide guidance in selecting a reference WDR. Note that the reference WDR must remain consistent throughout all monitoring and condition assessments. The compiled geomorphic reference dataset is described in the Scientific Support Document (WSTT, 2018) and consists of geomorphic reference site data provided by the WGFD and the US Forest Service in the mountainous regions of Wyoming.

Table 6. Range of WDR Observed in the Compiled Geomorphic Reference Dataset for Wyoming

Stream Type	B	C	E
25th Percentile	16	16	7
Mean	20	20	8
Median	18	20	8
75th Percentile	23	23	10

Data Collection Method:

Data can be collected using either longitudinal profile and cross-sectional survey methods or the rapid survey method. Both methods are outlined in Appendix A. It is recommended to measure this metric at multiple riffle cross sections with aggradation features to ensure that the widest value for the sub-reach is obtained and to document the extent of aggradation throughout the project reach.

2.7.e. Plan Form

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. Additional detail on calculating sinuosity can be found on page 2-32 of Rosgen (2014).

Data Collection Method:

Sinuosity should be measured using recent aerial imagery and should be assessed over the project length. If recent aerial imagery is not available or the stream channel is not visible in the imagery, then sinuosity should be measured in the field per the method outlined in Appendix A.

2.7.f. Riparian Vegetation

Riparian vegetation is a critical component of a healthy stream ecosystem and is defined as plant communities contiguous to and affected by surface and subsurface hydrology and fluvial disturbance. While plant communities are a biological component of the stream ecosystem, riparian vegetation also plays a critical role in supporting channel stability, physicochemical and biological processes, and is thus is included in the geomorphic category of the WSQT.

The riparian vegetation parameter should be assessed for all projects. Four metrics, listed below, have been prioritized as effective indicators of riparian condition within the tool's current structure. Data collection methods have been modified from the WSQT beta version to improve repeatability and consistency and will also allow for extrapolation of species information to draw inferences on vegetation composition and/or to apply additional regulatory performance standards at mitigation sites. Selection of metrics, methodology and development of reference curves are described in the Scientific Support for the WSQT (WSTT, 2018).

There are four metrics for riparian vegetation: Riparian Width (%), Woody Vegetation Cover (%), Herbaceous Vegetation Cover (%) and Percent Native Cover (%). All four metrics are recommended to score the riparian vegetation parameter in the WSQT. Additional vegetation metrics may be used to monitor and determine successful establishment of riparian and wetland vegetation communities but are not included in the WSQT version 1.0.

1. Riparian Width

The riparian width metric describes 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, fill, and development. This metric characterizes the current width of the riparian area, as compared with the reference expectation for that site. The current, observed riparian width is a measure of the current extent of the riparian zone. The reference expectation, or expected riparian width, is an estimate of the natural or potential extent of the riparian area. Each of these values should first be estimated using aerial imagery interpretation prior to validating in the field.

The riparian width metric is the percentage of the expected riparian area width that currently contains riparian vegetation and is free from development, as described above. Riparian width (%) is the field value entered into the WSQT and is calculated using the following equation:

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

<u>Data Collection Method:</u>

The riparian width metric was developed specifically for this tool and relies on a combination of desktop methods described below and field verification methods described in Appendix A.

<u>Expected riparian width:</u> Whenever possible, the expected riparian width is determined using aerial imagery and other spatial data to identify hydrologic and geomorphic indicators on the landscape which are validated in the field. In some situations, these indicators may no longer be observable, and the expected riparian width may be estimated using a reference meander width ratio for that valley type. The procedure is described below:

1. Using aerial imagery and other spatial data such as topographic layers or digital elevation models, identify the edge of the (expected) riparian area using substrate and hydrologic attributes within the project reach. The expected riparian width includes the width of the stream across the stream in each direction, landward to the extent of substrate, geomorphic, and hydrologic indicators of the floodplain. Substrate indicators are found within the portion of the valley bottom influenced by fluvial processes under the current climatic regime while hydrologic indicators are found where the valley bottom would be flooded at the stage of the 100-year recurrence interval flow (Merritt et al. 2017). Indicators may include a fluvially formed break in slope between bank edge and valley edge, a change in sediment from fluvial sediments (rounded) to hillslope sediment (angular), or evidence of flood events (e.g., bar deposition, staining, water marks, floodplain mapping, etc.). Note that Merritt et al. (2017) also describe biotic indicators as a third set of indicators to determine the riparian extent. While biotic indicators may be the easiest to delineate, they may not align with the expected riparian width in disturbed or modified sites.
2. Measure the width from the appropriate indicator on one side of the valley to the appropriate indicator to the other side of the valley. Note whether the width is uniform throughout the

representative sub-reach. If valley width, impacts, restoration, ownership, protection level, or management vary throughout the sub-reach then multiple measurements should be taken to determine an average expected riparian width value for the reach. Expected riparian width values should be noted on the Riparian Width field form prior to going out in the field.

3. During riparian data collection, expected riparian width measurements should be verified in the field using the procedure outlined in Appendix A.
4. Where significant incision or anthropogenic modification of the riparian area has occurred (e.g., development, grading, etc.) and aerial imagery, spatial data and/or field indicators cannot be used to delineate the expected riparian extent, the meander width ratio (MWR) may be used to calculate expected riparian width. 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 applies a typical MWR based on the valley type (Table 7). 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 (see equation below and Figure 15). A meander width ratio of 4.0 was selected to ensure that a minimum sinuosity of 1.2 could be achieved. The ratios for confined and colluvial valleys are less because sinuosity in these valley types is typically less than 1.2.

$$Riparian\ Area\ Width = W_{Bankfull} * MWR + 2 * W_{additional}$$

Table 7. MWR by 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

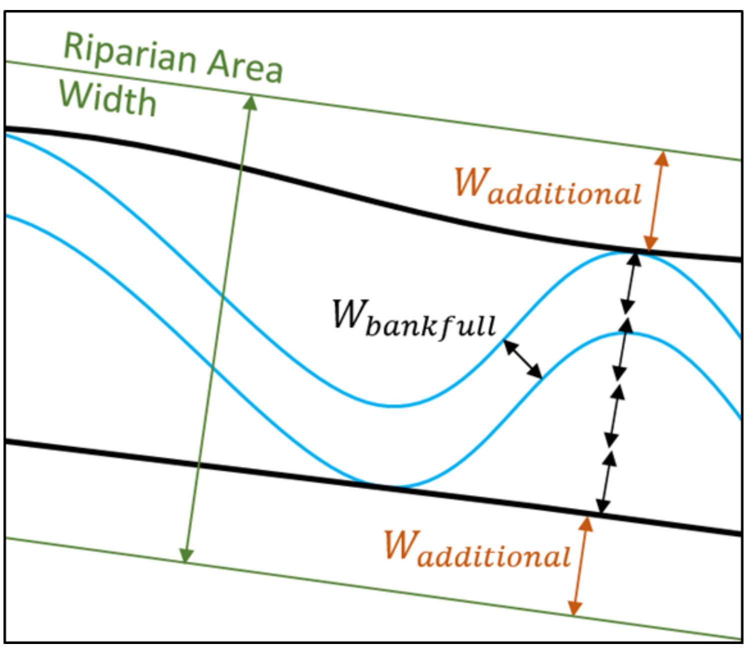


Figure 15. Expected Riparian Width Calculation Relying on Meander Width Ratio

Observed riparian width – The observed riparian width can be determined using aerial imagery and other spatial data to identify the current extent of riparian vegetation indicators on the landscape, which are then verified in the field.

1. Using aerial imagery, identify the edge of the observed riparian area within the project reach using biotic indicators, which include riparian vegetation characteristic of the region and plants known to be adapted to shallow water tables and fluvial disturbance (Merritt et al. 2017). 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).
2. Measure the width from the appropriate indicator on one side of the valley to the appropriate indicator to the other side of the valley. Note whether the width is uniform throughout the representative sub-reach. If the width is not uniform throughout the sub-reach, sufficient measurements should be taken to determine an average observed riparian width value for the reach. Observed riparian width values should be noted on the Riparian Width field form prior to going out in the field.
3. During riparian data collection, observed riparian width measurements should be verified in the field using the procedure outlined in Appendix A.
4. Apply the field-verified expected riparian width and observed riparian width measurements to the equation identified at the beginning of this section to calculate the WSQT value for riparian width (%).

2. Woody Vegetation Cover

This metric characterizes abundance and type of woody vegetation which can affect channel stability and floodplain roughness in addition to habitat. The metric uses data from riparian sampling plots collected according the instructions provided in Appendix A. The woody vegetation cover field value for the WSQT is the sum of absolute percent woody plant cover from shrub and tree species, averaged across all plots within the representative sub-reach.

$$Woody\ vegetation\ cover = \ Woody_{Shrub\ Species\ Cover} + Woody_{Tree\ Species\ Cover}$$

Note that estimates among different species are independent of each other, so the sum of the woody cover for overlapping species combined could add up to more than 100%.

Data Collection Method:

Riparian vegetation should be assessed within sampling plots located along the edge of bank (where bed-meets-bank) of the representative sub-reach (Figure 16). Within each riparian plot for the representative sub-reach, visually estimate the percent absolute cover of each plant species within the nested plot types to determine vegetation abundance, structure, composition and complexity. Practitioners will need basic knowledge of or the ability to key native and nonnative plants commonly found in riparian zones within the region to identify at least 80% of the species within a plot. The methods are a combination of techniques borrowed from the Corps of Engineers Wetland Delineation Manual Arid West, Great Plains and Western Mountains and Valleys Regional Supplements (USACE 2008, 2010a, and 2010b), the Hydrogeomorphic (HGM) Approach (Hauer et al. 2002), and the Bureau of Land Management

Assessment, Inventory, and Monitoring projects (BLM 2017). Instructions for setting up and monitoring riparian plots is described in Appendix A; a data form is provided in Appendix B.

3. Herbaceous Vegetation Cover

Herbaceous vegetation cover is important for bank stability, water quality, and habitat, particularly in systems where woody vegetation is not prevalent. This metric uses the data from the riparian sampling plots collected according the instructions provided in Appendix A. The herbaceous vegetation cover field value for the WSQT is the sum of absolute percent herbaceous plant cover from herbaceous species averaged across all plots within the representative sub-reach.

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

Note that estimates among different species are independent of each other, so the sum of the herbaceous cover for overlapping species combined could add up to more than 100%.

<u>Data Collection Method:</u>

See Data Collection Method for Woody Vegetation Cover above.

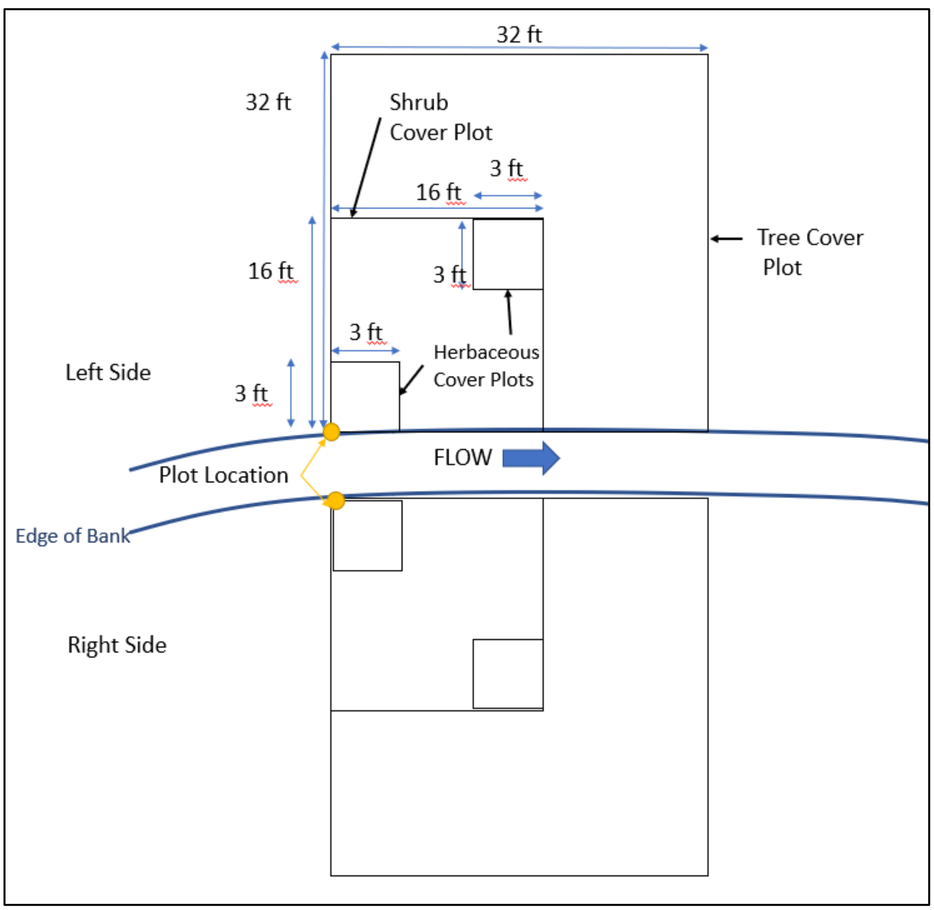


Figure 16. Riparian Vegetation Sample Plot Layout

4. Percent Native Cover

This metric helps characterize the composition and condition of the riparian communities. Data from riparian plots is collected according the instructions provided in Appendix A. The percent native cover metric for the WSQT is the relative cover of native species averaged across all plots within the representative sub-reach. Relative cover is the absolute cover of a species or group of species divided by the total coverage of all species, expressed as a percent. The percent native vegetation field value is calculated at each plot using the equation below. The values from all plots are averaged and this value is entered into the WSQT.

$$Percent\ Native\ Cover = \frac{Native\ Vegetation\ Cover}{Herb\ Vegetation\ Cover + Woody\ Vegetation\ Cover} * 100$$

Note that this metric converts summed absolute cover values into relative cover, therefore, the metric value will not exceed 100%.

<u>Data Collection Method:</u>

See Data Collection Method for Woody Vegetation Cover above.

2.8. Physicochemical Functional Category Metrics

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

2.8.a. Temperature

Temperature plays a key role in both physicochemical and biological functions, and there are several aspects of thermal regimes that affect biota (e.g., magnitude, variability, frequency, duration and timing of thermal events as described in Arismendi et al. 2013). There is one metric included in the WSQT for this parameter, the maximum weekly average temperature (MWAT), which characterizes the magnitude of August stream temperature. The Maximum Weekly Average Temperature (MWAT) is the largest mathematical mean of multiple, equally spaced, daily temperatures over a seven-day consecutive period. This metric is stratified by ambient stream temperature regime, where tier 1 is cold and tier 5 is warm (Table 3, page 37). Reference curves were derived using data and information presented in Peterson (2017).

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 (August; minimum 31 days). These are the mean daily temperatures.
2. Calculate the weekly average temperatures on a rolling seven-day basis for the August sampling period.
3. Identify the maximum of the rolling weekly average temperatures and enter as the field value in the WSQT.

<u>Data Collection Method:</u>

Placement and use of in-water temperature sensors should follow *Best Practices for Continuous Monitoring of Temperature and Flow in Wadeable Streams* (USEPA 2014). This procedure covers sensor selection, calibration, sensor placement, and data QAQC. Note that this procedure requires the deployment of an air temperature sensor. Daily air temperature observations from the nearest active weather station can be used in lieu of air temperature sensors.

For the WSQT, the sample 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 1 hour.

2.8.b. Nutrients

There is currently one metric 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 the 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 blooms of toxin producing algae.

Chlorophyll data should be expressed as milligrams of chlorophyll α per square meter of sampled rock substrate (mg/m^2).

Data Collection Method:

Methods for collecting chlorophyll α are included in Appendix A. Chlorophyll sample collection and processing should be conducted according to the WDEQ Standard Operating Procedure (WDEQ/WQD 2018). Only the rock scrape method (epilithic method) is applicable to the WSQT, meaning this metric is only applicable within stream reaches that contain gravel or larger bed materials and where riffles are present.

2.9. 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, metrics for fish were developed by the Wyoming Stream Technical Team in consultation with regional fish biologists at the Wyoming Game and Fish Department (WGFD).

2.9.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 metrics for macroinvertebrates are stratified by bioregion and are limited to analyzing samples collected from riffles using WDEQ’s targeted riffle sampling method (WDEQ 2017). One or both metrics 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 either or both metrics are subject to Corps 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 when RIVPACS is going to be applied at a project site.

To recognize the uncertainty and variability in stream ecosystems and maintain consistency with how WDEQ applies these models, the decision matrix in Figure 17 was incorporated into parameter scoring when field values are entered for both models. For most sites, the macroinvertebrate parameter score will simply average the metric index scores consistent with parameter scoring throughout the WSQT. For a small range of values, the parameter score will not be an average of the metric scores.

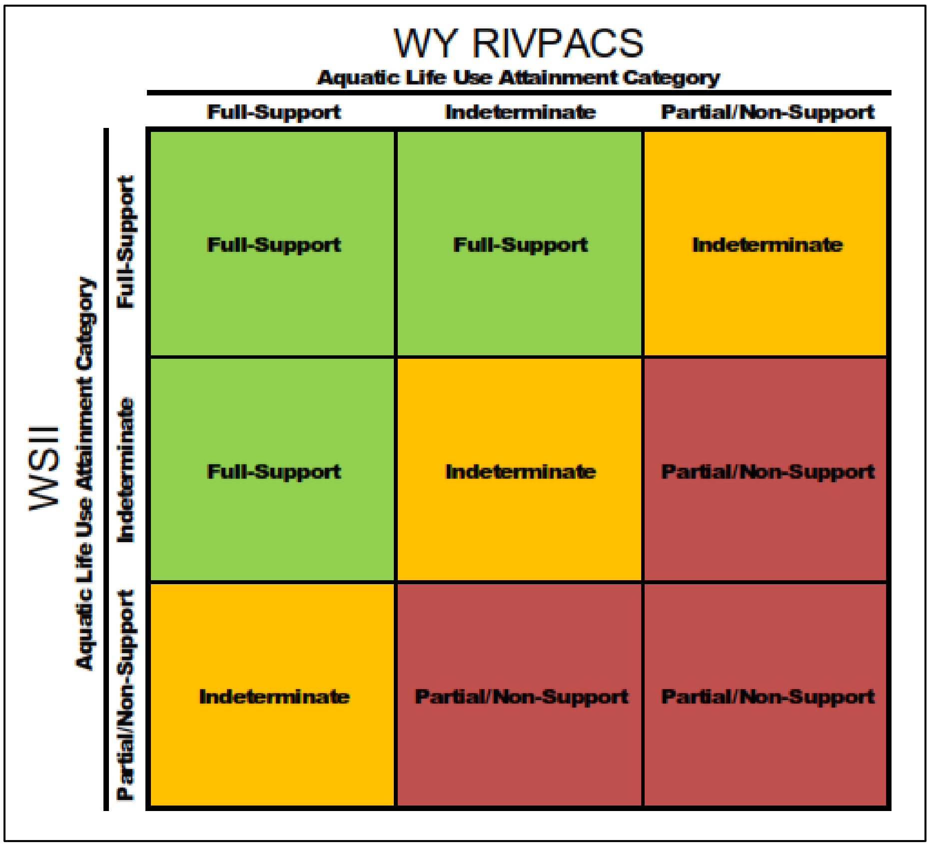


Figure 17. Decision Support Matrix from Hargett (2012)

Wyoming Stream Integrity Index (WSII)

The Wyoming Stream Integrity Index (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.

Data Collection Method:

Methods for collecting, processing and identifying macroinvertebrates are included in Appendix A and are consistent with the benthic macroinvertebrate sampling, processing, and identification procedures outlined in the Manual of Standard Operating Procedures for Sample Collection and Analysis (WDEQ/WQD 2018).

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.

The WSII score is entered as the field value for the WSQT.

5. River Invertebrate Prediction and Classification System (RIVPACS)

River Invertebrate Prediction and Classification System (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.

Once taxa are identified to genus, they should be consolidated into operational taxonomic units (OTUs) and reported in a taxa-abundance matrix. Contact WDEQ for questions on sampling, OTUs and assistance with calculating RIVPACS scores.

The RIVPACS score is entered as the field value for the WSQT.

Data Collection Method:

Methods for collecting, processing and identifying macroinvertebrates are included in Appendix A and are consistent with the benthic macroinvertebrate sampling, processing, and identification procedures outlined in the Manual of Standard Operating Procedures for Sample Collection and Analysis (WDEQ/DWQ 2018).

2.9.b. Fish

Fish are an integral part of functioning river ecosystems. Three metrics for fish are included in the WSQT: Observed/Expected Number of Native Fish Species (%); Presence/Absence of Species of Greatest Conservation Need (SGCN); and Game Species Biomass. Metrics should be applied based on restoration project goals and targeted improvements to the fish community. These metrics 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 user 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. A Chapter 33 permit from WGFD is required prior to collecting fish samples.

1. Native Fish Species Richness (% of expected)

This metric documents the diversity of the native fish community in comparison to reference expectations. 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. 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. The percent of the expected native fish assemblage observed in the stream is the field value entered into the WSQT and is calculated using the following equation:

$$Native\ Fish\ Species\ Richness = \frac{Observed\ Native\ Fish\ Assemblage}{Expected\ Native\ Fish\ Assemblage} * 100$$

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)[10], 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

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

surveys should be conducted. An average of at least two sampling events should be used to calculate the field value for the WSQT.

<u>Data Collection Method:</u>

Detailed fish surveys should be conducted within the project reach 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. Absence of Species of Greatest Conservation (SGCN)

Species of Greatest Conservation Need (SGCN) are identified in the SWAP (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 metric 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 (Table 8). 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 absent in each tier for the site.

Table 8. How to Calculate the Field Value for SGCN Metric

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 =		$C_1 + C_2 + C_3$

<u>Data Collection Method:</u>

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, weighted by tier. That is, 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 8). Note that if there are no species in a tier for the site then there are no species absent for that tier. The weighted number of SGCN species absent is the field value to be entered into the WSQT.

Example 11: Calculation of SGCN metric

A project is proposed in a transitional stream in the Bear River Basin. According to Appendix C, two SGCN species (Bonneville cutthroat trout, tier II and Northern leatherside chub, tier II) are expected in the stream under pristine conditions. 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 then determines if Bonneville cutthroat trout are present by sampling using standard methods over at least two sampling events. No Bonneville cutthroat trout are detected. The field value in the WSQT would be 2 since there was one Tier 2 SGCN species expected that was absent.

3. Game Species Biomass (% Increase)

This metric focuses on native or non-native game fish species determined to be a management priority following consultation with the WGFD and is not applicable to functional loss or impact projects. This metric is also not applicable in stocked streams.

This metric 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 proximate to the project reach but outside the influence of the project actions is preferred.

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.

If a value is entered for a metric in the Existing Condition Assessment, a value must also be entered for the same metric in all subsequent condition assessments (e.g. proposed, as-built, and monitoring). Since the metrics 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 Example 12).

Example 12: Calculation of Game Species Biomass

Example data and calculations are provided for a yellow ribbon trout stream where data are collected in different years.

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

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	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%**

Field Values for Game Species Biomass in a Yellow Ribbon Trout Stream:

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

Data Collection Method:

Detailed fish surveys should be conducted within the project reach and a control reach 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 pre-project. Note: this metric requires selection and sampling of a control reach *in addition* to sampling of the project reach.

Chapter 3. Calculating Functional Lift

This chapter outlines the process 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). The sections of the WSQT workbook that should be completed for restoration and mitigation projects are summarized in Table 9. See Chapter 1.2.c. for information on how the WSQT calculates functional lift.

Table 9. WSQT Worksheets Used for Restoration Projects

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

*Guidance on parameter selection is provided in Section 2.1. and detailed instructions for collecting and analyzing field values for all metrics are provided in Chapter 2 and Appendix A.

3.1. Site Selection

The WSQT can be used to assist with selecting or ranking the priority of 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 WSQT, functional lift is estimated from the difference in pre- and post-project condition scores, expressed as an overall change in functional feet. 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 site condition. Due to time constraints, the user may want to evaluate potential mitigation or restoration project sites using rapid methods available for some metrics (see Chapter 2 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. An index score of 0.70 or higher for floodplain connectivity, bed form diversity, and lateral migration; and
2. An index score of 0.60 or higher for riparian vegetation (recognizing that riparian vegetation may take multiple years to reach full potential).

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

3.2. Restoration or Mitigation Project Planning

3.2.a. Restoration Potential

Restoration potential is the highest level of restoration that can be achieved based on the health of the contributing catchment, reach-scale constraints, and the results of the reach-scale function-based assessment (Harman et al. 2012). Restoration potential is determined by the degree to which physical, chemical, and biological processes at both watershed and reach scales are maintained or restored. The "highest level" refers to the functional categories in the Stream Functions Pyramid, and whether a project can restore functional capacity within each of the categories to a reference standard. A project with full restoration potential would restore the functional capacity within all five categories to a reference standard. Partial restoration would improve some, but not all functions to reference standard. For example, partial restoration might mean improving stability and aquatic habitat back to a reference standard by implementing activities that manipulate processes in the Reach Hydrology & Hydraulics and Geomorphology categories, but not improving Physicochemical or Biology to a reference standard due to watershed stressors (Beechie et al. 2010; Harman et al. 2012).

Full Restoration Potential – The project has the potential to restore functions within all categories, including biology, back to a reference standard (see Table 1, page 11). This is consistent with the 'full-restoration' concept identified by Beechie et al. (2010), where actions restore habitat-forming processes and return the site to its natural or reference standard range of conditions and dynamics.

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

Partial restoration is the most common restoration-potential level for stream restoration projects. Watershed processes and reach-scale constraints influencing a project site are often functioning at a level where some functions/conditions, such as floodplain connectivity, channel stability, (dynamic equilibrium) and in-stream habitat can be restored, but watershed and reach-scale processes may be limiting the restoration of physicochemical and/or biological functions to reference standard. For partial restoration projects, improvements in all categories may be observed, but these improvements may not reflect a reference standard. This is similar to the 'partial-restoration' concept identified in Beechie et al. (2010), where actions restore some processes and functions, but do not return the site fully to its natural or reference range of conditions and dynamics.

There are likely situations where even partial restoration is not possible due to the severity of the catchment stressors and project constraints. For example, flow alteration (a catchment-scale stressor) may modify the hydrologic and sediment transport processes within a catchment, and these factors may be outside the control of the practitioner. Land use changes like sewer lines and roads may artificially constrain the project. Some stressors and constraints limit restoration potential to such a degree that the site may not be suitable for restoration activities.

Procedure for determining restoration potential

1. Determine the project reach limits and delineate the catchment area to the downstream end of the reach (See reach delineation in Chapter 2).
2. Complete the catchment assessment form. Review the scores for each category to determine if an identified stressor can be overcome or if it will prevent the project reach from obtaining even partial restoration. A stressor that prohibits partial restoration may be considered a “deal breaker” that could affect site selection until catchment-scale stressors can be improved. Guidance on filling out the Catchment Assessment form is provided in Chapter 2.
3. Upon completing the catchment assessment form, the user should determine if restoration activities can overcome any or all of the catchment perturbations. Refer to the individual category ratings in Step 2. Can the fair or poor ratings for each individual category be overcome by the scale of the project or by doing additional work in the catchment? If many of the ratings can change from fair or poor to good, then full restoration may be possible. If not, then partial restoration (or a “deal breaker”) is more likely.
    a. Compare the reach size (length and/or area) to the catchment size. Can the scale and type of restoration overcome the catchment stressors? At the reach scale, practitioners should consider several factors, including the scale of the restoration project in relation to the watershed. For small catchments where the length or area of the restoration project is large compared to the total stream length or catchment area, reach-scale activities may be able to overcome the stressors and perturbations.
    b. Consider whether catchment-scale efforts, in combination with a restoration project, are feasible and could overcome catchment perturbations/stressors. For example, if discontinuous flow is occurring upstream of the project reach, restoration may not be successful unless the practitioner can restore important aspects of the flow regime. These broader-scale efforts could also include managing sources of sediment imbalances within the contributing watershed, improving stormwater management practices, restoring more natural hydrology, removing connectivity barriers, etc. Note: evaluating and addressing stressors to underlying hydrologic or sediment transport processes will require additional design and/or modeling analyses that are outside the scope of this tool.
4. Identify reach-scale human-caused constraints. Explain how they could limit restoration potential. Constraints are human-caused conditions, structures and land uses that inhibit restoration activities at the reach scale and are outside of the control of the practitioner. A constraint is different than a stressor which occurs at the catchment-scale, outside of the project reach. Constraints can negatively affect processes needed to support full restoration potential (and in extreme cases can even prohibit partial restoration). Common constraints include land uses within the floodplain or valley bottom that minimize stream-corridor width (e.g., roads, easement widths, levees/berms, etc.), dams or diversions that affect natural

timing, magnitude, duration, frequency or rate of change of flows; and existing dams or culverts that function as migration barriers for fish and prevent streambed elevation changes during design. Note: natural conditions are not constraints. For example, while hillslopes constrain the lateral extent of meandering, they are not a constraint, as defined here. Hillslopes are a natural condition of the catchment. The presence of bedrock can limit changes to bed elevation and even prevent some aquatic species from migrating upstream. However, these are natural conditions that create heterogeneity of habitats and therefore aquatic life. They are not considered constraints in this methodology and would therefore not limit the restoration potential.

5. Use the WSQT to determine the baseline condition of the reach. The WSQT will quantify functional capacity by parameter and functional category.
6. Determine the current and future potential Stream Evolution Model (SEM) and/or Rosgen Channel Succession Stage. Is the stream trending towards greater or lesser functionality? What is the realistic final Stage or Stream Type as compared to the previously undisturbed Stage or Stream Type? Note: this information is also used to determine the Reference Stream Type in the WSQT and is described in Chapter 2.

   The SEM and Rosgen Channel Succession Stages are not described in this manual and users should consult the source material in applying these methods. The future SEM stage (Cluer and Thorne 2013) and/or Rosgen Stream Type can be determined by considering the reach-scale constraints, catchment assessment results in combination with the baseline, existing condition WSQT data. The SEM provides more detail for systems that started as stream/wetland complexes (anastomosed) than the Rosgen method and provides functional descriptions for each stage. Table 10 provides a crosswalk to assist the user in determining the SEM from the existing stream type for the project reach. The Rosgen approach includes channel evolution changes in a wider range of valley types than the SEM, e.g., a single-thread mountain stream. It also includes responses to a wider range of disturbances.

7. Based on Steps 1-6, describe the restoration potential as Full or Partial. Explain the reasons for your selection. Identify which parameters/functions could be restored to a functioning condition (reference standard) following the project and which may not. The restoration potential of the project reach is recorded on the catchment assessment form and described on the Project Assessment worksheet. Results are also entered in the site information and reference selection section of the QT worksheet.

Table 10. Crosswalk Linking Stream Evolution Model Stages to Rosgen Stream Type Succession

Stream Evolution Model Stages (Cluer and Thorne 2013)	Corresponding Rosgen Stream Types
Stage 0 - Anastomosing	DA
Stage 1 – Sinuous Single Thread	C, E
Stage 2 - Channelized	C, E, → Gc
Stage 3 - Degradation	Gc
Stage 3a – Arrested Degradation	Gc → F → Bc
Stage 4 – Degradation and Widening	Gc → F
Stage 5 – Aggradation and Widening	F → C
Stage 6 – Quasi Equilibrium	C, E
Stage 7 – Laterally Active	C, E, F

Stream Evolution Model Stages (Cluer and Thorne 2013)	Corresponding Rosgen Stream Types
Stage 8 - Anastomosing	DA

3.2.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 to meet the goals. Design goals and objectives can be used to inform parameter selection within the WSQT (see Example 13). 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 in 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 is not feasible if the restoration potential is limited 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 partial restoration 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 partial restoration potential; however, restoring native cutthroat trout populations to reference standard would not be expected or possible. If catchment-level improvements are implemented, over time full restoration could be achieved. This outcome would require reach-scale *and* catchment-scale restoration efforts.

Example 13: Project with Partial Restoration Potential

Partial Restoration Potential: The catchment draining to the project is mostly range or irrigated hay land. While the overall catchment health is fair, biological improvements are limited by flow alteration.

Goals: Improve aquatic habitat for native fish communities and reduce sediment supply from bank erosion.

Objectives: Fence out cattle and replant riparian vegetation to stabilize banks, reconstruct portions of channel to improve bedform diversity (habitat).

Possible Parameter List:

- Reach Runoff
- Floodplain Connectivity
- Lateral Migration
- Riparian Vegetation
- Bed Form Diversity
- Plan Form
- Nutrients
- Macroinvertebrates
- Fish

Monitoring is included for metrics within all categories because the project is expected to show some improvement. However, the project is not expected to restore nutrients, macroinvertebrates, and fish parameters to a reference standard.

3.3. Passive Versus Aggressive Restoration Approach Examples

The WSQT evaluates the functional lift of restoration activities through changes in site condition of 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 relying on varying amounts of effort. While an aggressive approach that includes significant modification may be needed in some streams, 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 less intensive projects if 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.

This section includes examples of three 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:

- Reach Runoff
- Floodplain Connectivity
- Large Woody Debris
- Lateral Migration
- Riparian Vegetation
- Bed Form Diversity
- Plan Form
- Nutrients
- Macroinvertebrates
- Fish

To illustrate the benefit of monitoring physicochemical and biological condition, it was assumed the projects showed 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 has not been channelized in the past and meanders within an alluvial valley. Cattle have 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 has been removed by grazing, which led to moderate erosion of several outside meander bends but not significant incision. Erosion was not higher because bank heights were low, and the stream was still connected to its floodplain.

The mitigation approach is to remove intensive grazing pressure by fencing out the cattle and replanting the riparian area. This passive approach is feasible because floodplain connectivity and bedform diversity are already within a functioning range of condition (note, it often takes significant channel modification to fix these two parameters). With these functions in place, a newly planted riparian corridor will improve lateral stability and support higher level functions in the physicochemical and biology functional categories (Figure 18). 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.

Function-Based Parameters	Existing Parameter	Proposed Parameter
Reach Runoff	0.82	0.90
Flow Alteration		
Floodplain Connectivity	0.71	0.71
Large Woody Debris	0.00	0.00
Lateral Migration	0.60	1.00
Riparian Vegetation	0.14	0.68
Bed Material		
Bed Form Diversity	0.82	0.82
Plan Form	1.00	1.00
Temperature		
Nutrients	0.13	0.18
Macros	0.21	0.36
Fish	0.60	0.64

Figure 18. Passive Restoration Approach WSQT Example

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. The channelization and removal of large wood has prevented pool-forming processes within the stream reach and bedform diversity is now in a not-functioning condition. The riparian vegetation has been substantially grazed, which negatively affects lateral migration; however, the functioning floodplain connectivity and corresponding low bank heights support it. The overall result is a lateral migration score in the functioning-at-risk range.

In this scenario, the mitigation approach involves fencing out the cattle, riparian planting, 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 19).

Function-Based Parameters	Existing Parameter	Proposed Parameter
Reach Runoff	0.82	0.90
Flow Alteration		
Floodplain Connectivity	0.71	0.71
Large Woody Debris	0.00	0.56
Lateral Migration	0.52	1.00
Riparian Vegetation	0.14	0.68
Bed Material		
Bed Form Diversity	0.40	0.82
Plan Form	0.00	0.00
Temperature		
Nutrients	0.13	0.18
Macros	0.21	0.36
Fish	0.60	0.64

Figure 19. Moderate Restoration Approach WSQT Example

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 in a not-functioning condition for reasons explained in former examples. Lateral migration is now also in a not-functioning condition 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 20.

Function-Based Parameters	Existing Parameter	Proposed Parameter
Reach Runoff	0.82	0.90
Flow Alteration		
Floodplain Connectivity	0.00	0.85
Large Woody Debris	0.00	0.48
Lateral Migration	0.24	1.00
Riparian Vegetation	0.14	0.68
Bed Material		
Bed Form Diversity	0.40	0.82
Plan Form	0.00	1.00
Temperature		
Nutrients	0.13	0.18
Macros	0.21	0.36
Fish	0.60	0.64

Figure 20. Aggressive Restoration Approach WSQT Example

The functional lift for each of the three scenarios outlined above is summarized in Table 11. 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 11. Summary of Restoration Approach Scenarios

Approach	Change in Functional Feet (FF) Monitoring RH&H and Geomorphology	Change in Functional Feet (FF) Monitoring RH&H, Geomorphology, Physicochemical and Biology
Passive	70	100
Moderate	104	128
Aggressive	364	416

Chapter 4. Calculating Functional Loss

This chapter describes how to use the WSQT to estimate functional loss associated with direct impacts to stream systems. This chapter provides step-by-step instructions on how project impacts and functional loss can be evaluated. See Chapter 1.2.c. for information on how the WSQT calculates functional loss. Guidance on how the functional loss calculations will inform compensatory mitigation requirements, or what permits may be required for specific activities is not included here; users should coordinate with the Corps and review the WSMP v2 for this guidance. The functional loss calculation does not consider temporal loss, the proximity of the mitigation to the impact, or other factors that may be addressed in the WSMP v2.

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 may be available; users should consult the WSMP v2 for guidance.

4.1. Selecting a Debit Option

The three debit options described in this section 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. A summary of the worksheets required to implement each are illustrated in Table 12. For purposes of calculating functional loss, the Catchment Assessment is not required.

Table 12. Summary of Debit Options

Debit Option	Existing Condition Score (ECS)	Proposed Condition Score (PCS)	Worksheets to complete
1	Assess existing condition using SQT	Estimate proposed condition using SQT	□ Project Assessment □ Quantification Tool (ECS and PCS)
2	Assess existing condition using SQT	Use Debit Tool	□ Project Assessment □ Quantification Tool (ECS only) □ Debit Tool
3	Assume a score of 1.00	Use Debit Tool	□ Project Assessment □ Debit Tool

4.2. 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 within the Reach Hydrology & Hydraulics and the Geomorphology categories using project design reports, drawings, field investigations, etc. For projects that impact physicochemical or biological functions, the user must also be able to reasonably predict how the project will affect physicochemical and biology parameters.

The following steps are necessary to complete debit option 1:

1. Determine the parameters and metrics that will be used to assess the reach (See parameter selection in Chapter 2).
2. Complete the Project Assessment worksheet (see Section 1.2.a).
3. Complete the Quantification Tool worksheet, including the Site Information and Reference Stratification section, the Existing Condition Assessment section and the Proposed Condition Assessment section (see Section 1.2.c and Chapter 4).

For the Proposed Condition Assessment, 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 metrics 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.

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 Reference Stratification section (See Section 1.2.c). The Functional Change Summary (Figure 21) provides the overall scores from the Existing Condition Assessment and Proposed Condition Assessment sections.

The ∆FF 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.

Example 14: Determining Proposed (Post-Impact) Condition Score

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 estimate the proposed floodplain connectivity field values. Bedform diversity metrics could also be estimated from the project design plans. 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 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.

FUNCTIONAL CHANGE SUMMARY	
Existing Condition Score (ECS)	0.79
Proposed Condition Score (PCS)	0.54
Change in Functional Condition (PCS - ECS)	-0.25
Existing Stream Length (ft)	1000
Proposed Stream Length (ft)	1100
Change in Stream Length (ft)	100
Existing Functional Feet (FF)	790
Proposed Functional Feet (FF)	594
Proposed FF - Existing FF	-196
Percent Change in FF (%)	-25%

Figure 21. Debit Option 1 Functional Change Summary Example

4.3. 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 4.5.) 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 13). 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 metrics that will be used to assess the reach (See Parameter Selection in Section 2.1). Users should consult with the Corps to determine the parameters necessary to evaluate impacts.
2. Complete the Project Assessment worksheet (see Section 1.2.a).
3. Complete the Site Information and Reference Stratification and Existing Condition Assessment sections of the Quantification Tool worksheet (see Sections 1.2.c and 4.2).
4. Complete the Debit Tool worksheet (Section 4.5).

In the WSQT, the Debit Tool worksheet will automatically populate existing condition scores from the Quantification Tool worksheet entered in step 3 above. Instructions for completing step 4 and detail on how functional loss is calculated in the Debit Tool are provided below.

4.4 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. Complete the Debit Tool worksheet (Section 4.5.)

4.5. Using the Debit Tool Worksheet

The Debit Tool is a worksheet within the WSQT described in Section 1.2.d. To calculate functional loss using the debit tool, the following information should be entered into the Debit Tool worksheet:

- Existing and Proposed Stream Lengths
- Impact Severity Tier

Following entry of this information, the Debit Tool worksheet will automatically calculate a proposed condition score and functional loss.

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 stream length will be less than the existing stream 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. Tiers 1 – 4 represent a range of impacts resulting from proposed activities; information to select between these tiers can come from project plans and documents, permit applications, discussions between the permit applicant and the Corps, etc. Tier 5 is exclusive to projects that completely fill the stream channel, and either pipe or relocate the original channel. Table 13 lists the impact severity tiers 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.

The Debit Tool calculates the proposed condition score differently depending on which impact severity tier is selected (Table 14). For example, impacts within Tiers 1 – 3 result in functional losses to Reach Hydrology & Hydraulics and Geomorphology functions, while Tier 5 impacts result in complete loss of all functions within the stream reach.

Table 13. Impact Severity Tiers and Example Activities

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

<u>Tiers 1-4</u> – The existing condition score and the impact severity tier are used to calculate the proposed condition using the multipliers shown in Table 14 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.

Multipliers for each impact tier were developed from linear regression equations of modeled impact scenarios using a simplified version of the WSQT; additional detail on how the multipliers 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 evaluation of only Reach Hydrology & Hydraulics and Geomorphology parameters. The percent loss associated with impact severity tiers 1 – 3 is calculated using an existing condition score based on an evaluation of functions within Reach Hydrology & Hydraulics, and Geomorphology. 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 0.60. For tier 4, 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 assumes 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.

<u>Tier 5</u> – Activities that completely fill the channel, removing all aquatic functions, are assigned to tier 5. Their PCS is an automatic 0, meaning that all aquatic functions have been lost. Streams enclosed in pipes are included in this tier because it is assumed that no hydraulic, geomorphology, physicochemical, and biology functions are present in this reach. While hydrology is still present, it is simply being conveyed through the reach and not supporting any other functions.

Table 14. Impact Severity Tiers and PCS Calculation

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%
5	PCS = 0	100%

3. 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 described in Chapter 1.2.c. 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 22).

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%*

Figure 22. Debit Option 2 Functional Loss Summary Example –Tier 3 Impact

Chapter 5. References

Air, Water, and Aquatic Environments Program (AWAE). (n.d.) Rocky Mountain Research Station, U.S. Forest Service, Boise, ID. NorWeST Modeled Stream Temperature Stream Lines.

AWAE. 2016. NorWeST stream temperature modeling procedures. Rocky Mountain Research Station, U.S. Forest Service, Boise, ID. http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST/downloads/NorWeST_StreamTemperatureModelDescription.pdf

Al-Hamdan, O.Z., F.B. Pierson, M.A. Nearing, C.J. Williams, J.J. Stone, P.R. Kormos, J. Boll, and M.A. Weltz. 2013. Risk Assessment of Erosion from Concentrated Flow on Rangelands Using Overland Flow Distribution and Shear Stress Partitioning. American Society of Agricultural and Biological Engineers ISSN 2151-0032.

Annear, T., S.Wolff, B. Wiley, R. Keith, K. Johnson, P. Mavrakis, and C. Meyer. 2006. Wyoming Game and Fish Division Administrative Report. https://wgfd.wyo.gov/WGFD/media/content/PDF/Fishing/Stream%20Class/WYSTREAM_STREAMRANKING.pdf

Arismendi, I., Johnson, S.L., Dunham, J.B. and Haggerty, R. 2013. Descriptors of natural thermal regimes in streams and their responsiveness to change in the Pacific Northwest of North America. Freshwater Biology, 58: 880-894. doi:10.1111/fwb.12094

Beechie, T.J., D.A. Sear, J.D. Olden, G.R. Pess, J.M. Buffington, H. Moir, P. Roni, and M.M. Pollock. (2010) Process-based Principles for Restoring River Ecosystems, BioScience, Volume 60, Issue 3, 1. https://doi.org/10.1525/bio.2010.60.3.7

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.

Biota and Harmony. 2014. Instream Flow Study Muddy Creek Basin Carbon County, Wyoming. http://library.wrds.uwyo.edu/instream_flow/Muddy_Creek_Basin_Carbon_County_Wyoming-Instream_Flow_Study-2014.html

Blakely, T.J., Harding, J. S., McIntosh, A.R. and Winterbourn, M.J. (2006), Barriers to the recovery of aquatic insect communities in urban streams. Freshwater Biology, 51: 1634–1645. doi:10.1111/j.1365-2427.2006.01601.x

Bonar, S.A., W.A. Hubert, and D.W. Willis, eds. 2009. Standard Methods for Sampling North American Freshwater Fishes. Published by the American Fisheries Society.

Bureau of Land Management. 2017. 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.

Carlson, E.A. 2009. Fluvial Riparian Classifications for National Forests in the Western United States. Fort Collins, CO. Thesis. Colorado State University.

Cluer, B. and C. Thorne. 2013. A Stream Evolution Model Integrating Habitat and Ecosystem Benefits. River Research and Applications, River Res. Applic., Published online in Wiley Online Library (wileyonlinelibrary.com).

Compensatory Mitigation for Losses of Aquatic Resources, 33 C.F.R. § 325 and 332 (2008)

Davis, J.C., G.W. Minshall, C.T. Robinson, and P. Landres. 2001. Monitoring Wilderness Stream Ecosystems. General Technical Report RMRS-GTR-70. US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, Colorado.

Environmental Law Institute (ELI), Stream Mechanics, and The Nature Conservancy. 2016. Stream Mitigation: Science Policy, and Practice. 137pp.

Fischenich, J.C. 2006. Functional Objectives for Stream Restoration. Vicksburg, M.S. U.S. Army Engineer Research and Development Center. EMRRP Technical Notes Collection, ERDC TN-EMRRP-SR-52.

Hargett, E.G. 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, WY.

Hargett, E.G. 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, WY.

Hargett, E.G. and J.R. Zumberge. 2013. Water quality condition of Wyoming perennial streams and rivers – Results of the First (2004-2007) and Second (2008-2011) Statewide probability surveys. Document #13-0049. Wyoming Department of Environmental Quality, Water Quality Division, Cheyenne, Wyoming. 54 p.

Harman, W.A., T.B. Barrett, C.J. Jones, A. James, and H.M. Peel. 2017. Application of the Large Woody Debris Index: A Field User Manual Version 1. Stream Mechanics and Ecosystem Planning & Restoration, Raleigh, NC.

Harman, W.A., and C.J. Jones. 2017. Calculating Functional Loss Using the Stream Quantification Tool and Debit Calculator,15 pp. Environmental Defense Fund.

Harman, W.A., and C.J. Jones. 2016. Functional Lift Quantification Tool for Stream Restoration Projects in North Carolina: Spreadsheet User Manual Version 2. Environmental Defense Fund. Raleigh, NC.

Harman, W., R. Starr, M. Carter, K. Tweedy, M. Clemmons, K. Suggs, and 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.

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.

Hughes, J.M. 2007. Constraints on recovery: using molecular methods to study connectivity of aquatic biota in rivers and streams. Freshwater Biology, 52: 616–631. doi:10.1111/j.1365-2427.2006.01722.x

Lake, P.S., N. Bond and P. Reich. 2007. Linking ecological theory with stream restoration. Freshwater Biology, 52: 597–615. doi:10.1111/j.1365-2427.2006.01709.x

Leopold, L.B., 1994. *A View of a River*. Harvard University Press, Harvard University, Cambridge, MA.

Lowham, H.W. 1988. Streamflows in Wyoming: U.S. Geological Survey Water-Resources Investigations Report 88-4045, 78 p.

Lowham, H.W., et al. 2009. Estimating Streamflow from Concurrent Discharge Measurements. Wyoming Water Development Commission. Lander, Wyoming.

Mayer, P.M., S.K. Reynolds, M.D. McCutchen, and T.J. Canfield. 2006. Riparian Buffer Width, Vegetative Cover, and Nitrogen Removal Effectiveness: A Review of Current Science and Regulations. US Environmental Protection Agency EPA/600/R-05/118, Washington, DC.

McCarthy, J., C. Jones, W. Harman, P. Wolken, P. Dey and J. ZumBerge. *In Draft.* Wyoming Stream Quantification Tool Scientific Support Document DRAFT. U.S. Army Corps of Engineers, Omaha District.

Merritt, David M.; Manning, Mary E.; Hough-Snee, Nate, eds. 2017. The National Riparian Core Protocol: A riparian vegetation monitoring protocol for wadeable streams of the conterminous United States. Gen. Tech. Rep. RMRS-GTR-367. Fort Collins, CO: U.S.

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.

Natural Resources Conservation Service (NRCS). 1986. Urban Hydrology for Small Watersheds Technical Release No. 55. United States Department of Agriculture Natural Resources Conservation Service, Conservation Engineering Division, Washington, D.C. http://www.wcc.nrcs.usda.gov/water /quality/common/tr55/tr55.pdf

NRCS. 2007. National Engineering Handbook part 654, Stream Restoration Design. U.S. Department of Agriculture NRCS. Washington D.C.

Peterson, C.M. May 2017. Development of thermal tiers and regulatory criteria for Wyoming stream fishes., M.S., Wyoming University Department of Zoology and Physiology.

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

Renwick, W.H. 1992. Equilibrium, disequilibrium, and nonequilibrium landforms in the landscape, in *Geomorphic Systems, Proceedings of the Binghamton Geomorphology Symposium*, edited by J.D. Phillips and W.H. Renwick. Elsevier, Amsterdam, pp. 265-276.

Roni, P. and T. Beechie, eds. 2012. *Stream and Watershed Restoration: A Guide to Restoring Riverine Processes and Habitats,* John Wiley & Sons, Ltd.

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

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

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

Skidmore, P.B., C.R. Thorne, B.L. Cluer, G.R. Pess, J.M. Castro, T.J. Beechie, and C.C. Shea. 2011. Science base and tools for evaluating stream engineering, management, and restoration proposals. U.S. Dept. Commerce, NOAA Tech. Memo. NMFS-NWFSC-112, 255 p.

Somerville, D.E., and B.A. Pruitt. 2004. Physical Stream Assessment: A Review of Selected Protocols for Use in the Clean Water Act Section 404 Program. Prepared for the U.S. Environmental Protection Agency, Wetlands Division (Order No. 3W-0503-NATX). Washington, D.C. Document No. EPA 843-S-12-002. https://www.epa.gov/sites/production/files/2015-08/documents/physical_stream_assessment_0.pdf

Spurr, S. H., and B. V. Barnes. 1980. Forest ecology, 3d ed edition. John Wiley and Sons Inc., New York, NY.

Starr, R., W. Harman, S. Davis. 2015. FINAL DRAFT Function-Based Rapid Field Stream Assessment Methodology. U. S. Fish and Wildlife Service, Chesapeake Bay Field Office, Annapolis, MD. CAFE S15-06.

Starr, R. and W. Harman, 2016. DRAFT Final Function-Based Stream Restoration Project Process Guidelines. U. S. Fish and Wildlife Service, Chesapeake Bay Field Office, Annapolis, MD. CBFO S16-03.

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

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

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

Tetra Tech, Inc. 2011. User’s Guide Spreadsheet Tool for the Estimation of Pollutant Load (STEPL). US Environmental Protection Agency, Fairfax, VA.

United States Army Corps of Engineers (USACE). 2008a. Regulatory Guidance Letter No. 08-03. Minimum Monitoring Requirements for Compensatory Mitigation Projects Involving the Restoration, Establishment, and/or Enhancement of Aquatic Resources. http://www.usace.army.mil/Portals/2/docs/civilworks/RGLS/rgl08_03.pdf

USACE. 2008. Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Arid West Region (Version 2.0), ed. J. S. Wakeley, R. W. Lichvar, and C. V. Noble. ERDC/EL TR-08-28. U.S. Army Engineer Research and Development Center, Vicksburg, MS.

USACE. 2010a. Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Great Plains Region (Version 2.0), ed. J. S. Wakeley, R. W. Lichvar, and C. V. Noble. ERDC/EL TR-10-1. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

USACE. 2010b. Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Western Mountains, Valleys, and Coast Region (Version 2.0), ed. J. S. Wakeley, R. W. Lichvar, and C. V. Noble. ERDC/EL TR-10-3. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

USACE. 2013. Wyoming Stream Mitigation Procedures (WSMP). USACE Omaha District, Wyoming Regulatory Office. Cheyenne, WY.

USACE. 2018. Wyoming Stream Mitigation Procedure (WSMP) Version 2. USACE Omaha District, Wyoming Regulatory Office. Cheyenne, WY.

U.S. Department of the Interior (U.S. DOI). 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

U.S. EPA. 2014. Best Practices for Continuous Monitoring of Temperature and Flow in Wadeable Streams. Global Change Research Program, National Center for Environmental Assessment, Washington, D.C; EPA/600/R-13/170F.

U.S. Fish and Wildlife Service (USFWS). 2009. A System for Mapping Riparian Areas in the Western United States. Division of Habitat and Resource Conservation, Branch of Resource and Mapping Support, Arlington, VA.

Winward, A.H. 2000. Monitoring the vegetation resources in riparian areas. Gen. Tech. Rep. RMRSGTR-47. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 49 p.

Wyoming Department of Environmental Quality, Water Quality Division (WDEQ/WQD). 2018. Manual of Standard Operating Procedures for Sample Collection and Analysis. Wyoming Department of Environmental Quality, Water Quality Division, Watershed Program, Cheyenne, WY.

WDEQ/WQD. 2017. Macroinvertebrate Sampling – Targeted Riffle/Run Alternate Method for Depths up to 1.5 Feet. Wyoming Department of Environmental Quality, Water Quality Division, Watershed Protection Program, Cheyenne, WY.

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

Wyoming Stream Technical Team. 2018. Scientific Support for the Wyoming Stream Quantification Tool, Version 1. U.S. Army Corps of Engineers, Omaha District, Wyoming Regulatory Office. Cheyenne, WY.

Yochum, S.E. 2018. Guidance for Stream Restoration. U.S. Department of Agriculture, Forest Service, National Stream & Aquatic Ecology Center, Technical Note TN-102.4. Fort Collins, CO.