Colorado Stream Quantification Tool and Debit Calculator User Manual (Beta Version)

Army Corps of Engineers

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Acknowledgements

The Colorado Stream Quantification Tool and supporting materials are adapted for Colorado from the Wyoming Stream Quantification Tool v1.0 (USACE, 2018) which was developed by the Wyoming Stream Technical Team, whose members include Will Harman, Cidney Jones, Julia McCarthy, Paul Dey, Jeremy Zumberge, and Paige Wolken. The regionalization of this tool for Colorado was funded by USEPA Region 8, USEPA Headquarters and USACE Albuquerque District through a contract with Ecosystem Planning and Restoration (contract # EP-C-17-001).

The Colorado Stream Quantification Tool (CSQT) is the collaborative result of agency representatives, Stream Mechanics, and Ecosystem Planning and Restoration (EPR), collectively referred to as the CSQT Steering Committee (CSQT SC). Members include:

Will Harman, Stream Mechanics
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Chris Sturm, Colorado Water Conservation Board

Many others provided valuable contributions to the Colorado and Wyoming documents, including: Andy Treble (CPW) and Jay Skinner (CPW) who provided input on fish metrics and assemblage data, Kiel Downing (USACE Omaha/Albuquerque District), Travis Morse (USACE Sacramento District), Karlyn Armstrong (CPW) and Jack Lander (CWCB) who provided valuable review and comment, Mike Robertson and other Aquatic Staff with Wyoming Game and Fish Department who assisted with data collection and provided input on fish metrics, WDEQ Water Quality Division staff who assisted with data collection, Barbara Chongtoua with Urban Drainage and Flood Control District who provided important context within urban environments, and LeeAnne Lutz and Amy James (EPR). Valuable peer review on USACE (2018) was provided by Sarah Miller, Eric Somerville, Ken Fritz, Brian Topping, Rachel Harrington, Billy Bunch, Sarah Marshall, and Joanna Lemley. This document also benefited from others who provided feedback and comment on the WSQT Beta Version through the Public Notice issued by the Wyoming Regulatory Office.

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Preface

Document History

- The Colorado Stream Quantification Tool and Debit Calculator (CSQT) Beta Version were developed using the WSQT v1.0 and associated documents as a starting point. This manual, the CSQT and Debit Calculator workbooks, and the scientific support for the CSQT have been edited from the WSQT v1.0 for use in Colorado.
- Several metrics have been added to the CSQT and are newly available in the Beta Version for public comment and testing. These metrics are considered provisional while the public comment and testing period is ongoing. Provisional metrics include the percent impervious surface and water quality capture volume metrics within the reach runoff parameter; average depth and velocity metrics within the baseflow dynamic parameter; return interval within the floodplain connectivity parameter; dissolved oxygen concentration; and the metrics included in the Flow Alteration Module.
- The Wyoming Stream Quantification Tool (WSQT), Beta Version was released for testing and public comment by the U.S. Army Corps of Engineers (USACE) Omaha District Wyoming Regulatory Office in August 2017 for 120 days. The USACE and Wyoming Stream Technical Team (WSTT) gratefully received technical comments from 4 agencies and 6 practitioners. The WSTT reviewed and responded internally to the 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 support document to provide the scientific rationale of the WSQT.
- The WSQT v1.0 was released by USACE for program implementation in Wyoming along with an updated Wyoming Stream Mitigation Procedures (v2) document in July 2018.

Document Availability and Revisions

A digital copy of the CSQT and associated documents can be obtained on the Regulatory In-lieu fee and Bank Information Tracking System (RIBITS) website under Assessment Tools for Colorado:

https://ribits.usace.army.mil/

Or at the Stream Mechanics website:

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

A copy may also be requested from any of the USACE Regulatory Offices in Colorado.

The following spreadsheets and documents are available:

- CSQT Workbook – Microsoft Excel Workbook described in detail in the User Manual.
- Debit Calculator Workbook – Microsoft Excel Workbook described in detail in the Colorado Mitigation Procedures (COMP; USACE 2019) and the User Manual.

- Colorado Stream Quantification Tool and Debit Calculator Beta Version User Manual – This manual describes the CSQT and Debit Calculator workbooks, all calculations performed by the workbooks, and how to collect data and calculate input for the CSQT.

- Scientific Support for the CSQT – a comprehensive review of the function-based parameters and metrics, reference standards, stratification methods, scoring and references used in the CSQT. The Scientific Support for the CSQT also includes a list of metrics summarizing this information.

- Colorado Mitigation Procedures (COMP; USACE 2019) – USACE procedures for using the CSQT and Debit Calculator workbooks to calculate credits and debits.

This suite of documents will be revised and updated following public comment and testing. Future versions of the tool will be updated and revised periodically as additional data are gathered and reference standards and metrics are refined. Field data supporting refinement of reference curves and evaluation of metrics are appreciated.

The CSQT architecture is flexible and can accommodate additional parameters and metrics that are accompanied by reference curves and index values. If a user is interested in proposing additional parameters or metrics for incorporation into the tool, they should provide a written proposal for consideration. The written proposal should include a justification and rationale (e.g., data sources and/or literature references) and should follow the framework for identifying threshold values and index scores that is outlined in the Scientific Support for the CSQT (CSQT SC 2019).

Technical feedback may be submitted at any time to the USACE Pueblo Regulatory Office at 201 West 8th Street Suite 350, Pueblo, Colorado, 81003, or contact the office at (719) 744-9119; an email address can be provided on request.

DISCLAIMER

The Colorado Stream Quantification Tool and Debit Calculator, including workbooks and supporting documents, are intended for the evaluation of Clean Water Act Section 404 (CWA 404) compensatory mitigation projects and impact sites and their departure from reference conditions in terms of functional loss or lift, respectively. The metrics are scored based on their current condition as compared to a reference standard. Consultation with the local Corps office is recommended prior to the use of this tool related to any CWA 404 activities. In part, or as a whole, the function-based parameters, metrics, and index values are not intended to be used as the basis for engineering design criteria. The U.S. Army Corps of Engineers assumes no liability for engineering designs based on these tools. 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 designs.

Acronyms

BEHI/NBS – Bank Erosion Hazard Index / Near Bank Stress
BHR – Bank Height Ratio
CDPHE – Colorado Department of Public Health and Environment
CDPS – Colorado Discharge Permit System
CFR – Code of Federal Register
COMP – Colorado Mitigation Procedures
CS – Cold Stream
CSQT – Colorado Stream Quantification Tool
CSQT SC – Colorado Stream Quantification Tool Steering Committee
Corps – United States Army Corps of Engineers (also, USACE)
CPW – Colorado Parks and Wildlife
CWA 404 – Section 404 of the Clean Water Act
DM – Daily Maximum Temperature
DO – Dissolved Oxygen
EPA – US Environmental Protection Agency
ER – Entrenchment Ratio
FF – Functional Feet
GSR – Greenline Stability Rating
HSI – Habitat Suitability Indices
HUC – Hydrologic Unit Code
LDA – Lateral Drainage Area
LWD – Large Woody Debris
LWDI – Large Woody Debris Index
MMI – Multi-metric Index
MWAT – Maximum Weekly Average Temperature
MWR – Meander Width Ratio
NLCD – National Land Cover Database
NRCS – Natural Resource Conservation Service
NRSA – National Rivers and Streams Assessment (dataset)
O/E – Ratio of Observed/Expected
Q – Discharge, also stream flow or flow
SEM – Stream Evolution Model
SFPF – Stream Function Pyramid Framework
SGCN – Species of Greatest Conservation Need
TMDL – Total Maximum Daily Load
USACE – US Army Corps of Engineers (also, Corps)
USDOI – US Department of Interior
USEPA – US Environmental Protection Agency (also, EPA)
USFWS – US Fish and Wildlife Service
USGS – US Geologic Survey
UT – Unnamed Tributary
WDR – Width Depth Ratio
WDRS – Width Depth Ratio State
WQCD – Water Quality Control Division
WQCV – Water Quality Capture Volume
WS – Warm Stream
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.

Colorado Stream Quantification Tool and Debit Calculator (CSQT) – The CSQT is a spreadsheet-based calculator that scores stream condition before and after restoration or impact activities to determine functional lift or loss, respectively, and can also be used to determine restoration potential, develop monitoring criteria and assist in other aspects of project planning. The CSQT is comprised of two workbooks, the CSQT and Debit Calculator workbooks, that have some overlapping components; and both are based on principles and concepts of the SFPF. References to CSQT describe concepts that are applicable within both CSQT and Debit Calculator workbooks.

CSQT workbook – the Microsoft-Excel workbook file used to evaluate change in condition at a mitigation or restoration site.

Colorado Stream Quantification Tool Steering Committee (CSQT SC) – The group who worked on the development of the CSQT and contributed to various aspects of this document.

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)

Debit Calculator workbook – the Microsoft-Excel workbook file used to evaluate change in condition at impact sites.

Field Value – A field measurement or calculation input into the CSQT for a specific metric. Units vary based on the metric or measurement method used.

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. The change in functional feet (ΔFF) is the difference between the Existing FF and the Proposed FF.

Function-Based Parameter – A structural measure which characterizes a condition at a point in time, or a process (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 scores.

Impact Severity Tiers – The Debit Tool worksheet 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 evaluate the condition of a structural measure or 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).

Native Flow – For the purposes of the CSQT, native flows are the estimates of the stream flows that would result from natural hydrologic processes such as rainfall-runoff and snowmelt-runoff without anthropogenic influence at a given location.

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 Area – The geographic extent of a project. This area may include multiple project reaches, where there are variations in stream physical characteristics and/or differences in project designs within the project area.

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 other forms that 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 CSQT, 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 a project reach that is selected for field data collection of parameters and metrics. The representative sub-reach is typically 20 times the bankfull width or two meander wavelengths (Leopold 1994).

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):

Substrate and topographic attributes -- the portion of the valley bottom influenced by fluvial processes under the current climatic regime,

Biotic attributes -- riparian vegetation characteristic of the region and plants known to be adapted to shallow water tables and fluvial disturbance, and

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 the Stream Quantification Tool from Wyoming that has been adapted and modified for use in Colorado.

Wyoming Stream Technical Team (WSTT) – The group who worked on the development of the WSQT and associated documents.

Overview

The Colorado Stream Quantification Tool and Debit Calculator (CSQT) is a spreadsheet-based calculator designed to inform permitting and compensatory mitigation decisions within the Clean Water Act Section 404 program (CWA 404). When used within the CWA 404 context, coordination with the Corps on tool use and parameter selection is recommended prior to data collection. The CSQT can also be applied to restoration projects outside of the CWA 404 regulatory context. These Microsoft Excel Workbooks have been developed to characterize stream ecosystem functions by evaluating a suite of indicators that represent structural or compositional attributes of a stream and its underlying processes. Indicators in the CSQT represent parameters that are often impacted by authorized projects or affected (e.g. enhanced or restored) by mitigation actions undertaken by restoration providers. The CSQT has been modified from the Wyoming Stream Quantification Tool Version 1.0 (WSQT v1.0; USACE 2018a) and regionalized for use in Colorado. Many of the parameters, metrics and reference curves within the CSQT Beta Version are similar to or identical to those in the WSQT v1.0 (USACE 2018a). Other stream quantification tools and user manuals have been developed for use in other states and regions, including North Carolina (Harman and Jones 2017), Tennessee (TDEC 2018) and Georgia (USACE 2018b).

The CSQT is an application of the Stream Functions Pyramid Framework (SFPF; Harman et al. 2012) and use function-based parameters and metrics to assess four functional categories: reach hydrology and hydraulics, geomorphology, physicochemical, and biology. The CSQT 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 impact or restoration activities are implemented. Additionally, the CSQT includes a Flow Alteration Module to assess hydrologic changes at a project site. The change in condition from the project reach assessment and the Flow Alteration Module 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 as defined in the 2008 Compensatory Mitigation for Losses to Aquatic Resources; Final Rule (2008 Rule).

The main goal of the CSQT is to produce objective, verifiable, and repeatable results by consolidating well-defined procedures for objective and quantitative measures of defined stream variables. The CSQT includes 34 metrics within 14 parameters that can be evaluated at a project site. A basic set of metrics within 5 parameters is required at all project sites evaluated for CWA 404 purposes to provide consistency between impacts and compensatory mitigation and allow for more consistent accounting of functional change. Users can include additional parameters and metrics on a project-specific basis (see Section 2.3 on Parameter Selection). The User Manual provides data collection methods related to each parameter. For some metrics, methods include both rapid and more detailed forms of data collection, allowing the tool to be used for rapid or more comprehensive site assessment.

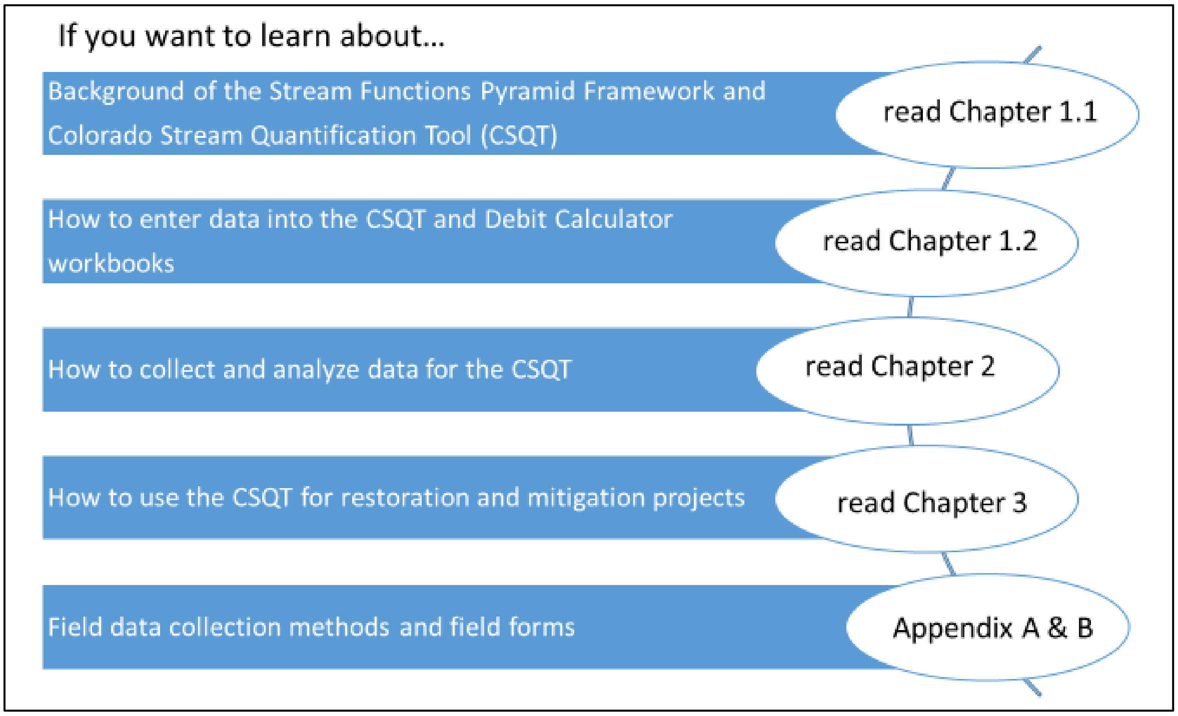
This manual describes the CSQT and Debit Calculator workbooks and how to collect and analyze data entered into these workbooks. Companion documents include the Colorado Mitigation Procedures (COMP; USACE 2019), which provides policy direction for how and when the CSQT will be used for the CWA 404 regulatory program and how tool results are translated into credits and debits; and the Scientific Support for the CSQT, which provides rationale for scoring in the CSQT and describes how measured stream conditions were converted into dimensionless index scores (CSQT SC 2019).

PURPOSE AND USE OF THE CSQT

The purpose of the CSQT is to calculate functional lift and loss associated with restoration and impact activities within perennial, intermittent, and ephemeral streams that fall within the scope of the CWA 404 regulatory program. The tools are calculators 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 verified during post-construction monitoring events in the CSQT workbook. On the impact side, functional loss can be estimated several ways using the Debit Calculator workbook. Estimates of functional lift and functional loss can inform CWA 404 permitting and mitigation decisions; the application of the CSQT in the CWA 404 Regulatory Program in Colorado is outlined in the COMP (USACE 2019). Debit and credit determination methods are not included in this manual but are outlined in the COMP. Users are strongly encouraged to contact the Corps to obtain project-specific direction. Not all portions of the CSQT or Debit Calculator workbooks will be applicable to all projects. Figure 1 can assist in navigating the user manual for specific project types.

The CSQT can also help determine if a proposed site has the potential to be considered for a stream restoration or mitigation project and provides a framework to guide restoration planning. The catchment assessment and restoration potential process accompanying the CSQT (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, performance standards, and monitoring plans can be developed that link restoration activities to measurable changes in stream functional categories and function-based parameters assessed by the tool.

Figure 1: Manual Directory



KEY CONSIDERATIONS

The CSQT and supporting documentation have been developed to meet the function-based approaches set forth in the 2008 Rule. Therefore, the following concepts are critical in understanding the applicability and limitations of this 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 CSQT is designed to assess the same metrics at a site over time, thus providing information on the degree to which the condition of the stream system changes following impacts or restoration activities. We refer to the CSQT as a change 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 CSQT itself does not score or quantify watershed condition. Watershed condition reflects the external elements that influence functions within a project reach and may affect project site selection or the restoration potential of a site (see Chapter 3).
- The CSQT is not a design tool. Many function-based parameters are critical to a successful restoration design but sit outside of the scope of the CSQT. The CSQT instead measures the hydraulic, geomorphological and ecological responses or outcomes related to a project at a reach scale.

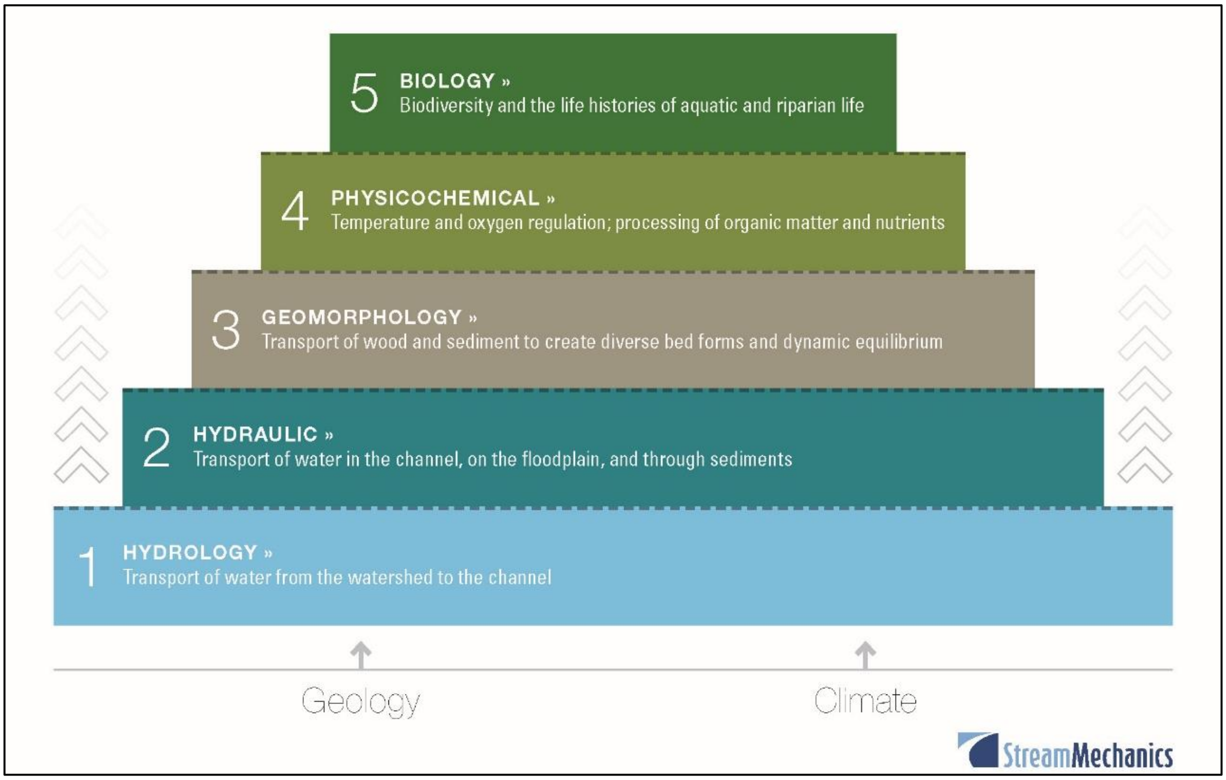
Chapter 1. Background and Introduction

The Colorado Stream Quantification Tool and Debit Calculator (CSQT) is an application of the Stream Functions Pyramid Framework (SFPF). Therefore, to understand the structure of the CSQT, it's important to first understand the SFPF. This chapter provides a brief overview of the SFPF followed by an overview of the elements included in the CSQT and Debit Calculator workbooks.

1.1. Stream Functions Pyramid Framework (SFPF)

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.[1] 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.

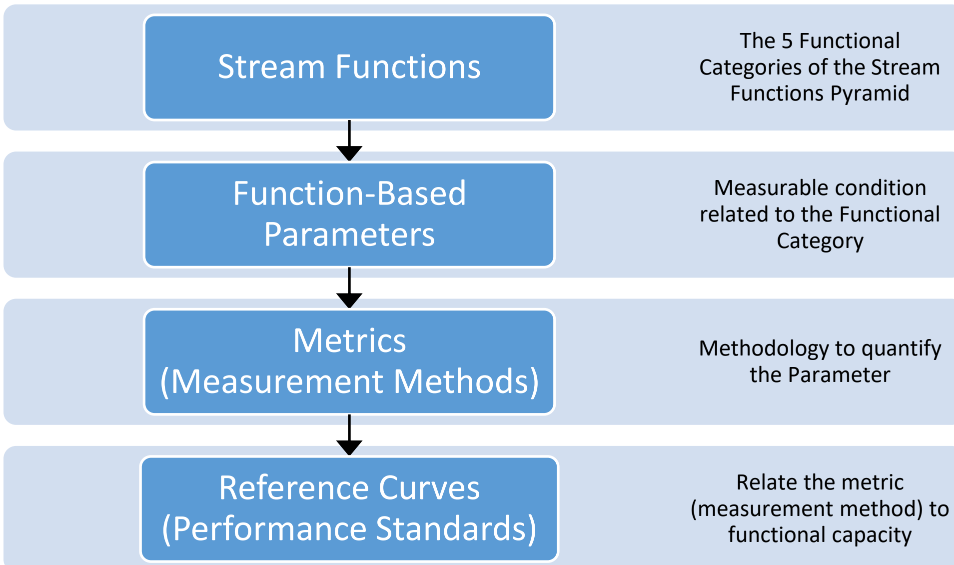
Figure 2: Stream Functions Pyramid (Image from Harman et al. 2012)



[1] The CSQT merges the original Hydrology and Hydraulics categories into a new combined category (referred to as the Reach Hydrology and Hydraulics Category). This change was made to provide more proportional weighting within the CSQT.

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

Figure 3: Stream Functions Pyramid Framework



This comprehensive framework includes more detailed forms of analysis to quantify stream functions and functional indicators of underlying stream processes. In this framework, function-based parameters describe and support the functional statements of each functional category, and the 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.

1.2. Colorado Stream Quantification Tool and Debit Calculator (CSQT)

Following the SFPF, function-based parameters and metrics were selected to quantify stream condition across the ecoregions and stream types found in the western U.S. Each metric is linked to reference curves that relate measured field values to a regional reference condition. In the CSQT, 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 not-functioning conditions (Table 1). The reference curves in the CSQT 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.[2]

[2] 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 CSQT (CSQT SC 2019).

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

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 supports aquatic ecosystem structure and function at a reference standard condition. A score of 1.00 does not represent the best attainable condition, but an unaltered or pristine system. A score of 0.70 represents a system that is attaining a high level of function 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 aquatic ecosystem structure and function. 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 toward 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 aquatic ecosystem structure and function. A score of 0.29 represents a condition that is severely altered or impaired relative to reference conditions, and a score of 0.00 represents a condition that is indicative of no functional capacity.	0.00 to 0.29

The CSQT workbook (CSQT_BETA version.xls) is a Microsoft Excel Workbook comprised of 8 worksheets. There are no macros in the workbook and all formulas are visible, though some worksheets are locked to prevent editing. One workbook should be assigned to each project reach within a project area. Each of the following worksheets is described in this Section.

The CSQT worksheets include:

- Project Assessment
- Catchment Assessment
- Quantification Tool (locked)
- Flow Alteration Module (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 Debit Calculator workbook (CSQT Debit Calculator_BETA version.xls) is a Microsoft Excel Workbook comprised of 5 worksheets. There are no macros in the workbook and all formulas are visible, though some worksheets are locked to prevent editing. One workbook should be assigned to each project reach within a project area. Each of the following worksheets is described in this Section.

The Debit Calculator worksheets include:

- Project Assessment
- Quantification Tool (locked)
- Debit Tool (locked)
- Flow Alteration Module (locked)
- Reference Curves (locked)
- Pull Down Notes – This worksheet is hidden and contains all the inputs for drop down menus throughout the workbook.

1.2.A. Project Assessment Worksheet

The Project Assessment worksheet allows for a description of the project reach, the proposed project, and its effect on the stream within the project area. This worksheet is included in both CSQT and Debit Calculator workbooks, but contains different components, as described below.

This worksheet will communicate the goals of the project and its associated restoration potential. 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.

Components of the Project Assessment Worksheet

Programmatic Goals (CSQT only) – 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, TMDL, Grant, or Other.

Reach Description (CSQT and Debit Calculator) – 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 Section 2.4.

Aerial Photograph of Project Reach (CSQT and Debit Calculator) – 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.

Restoration Approach (CSQT only) – In Box 1, the user should explain programmatic goals, discuss restoration potential, and define project goals and objectives (see Example 1).

Box 2 should be used to explain the connection between the restoration potential and the programmatic goals. The restoration potential can be classified as partial or full restoration, and this classification comes from the Catchment Assessment worksheet (see below).

Finally, Box 3 should be used to describe the function-based goals and objectives of the project. 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 improvements to reach hydrology and hydraulics, and/or geomorphology 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

This worksheet is present in the CSQT workbook, but not the Debit Calculator workbook. The Catchment Assessment worksheet assists in characterizing watershed processes and stressors that exist outside of the project reach but affect functions and processes within the reach. It also highlights factors necessary to consider or address during the project design to maximize the likelihood of a successful project. This worksheet contains 12 categories to be rated as Good, Fair, or Poor. 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. Based on the category ratings, the user should provide an overall watershed condition and determine the restoration potential for the reach. The user should refer to Section 3.2.a for determining the Restoration Potential for the reach. Detail on rating the 12 categories is provided in Section 2.2.

1.2.C. Quantification Tool Worksheet

This worksheet is included in the CSQT and Debit Calculator workbooks. The Quantification Tool worksheet calculates the change in condition scores based on data entry describing the existing and proposed conditions of the project reach. The Quantification Tool worksheet contains three areas for data entry: Site Information and Reference Selection, Existing Condition Assessment field values, and Proposed Condition Assessment field values. Cells that allow input are shaded gray and all other cells are locked. Each section of the worksheet is discussed below.

Site Information and Reference Selection

The Site Information and Reference Selection section consists of general site information and classifications to determine which reference curve(s) to apply in calculating index values for relevant metrics (Figure 4). Information on each input field and guidance on how to select values are provided in Section 2.4. The restoration potential field is linked to the input cell on the Catchment Assessment worksheet and the reference stream type is linked to the input cell on the Project Assessment worksheet.

Figure 4: Example Site Information and Reference Selection Input Fields

Site Information and Reference Selection	
Project Name:	Halfmoon Example
Reach ID:	1
Restoration Potential:	Partial
Existing Stream Type:	C
Reference Stream Type:	Ba
Ecoregion:	Mountains
Biotype:	1
Drainage Area (sq.mi.):	23.4
Proposed Bankfull Width (ft):	25
Proposed Bed Material:	Gravel
Project Reach Stream Length - Existing (ft):	1000
Project Reach Stream Length - Proposed (ft):	1200
Stream Slope (%):	0.5
River Basin:	Arkansas
Stream Temperature:	WS-I
Reference Vegetation Cover:	Forested
Stream Productivity Class:	Moderate
Valley Type:	Confined Alluvial

Existing and Proposed Condition Assessment Data Entry

Once the Site Information and Reference Selection section has been completed, the user can input data into the field value column of the Existing and Proposed Condition Assessment tables (Figure 5).

A user will rarely input data for all metrics or parameters within the tool. Guidance on parameter selection is provided in Chapter 2.3. The function-based parameters and metrics are listed by functional category, starting with Reach Hydrology and Hydraulics. Multiple tables in the CSQT are color-coded to show the delineation between functional categories: blue for reach hydrology and hydraulics, orange for geomorphology, yellow for physicochemical, and green for biology.

The Existing Condition Assessment field values are derived from data collection and analysis methods outlined in Chapter 2 and Appendix A. For some metrics, methods include both rapid and more detailed forms of data collection; field values can be calculated using data from either rapid or more comprehensive site assessment. 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 restored and impacted conditions. For the Proposed Condition Assessment, the user should rely on available data to estimate proposed condition field values. The same parameters used to calculate 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-project condition of the stream reach should be based on project design studies and calculations, drawings, field investigations, and best available science.

Figure 5: Example Field Value Data Entry in the Condition Assessment Table

Functional Category	Function-Based Parameter	Metric	Field Value
Reach Hydrology & Hydraulics	Reach Runoff	Land Use Coefficient	65
		Impervious Cover (%)	
		Concentrated Flow Points (#/1000 LF)	0
		Water Quality Capture Volume	
	Baseflow Dynamics	Average Velocity (fps)	4
		Average Depth (ft)	0.72
	Floodplain Connectivity	Return Interval (yr)	
		Bank Height Ratio	1
		Entrenchment Ratio	14
		Percent Side Channels (%)	25
Geomorphology	Large Woody Debris	LWD Index	250
		No. of LWD Pieces/ 100 meters	
	Lateral Migration	Greenline Stability Rating	
		Dominant BEHI/NBS	VL/M
		Percent Streambank Erosion (%)	7
		Percent Armoring (%)	10
	Bed Material Characterization	Size Class Pebble Count Analyzer (p-value)	
	Bed Form Diversity	Pool Spacing Ratio	3.9
		Pool Depth Ratio	2
		Percent Riffle (%)	56
		Aggradation Ratio	1.2
	Plan Form	Sinuosity	1
	Riparian Vegetation	Riparian Width (%)	70
		Woody Vegetation Cover (%)	80
		Herbaceous Vegetation Cover (%)	
		Percent Native Cover (%)	80
Physicochemical	Temperature	Daily Maximum Temperature (°C)	20
		MWAT (°C)	
	Dissolved Oxygen	Dissolved Oxygen Concentration (mg/L)	7
	Nutrients	Chlorophyll a (mg/m2)	50
Biology	Macroinvertebrates	CO MMI	40
	Fish	Native Fish Species Richness (% of Expected)	65
		SGCN Absent Score	
		Wild Trout Biomass (% Change)	

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 scores that are used to calculate functional change.

Index Values – The reference curves available for each metric are visible in the Reference Curves worksheet. When a field value is entered for a metric on the Quantification Tool worksheet, these reference curves are used to calculate an index value.

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 a numeric index value, the Site Information and Reference Selection section may be missing data (Example 2b).

If the worksheet does not return a numeric index value, the user should check the Site Information and Reference Selection for data entry errors and then check the stratification for the metric in the Reference Curve worksheet. Note that incorrect information in the Site Information and Reference Selection section may result in applying reference curves that are not suitable for the project.

Example 2: Populating Index Values in CSQT

(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 Selection section of the worksheet.

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

Scoring – In the CSQT, scores are averaged within each level of the stream functions pyramid framework. 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 scores; overall score weighting by category is shown in Table 2. Category scores are additive, so a maximum overall score of 1.00 is only possible when parameters within all four categories are evaluated. For example, if only Reach Hydrology & Hydraulics and Geomorphology parameters are evaluated, the maximum overall score will be 0.60. Additional discussion of and rationale for scoring is provided in the Scientific Support for the CSQT (CSQT SC 2019).

Figure 6: Scoring Example

Functional Category	Function-Based Parameter	Parameter	Category	Category
Reach Hydrology & Hydraulics	Reach Runoff	0.46	0.50	Functioning At Risk
	Baseflow Dynamics	0.59		
	Floodplain Connectivity	0.44		
Geomorphology	Large Woody Debris	0.16	0.31	Functioning At Risk
	Lateral Migration	0.30		
	Bed Material Characterization			
	Bed Form Diversity	0.23		
	Plan Form	0.36		
	Riparian Vegetation	0.49		
Physicochemical	Temperature	0.39	0.40	Functioning At Risk
	Dissolved Oxygen	0.47		
	Nutrients	0.35		
Biology	Macroinvertebrates	0.07	0.13	Not Functioning
	Fish	0.19		

Table 2: Functional Category Weights

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

Calculating Functional Feet – The change at an impact or mitigation site is the difference between the existing (pre-project) and proposed (post-project) overall scores. Existing and proposed condition scores are multiplied by stream length to calculate the change in functional feet (ΔFF).

The Quantification Tool worksheet calculates change 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. $\text{Change in FF } (\Delta FF) = Proposed\ FF - Existing\ FF$

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.

Color Coded Scoring – When index values are populated in the Quantification Tool worksheet, cell colors will automatically change color to identify where on the reference curve the field value lies (Figure 6). Green coloring indicates field values and index scores that represent a functioning (reference standard) range of condition; yellow indicates field values and index scores that represent a functioning-at-risk range of condition; and, red indicates field values and index scores that represent a not-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 CSQT workbook (both are described below). Note that color coding is not provided for the overall 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.

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 Selection 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 (ΔFF).

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 (Proposed FF – Existing FF) is the amount of functional lift or loss resulting from the project. Functional change is also expressed as the percent change in functional feet for a project reach:

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

Figure 7: Example Functional Change Summary Table

FUNCTIONAL CHANGE SUMMARY	
Existing Condition Score (ECS)	0.44
Proposed Condition Score (PCS)	0.75
Change in Functional Condition (PCS - ECS)	0.31
Existing Stream Length (ft)	2000
Proposed Stream Length (ft)	2500
Change in Stream Length (ft)	500
Existing Functional Feet (FF)	880
Proposed Functional Feet (FF)	1875
Proposed FF - Existing FF (ΔFF)	995
Percent Change in FF (%)	113%
ΔFF from Flow Alteration Module	441.70
Total Proposed FF - Existing FF (ΔFF)	1436.70

This summary table includes the change in functional feet (ΔFF) calculated in the Flow Alteration Module and adds that value to the ΔFF for the project reach to generate the total ΔFF calculated in the CSQT or Debit Calculator workbooks. The Flow Alteration Module is described in the Section 1.2.d.

Mitigation Summary –This summary table (Figure 7) also reports the change in functional feet (ΔFF) that results from the reach-scale restoration activities and the Flow Alteration Module. 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. Note that the Flow Alteration Module covers an affected stream length that is separate from the project reach length (see Section 2.9). Where multiple project reaches are covered by the affected stream length of the Flow Alteration Module, the user would only enter data into the Flow Alteration Module of one workbook.

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. above.

Figure 8: Example Functional Category Report Card

FUNCTIONAL CATEGORY REPORT CARD			
Functional Category	**ECS**	**PCS**	**Functional Change**
Reach Hydrology & Hydraulics	0.50	0.80	0.30
Geomorphology	0.33	0.80	0.47
Physicochemical	0.40	0.65	0.25
Biology	0.13	0.15	0.02

Function-Based Parameters Summary – This summary 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 and serves as a quality control check to see if a parameter was assessed for both the existing and proposed condition assessments. For example, the parameter summary table illustrates which parameters within the geomorphology functional category were assessed and contributing to the overall lift at the site. The color coding within this table is described in Section 1.2.c. above.

Figure 9: Example Function-Based Parameters Summary Table

FUNCTION BASED PARAMETERS SUMMARY			
Functional Category	**Function-Based Parameters**	**Existing Parameter**	**Proposed Parameter**
Reach Hydrology & Hydraulics	Reach Runoff	0.46	0.46
	Baseflow Dynamics	0.59	1.00
	Floodplain Connectivity	0.44	0.94
Geomorphology	Large Woody Debris	0.16	0.32
	Lateral Migration	0.40	1.00
	Bed Material Characterization		
	Bed Form Diversity	0.23	0.89
	Plan Form	0.36	1.00
	Riparian Vegetation	0.49	0.80
Physicochemical	Temperature	0.39	0.89
	Dissolved Oxygen	0.47	0.70
	Nutrients	0.35	0.35
Biology	Macroinvertebrates	0.07	0.12
	Fish	0.19	0.19

1.2.d. Monitoring Data Worksheet

This worksheet is included in the CSQT workbook, but not the Debit Calculator workbook. 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 17). 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, e.g., 1 for the first growing season post-project. The methods for calculating index values and scoring are identical to the Quantification Tool worksheet (Section 1.2.c).

In order to calculate functional change, the same metrics must be used in each condition assessment. In other words, if a value is entered for a metric in the Existing Condition Assessment, a field value must also be entered for the As-Built Condition and for monitoring events in the Monitoring Data worksheet. Field values in in the Monitoring Data worksheet should only be entered for the appropriate monitoring events. A condition assessment is not likely to be completed every calendar year.

1.2.e. Data Summary Worksheet

This worksheet is included in the CSQT workbook, but not the Debit Calculator. 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.f. Flow Alteration Module Worksheet

This worksheet is included in the CSQT and Debit Calculator workbooks. The Flow Alteration Module worksheet is a supplementary calculator where users enter data describing the existing and proposed hydrologic conditions of an affected stream reach. The Flow Alteration Module worksheet contains three areas: Site Information, Condition Assessments, and the Functional Change Summary. Cells that allow input are shaded gray and all other cells are locked. Each section of the worksheet is discussed below.

<u>Site Information</u>:

The Site Information section consists of general site information and the affected stream length. Guidance on how to determine the affected stream length is provided in Section 2.1.

<u>Condition Assessment Data Entry</u>:

Once the Site Information section has been completed, the user can input data into the field value columns of the Existing, Proposed, or monitoring Condition Assessment tables. In the CSQT, there are 10 monitoring condition assessment tables in the Flow Alteration Module worksheet. The monitoring years must be entered on this sheet and should match the monitoring years entered for the project reach on Monitoring Data worksheet. Data entry for monitoring events is discussed in detail in Section 1.2.d.

The user will input field values for the applicable metrics within the module (Figure 10). Guidance on metric selection and calculation is provided in Section 2.9.

Figure 10: Example Flow Alteration Module Condition Assessment

Metric	Field Value	Index Value	Module
Mean Annual Q (O/E)	0.52	0.58	0.70
Mean Aug Q (O/E)	0.65	0.72	
Mean Sept Q (O/E)	0.88	0.98	
Mean Jan Q (O/E)	0.71	0.79	
Mean Annual Peak Daily Q (O/E)	0.56	0.62	
7-Day Minimum (O/E)	0.48	0.53	

The Flow Alteration Module is a hydrologic assessment of functional change between existing and proposed conditions. The Existing Condition Assessment field values are derived from data collection and analysis methods outlined in Chapter 2 which require daily or monthly time step flow records. The Proposed Condition Assessment field values should be generated through altering the pre-project condition flow record to reflect the proposed hydrology according to operational commitments, acquisition/ change of existing water rights, or new facilities that enable the proposed hydrology to occur. 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.

SCORING FUNCTIONAL LIFT AND LOSS

Scoring in the Flow Alteration Module is similar to the scoring described in Section 1.2.c. for the Quantification Tool worksheet. Scoring occurs automatically as field values are entered into the Condition Assessment tables. Metric index values are averaged to calculate a module score as shown in Figure 10.

Functional lift is generated when the existing condition is more functionally impaired than the proposed condition. A negative value would represent a functional loss. Existing and proposed module scores are multiplied by the affected stream length to calculate the existing and proposed functional feet (Figure 11). Since the Flow Alteration Module only assesses hydrology, the module score is weighted by 20%. Functional feet are calculated by multiplying the weighted score by affected stream length. The ΔFF from the Flow Alteration Module is then added to the ΔFF in the Quantification Tool worksheet.

Figure 11: Example Flow Alteration Module Functional Change Summary Table

FUNCTIONAL CHANGE SUMMARY	
Module Existing Condition Score (mECS)	0.79
Module Proposed Condition Score (mPCS)	0.83
Change in Functional Condition (mPCS - mECS) *	0.01
Affected Stream Length (ft)	55213
Existing Functional Feet (FF)	43618
Proposed Functional Feet (FF)	45827
Proposed FF - Existing FF (ΔFF) *	442
Percent Change in FF (%)	1%

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, Monitoring Data, and Flow Alteration Module worksheets. This worksheet is present in both the CSQT and Debit Calculator workbooks. For information on reference curves, refer to Section 1.2. *This worksheet is included for information purposes and does not require any data entry. This worksheet is locked to protect the calculations used to convert field values to index values.*

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 not-functioning conditions (Table 1, page 13). Reference curves are tied to specific benchmarks (thresholds) that represent the degree to which the reach condition departs from reference standard as described in Table 1. 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 CSQT (CSQT SC 2019).

There may be instances where better data to inform reference standard and index values are available for a project. The Corps can approve an exception to using the reference curves and index values for a metric within the CSQT where sufficient data are available to identify reference standards.

1.2.H. DEBIT TOOL WORKSHEET

This worksheet is only present in the Debit Calculator workbook, and not in the CSQT workbook. The Debit Tool worksheet is where users enter data describing the impacts to each reach and select an impact severity tier. The Debit Tool worksheet is also used to estimate functional loss for projects when data to inform proposed condition scores are not available.

The Debit Tool worksheet contains three areas for data entry: Debit Option, Site Information, and Impact Severity Tier. Cells that allow input are shaded gray and all other cells are locked. This worksheet also includes a table describing the impact severity tiers, an ECS table, a PCS Calculator, and a Functional Loss Summary table.

DEBIT OPTION

There are three options for calculating functional loss at an impact site. Users should select Option 1, 2 or 3 from the dropdown menu. These options are described below and summarized in Table 3; additional detail is provided in the COMP (USACE 2019).

1. Option 1 calculates functional loss using the Quantification Tool worksheet (Section 1.2.c). For this option, the user must conduct an existing condition assessment within the project reach. If a project has a Tier 0-3 level of impact (Table 4, page 27), only Reach Hydrology & Hydraulics and Geomorphology metrics need to be assessed. For this option, the user should be able to accurately predict the functional loss within the Reach Hydrology & Hydraulics and the Geomorphology categories using project design reports, drawings, and/or field investigations. For projects that impact physicochemical or biological functions (Tier 4-5 impacts), physicochemical and biological parameters should also be evaluated or a

default existing condition score should be entered into the Quantification Tool worksheet. The default existing condition score is 0.80, except in Outstanding Waters where the default score is 1.00. For Tier 4-5 impacts, the user must also be able to reasonably predict how the project will affect physicochemical and biology parameters.

2. Option 2 calculates functional loss using a combination of existing condition assessment data from the Quantification Tool worksheet (Section 1.2.c) and the formulas in the Debit Tool worksheet to calculate functional loss. For this option, the user must conduct an existing condition assessment of the project reach in the same way as Option 1. The Debit Tool worksheet will automatically populate existing condition information entered in the Quantification Tool worksheet. The user will then enter necessary information into the Debit Tool worksheet, including an Impact Severity Tier (Table 4), and the Debit Tool worksheet will generate a proposed condition score, and a suite of summary information including the change in functional feet.

3. Option 3 calculates functional loss using only the Debit Tool worksheet. Users do not need to conduct an existing condition assessment. For this option, the Debit Tool worksheet relies on a default existing condition score (ECS). Just as with Option 2, the Debit Tool calculates the proposed (post-impact) condition score and functional loss. This option is the fastest and easiest method for determining functional loss.

Table 3: Summary of Debit Options

Debit Option	Existing Condition Score (ECS)	Proposed Condition Score (PCS)
1	Assess existing condition using Quantification Tool worksheet	Estimate proposed condition using Quantification Tool worksheet
2	Assess existing condition using Quantification Tool worksheet	Use Debit Tool worksheet
3	Use Debit Tool worksheet	Use Debit Tool worksheet

SITE INFORMATION:

The Site Information section of the Debit Tool worksheet includes space to enter the permit number, project name, reach ID, existing and proposed stream lengths (measured in linear feet) and whether the project reach occurs within an Outstanding Water.

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.

Proposed Stream Length – Calculate the anticipated length of stream channel after the impact has occurred. For artificial water conveyances, the proposed length is the length of the conveyance. If the stream will be straightened by the permitted activity, the proposed stream length will be less than the existing stream length.

Outstanding Water – Indicate whether the project reach occurs within an Outstanding Water segment of stream.[3] User should select Y or N in the dropdown menu.

IMPACT SEVERITY TIER:

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. The explanatory text should include a description of the proposed project, any anticipated impacts to aquatic ecosystem functions and parameters within the project reach, and justification for Impact Severity Tier selection. Information to support tier selection may include project plans and documents, permit applications, and discussions between the permit applicant and the Corps.

Selection of an impact severity tier is needed in order to calculate a proposed condition score using the Debit Tool worksheet. The impact severity tier is a categorical determination of the adverse impact to stream functions, ranging from no permanent loss (Tier 0) to total permanent loss (Tier 5). Table 4 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.

Table 4: 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, utility crossings.
2	Impacts to riparian vegetation, lateral migration, and bed form diversity	Utility crossings, bridges, channel stabilization, bottomless arch culverts
3	Impacts to riparian vegetation, lateral migration, bed form diversity, and floodplain connectivity	Bottomless arch culverts, channelization, grade control
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	Loss of all aquatic functions	Pipes, relocation, fill of small channels from mining or development

CALCULATING FUNCTIONAL LOSS

The Debit Tool worksheet calculates the proposed condition score based on which impact severity tier is selected (Table 5). For example, impacts within Tiers 1 – 3 result in functional losses to Reach Hydrology & Hydraulics and Geomorphology functions, while Tier 4-5 impacts result in loss across all functional categories. The percent loss associated with impact severity

[3] Outstanding Waters relies on the CDPHE designation; maps can be found on the CDPHE website or the CNHP Watershed Planning Toolbox https://cnhp.colostate.edu/cwic/tools/toolbox/

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 relies on a default existing condition unless data are provided in the existing condition assessment of the Quantification Tool worksheet. The default existing condition score is 0.80, except in Outstanding Waters where the default score is 1.00.

Table 5: 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%

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 12).

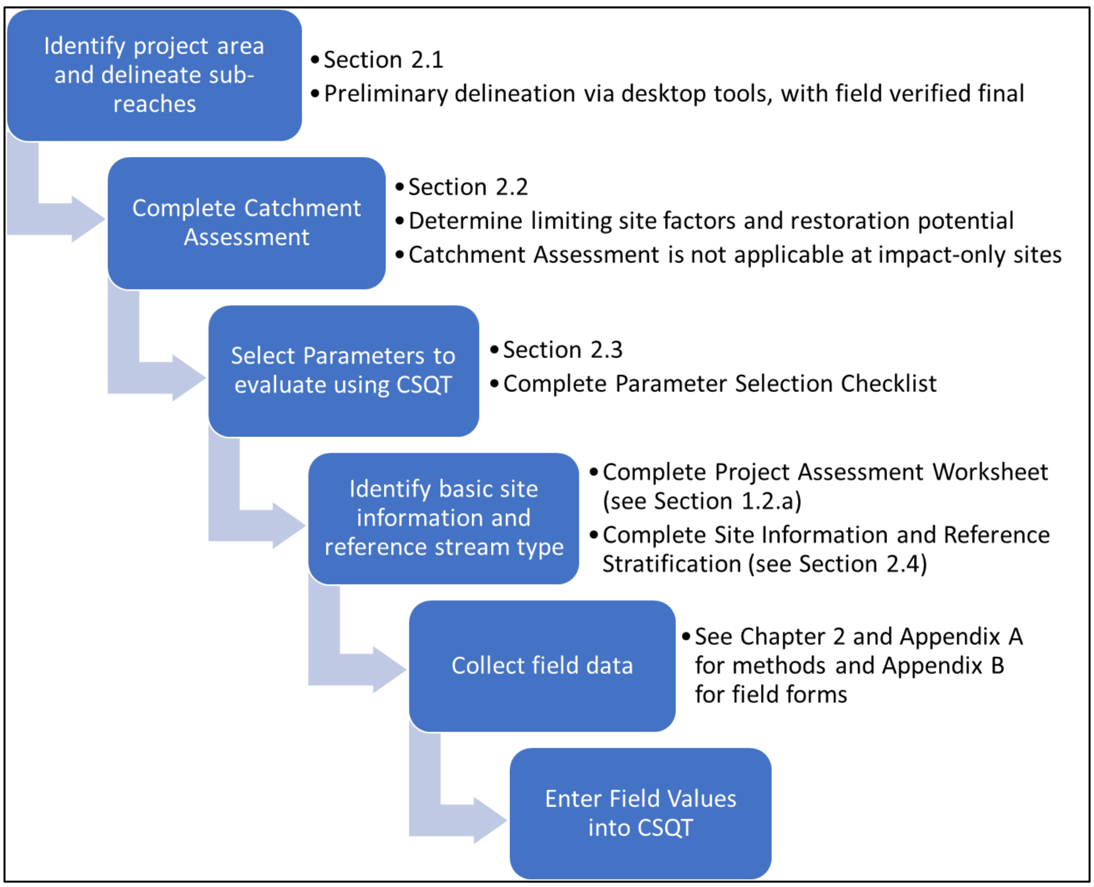
Figure 12: Debit Option 2 Functional Loss Summary Example –Tier 3 Impact

FUNCTIONAL LOSS SUMMARY	
Existing Condition Score (ECS)	0.24
Proposed Condition Score (PCS)	0.09
Condition Loss	-0.15
Existing Stream Length (ft)	2500
Proposed Stream Length (ft)	2300
Proposed - Existing Stream Length (ft)	-200
Existing Functional Feet (FF)	600
Proposed Functional Feet (FF)	207
Proposed FF - Existing FF (ΔFF)	**-393**
Functional Loss (%)	-66%

Chapter 2. Data Collection and Analysis

This chapter provides instruction on how to collect and analyze data used in the CSQT and Debit Calculator workbooks. Figure 13 provides a flow chart of the typical process. Individuals collecting and analyzing these data should have experience and expertise in botany, ecology, hydrology, and geomorphology. Interdisciplinary teams with a combination of these skill sets 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. Additionally, the analysis for the Flow Alteration Module and the water quality capture volume metric require training and experience with hydrologic modeling and analyses, although these are optional components within the CSQT.

Figure 13: CSQT Process Flow Chart



This chapter includes methods for metrics that can be evaluated in the office, steps for calculating metrics, as well as a summary of field methods. For some metrics, multiple field methods are provided that will allow for either rapid or more comprehensive site assessment. Detailed field procedures are provided in Appendix A. Few metrics are unique to the CSQT, 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 CSQT.

2.1. Reach Delineation and Representative Sub-Reach Selection

The CSQT 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 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 or magnitude of impacts. 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 2.1.a and 2.1.b respectively.

The CSQT also includes an optional Flow Alteration Module that requires the user to determine the length of stream affected by a proposed change in flow regime which may be distinct from the reach length entered in the Quantification Tool worksheet. More detail on the affected stream length is provided in Section 2.9.

2.1.a. Delineation of Project Reach(es)

The user should determine whether their project area encompasses a single homogeneous reach, or multiple potential 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. Reaches within a project site may vary in length depending on the variability of the physical stream characteristics within the project area.

Practitioners can use aerial imagery, NHD data and other desktop tools to preliminarily determine reach breaks; these delineations should be verified in the field. Practitioners 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, e.g. 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 changes to valley morphology, stream type (Rosgen 1996) or bed material composition.
- Reach breaks should occur where there are diversion dams or other flow modification structures on the stream, with separate reaches upstream and downstream of the structure. The diversion dam or structure would also be its own reach.
- 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, dams, stabilization, or culverts/pipes. For example, a culvert's footprint would be

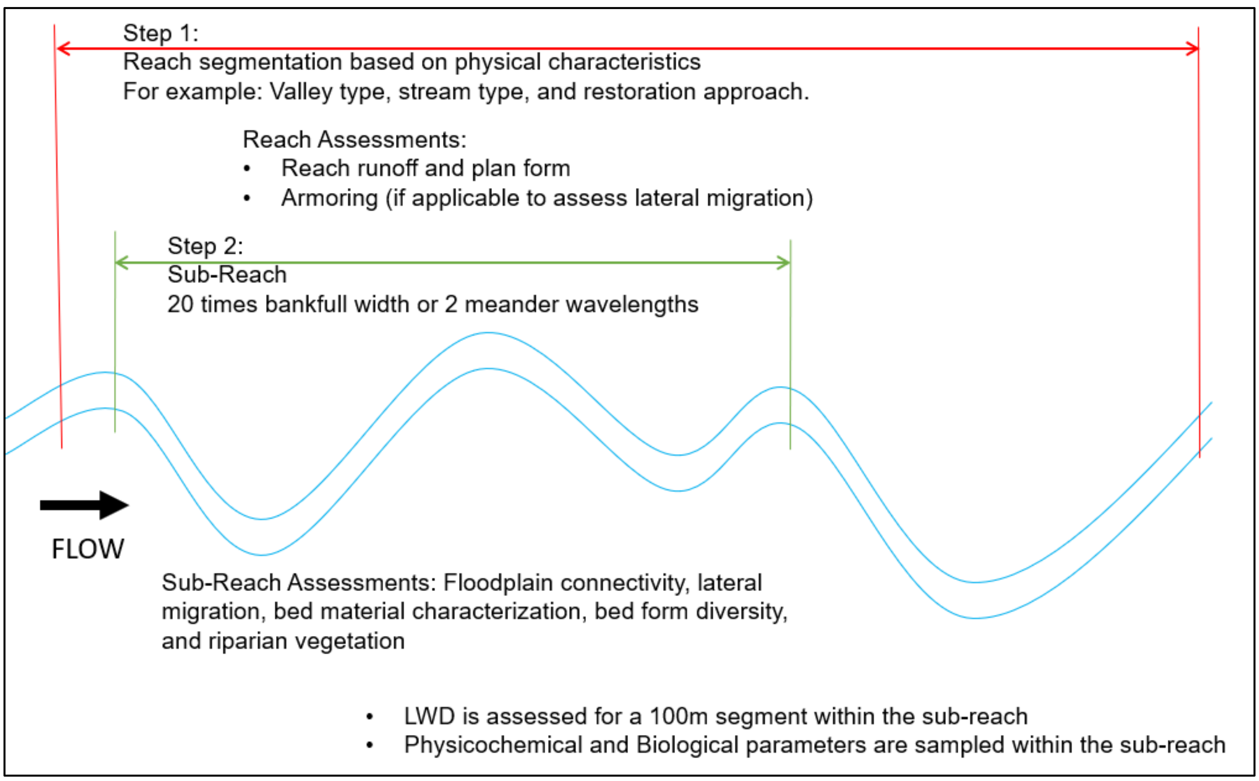
evaluated as a separate project reach from the reaches immediately up and downstream of the culvert.

- Multiple project reaches are needed where there are differences in the magnitude of impact or mitigation approach (e.g., enhancement vs. restoration) within the project area. For example, restoration approaches that reconnect stream channels to their original floodplain versus bank stabilization activities.

2.1.B. Representative Sub-Reach Determination

Some metrics will be evaluated along an entire project reach length, some will be evaluated at a specific point within the project reach and other metrics will be evaluated in a representative sub-reach (Figure 14). Selecting a representative sub-reach is necessary to avoid having to quantitatively assess very long stream lengths with similar physical conditions. The representative-sub reach is 20 times the bankfull width or two meander wavelengths (Leopold 1994), whichever is longer. If the entire reach is shorter than 20 times the bankfull width, then the entire project reach should be assessed. Guidelines are provided below for each functional category.

Figure 14: Reach and Sub-Reach Segmentation



<u>Reach Hydrology & Hydraulics Functional Category</u>:

- Reach runoff metrics are evaluated within the entire project reach.
- Baseflow dynamics metrics are evaluated at riffles in the representative sub-reach.
- Floodplain connectivity is assessed within the representative sub-reach.

<u>Geomorphology Functional Category</u>:

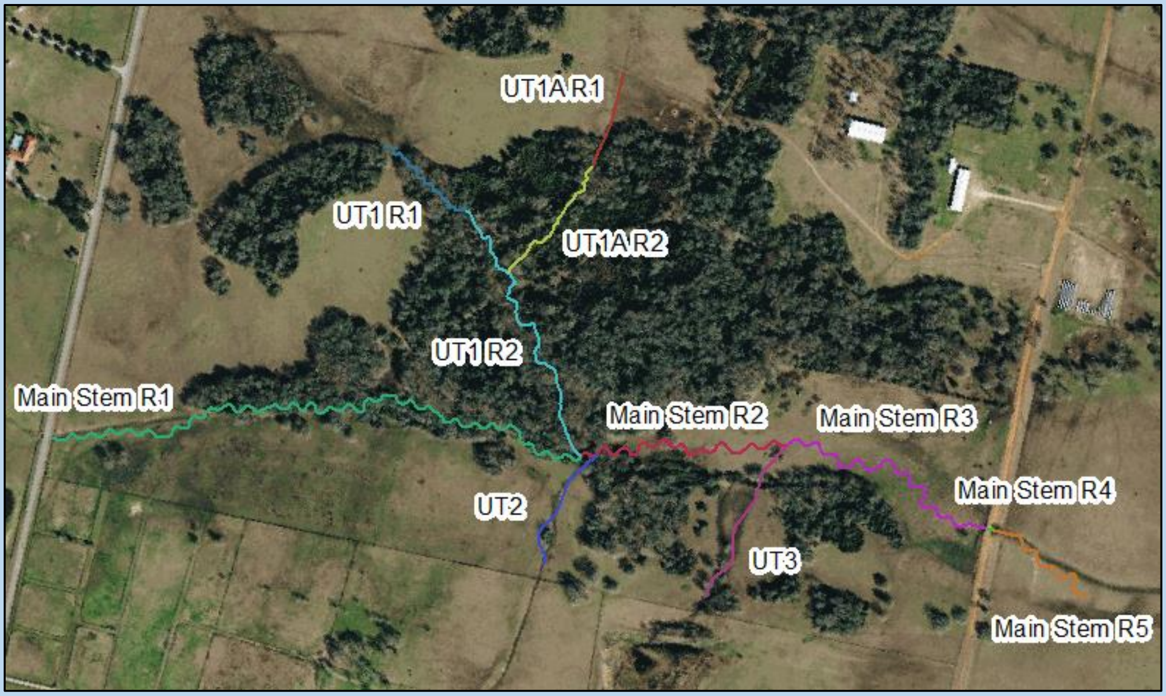
- Large woody debris (LWD) is assessed within a 328-foot (100 meter) segment located, whenever possible, within the representative sub-reach. If the project reach is less than 328 feet, the LWD assessment should extend proportionally into the adjacent upstream and downstream segments to achieve the required stream length.
- Lateral migration, bed material characterization, bed form diversity, and riparian vegetation are assessed within the representative sub-reach. There is one exception. Armoring, which is a metric under lateral migration, is assessed along the entire project reach.
- Sinuosity is assessed over the entire project reach. Where the project reach is less than 20 times the bankfull width, it is not appropriate to evaluate this parameter.

<u>Physicochemical and Biology Functional Categories</u>:

- Sampling should occur within the project reach, but specific locations will vary by metric, and are described in the metric sections in this Chapter and in Appendix A.

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 bed form 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.

2.2. 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.). It is a decision-support tool rather than a quantitative scoring tool. Therefore, results from the Catchment Assessment are not scored in the CSQT, but are used to help inform a restoration potential decision. *The Catchment Assessment worksheet is included in the CSQT workbook, but not the Debit Calculator workbook.*

The Catchment Assessment worksheet includes descriptions of processes and stressors that exist outside of the project reach or conservation easement and may limit functional lift. The Catchment Assessment does not pertain to stressors occurring within the project reach/easement area that can be addressed as part of with restoration activities. The Catchment Assessment evaluates conditions primarily upstream, but sometimes downstream of the project reach. Instructions for collecting data and describing each process and stressor are provided in this section.

The Catchment Assessment relies on data available from various online or local resources and site-specific data that can be obtained through site walks within the project area. There are 11 defined categories, with space for an additional user-defined category. There are three choices to rate the catchment condition for each category: Good, Fair, and Poor. Data needed to assess each category are described below; descriptions of good, fair, and poor are in the Catchment Assessment worksheet. Data used to evaluate each selection should be documented. Once all categories of the Catchment Assessment are completed, the user should provide an overall watershed condition, based on their best professional judgement, and determine the restoration potential for the reach. The user should refer to Section 3.2.a for determining the Restoration Potential for the reach.

IMPOUNDMENTS

Impoundments are structures that can impede longitudinal (river corridor) connectivity. The presence of a dam downstream of a project may 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 a project area. An impoundment that is proximate or otherwise has an adverse effect on the project area and fish passage would result in a lower rating.

The location of dams or other impoundments within the catchment can be determined through field walks, 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.

FLOW ALTERATION

Flow alteration represents the role impoundments, water allocation, and effluent discharges can play in altering catchment hydrology and stream physicochemical and aquatic habitat conditions. Users should consider any alterations to the timing, magnitude, frequency, duration, and rate of change, as compared with the natural flow regime. 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 decreasing or increasing flows). Landscape-scale information can be used to inform conclusions about flow alteration, including dam storage ratios, dam density, the density of agricultural ditches, active points of diversion and decreed instream flow reaches. Dam storage ratios reflect the storage within the watershed compared with the average annual flow, and these data are available through EPA's 2017 Preliminary Healthy Watersheds Assessment for each HUC 12 watershed in Colorado.[4] Other sources of information may include local stream or integrated water management plans, and the Colorado Watershed Planning Toolbox.[5]

A catchment in good condition has a natural flow regime with little to no flow alteration occurring upstream of the project reach. A catchment in poor condition has stream flows that are heavily altered. A fair or poor rating may also occur where more than one aspect of the flow regime is altered (i.e., alterations to the timing, magnitude, frequency, duration and rate of change), or where a single aspect of the natural flow regime is substantially modified.

URBANIZATION

Urbanization represents the influence urban and residential development can have on hydrology and water quality in downstream reaches. Trends in land use can be determined through examining time-series aerial imagery or by examining land cover data available online through the National Land Cover Database (NLCD).[6] The NLCD includes datasets for percent impervious cover, developed, and forested land from 1992, 2001, 2006, and 2011 (2016 data will be available in 2019). 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 CO (e.g., natural cover within the watershed, population density, imperviousness, and road density) and in the Colorado Watershed Planning Toolbox (e.g., landscape disturbance index).

A catchment in good or fair condition for this category would include natural land cover, rural, or otherwise slow-growth-potential communities and land uses. Catchments rated as poor in this category, such as urban or urbanizing communities, have ongoing development or imminent large-scale development.

FISH PASSAGE

This category considers the proximity and effects of anthropogenic barriers that may 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

[4] https://www.epa.gov/hwp/download-2017-preliminary-healthy-watersheds-assessments
[5] https://cnhp.colostate.edu/cwic/tools/toolbox/
[6] https://gapanalysis.usgs.gov/gaplandcover/data/download/

fish, such as culverts, low head dams, grade control structures, and other physical or hydraulic barriers The user should consider whether the flow depth and velocity or vertical height across a structure or barrier may limit movement of certain species or life stages of species historically or naturally present within that catchment. The rating is primarily based on proximity of the project reach to known fish barriers; however, consideration also may be given to whether barriers further away may have effects on fish populations within the reach. A catchment in poor condition for this category may have barriers that create severe limitations to fish passage that adversely affect fish populations within the project reach. A fair condition may represent a catchment where minor fish passage issues are occurring during some, but not all times of the year, or barriers present nearby have been shown not to significantly affect fish populations within the project reach. A catchment in good condition would have no proximate fish barriers, or structures that do not have adverse effects on fish populations. If a structure is proximate to the project reach but has a beneficial effect like serving as a barrier to invasive species, then the catchment may be in good condition.

Information sources described in the flow alteration and impoundment sections can also be used to inform this metric. In addition, consultation with the area fish biologist from Colorado Parks and Wildlife may yield additional information regarding the presence and severity of barriers within the catchment.

ORGANISM RECRUITMENT

This category considers the effects of altered or impaired channel substrates on the potential for recruitment and colonization of aquatic organisms within the stream reach, recognizing that recruitment and colonization is affected by the presence of desired communities in proximity to the project site. Impairments to the channel, such as hardened or armored channels and substrates, excessive sedimentation, culverts, or piping may prevent macroinvertebrate and fish communities from inhabiting a stream reach and extended lengths of channel impairments may reduce the possibility of organism recruitment to the project reach. A catchment in poor condition may have substantial channel impairments preventing desirable species from inhabiting areas immediately upstream or downstream of the project reach (i.e., within 1 km or 0.62 mi), whereas good condition is represented by adjoining reaches with native bed and bank material.

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 immigrate from nearby catchments along non-water avenues (e.g., aerial dispersion, zoochory). This category can be assessed by walking the site and the stream reaches immediately upstream and downstream of the project reach or reviewing aerial imagery to determine if there are any impairments to organism recruitment including excessive deposition of fine sediments, concrete, piped or hardened stretches of channel.

COLORADO INTEGRATED REPORT (305(B) AND 303(D) STATUS) FOR AQUATIC LIFE USES

The Colorado Department of Public Health and Environment (CDPHE), Water Quality Control Division (WQCD) 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 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 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. Spatial information on category 4A and 5 waters is available in the Colorado Watershed Planning Toolbox. 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 rating in this category would indicate that full restoration potential would be difficult or impossible unless a large percent of the catchment is being restored.

There are many waters with degraded biological condition that are unassessed, thus they are absent from the 303(d) list. If recent water quality data have been collected for the reach, then it can be used to inform a condition rating in this category even if the water is not listed as impaired by Colorado WQCD.

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 its proximity to the project site. This category addresses large scale land uses common to Colorado that are often independent from urbanization, including energy development and infrastructure (oil, gas, and wind), mining, timber harvest, and roads. For example, roads or other infrastructure associated with energy development 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 and serve as a source of fine sediment. This category asks the user to assess whether activities are likely to occur within a 1-mile radius of the project, and the potential for those activities to adversely affect 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 Colorado Division of Reclamation Mining and Safety[7] and the Colorado Oil and Gas Conservation Commission.[8] The most recent State Transportation Improvement Program[9] is available from the Colorado Department of Transportation to determine what projects are expected to receive funding during a 4-year time span. Landscape-scale information is also available through EPA's 2017 Preliminary Healthy Watersheds Assessment for each HUC 12 watershed in CO[4] and the Colorado Watershed Planning Toolbox.[5]

CDPS Permits

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[7] https://mining.state.co.us

[8] https://cogccmap.state.co.us

[9] https://www.codot.gov/programs/planning/transportation-plans-and-studies/stip

The Colorado Discharge Permit System (CDPS) 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 CDPS facilities upstream of the project reach while a poor catchment in this category would have CDPS 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. CDPS stormwater and temporary discharge permits are excluded from consideration for this parameter. The Colorado Water Quality Control Division lists the minor and major CDPS permitted facilities.[10]

Riparian Vegetation

This category considers the extent and connectivity of riparian areas within and upstream of the project area. Riparian areas serve as wildlife habitat corridors, as the vegetation protects the stream channel from erosive runoff velocities and provides nutrient and pollutant removal benefits. Catchments in good condition will have natural riparian plant communities extending across the majority (i.e.., more than 2/3) of the 100-year floodplain, and riparian corridors that are largely (i.e., over 80%) contiguous along the contributing catchment stream length. Catchments in poor condition will have limited natural plant communities (i.e., extending across less than 1/3 of the 100-year floodplain), and/or substantial gaps in the riparian corridor (i.e., that exceed 30% or more of the contributing catchment stream length).

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). FEMA floodplain data is available in the Colorado Watershed Planning Toolbox.[5] 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 CO.[4] 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.

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 alterations in 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.

[10] https://www.colorado.gov/pacific/cdphe/water-division-permit-public-actions

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 indicating moderate or high levels of excess sediment, and this is not a naturally occurring condition, then the catchment condition would be considered fair or poor, respectively. If there are only a few small sources of sediment or sediment sources are naturally occurring, then the catchment condition is good.

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.

There are many 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 assessment but could be used to inform this category if WARSSS was applied for other reasons in the project.

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.

2.3. Parameter Selection

The CSQT and Debit Calculator workbooks includes 34 metrics used to quantify 14 parameters. They also includes a Flow Alteration Module that adds (or subtracts) functional feet to the reach score based on the magnitude of flow alteration within a larger, hydrologically affected reach. Not all metrics and parameters will need to be evaluated at each site. The user should consider landscape setting and function-based goals/objectives and restoration potential when selecting parameters. A parameter selection checklist is provided in Appendix B and should be completed for each project using the guidance in this section.

IMPORTANT CONSIDERATIONS:

- For CWA 404 projects, the Corps has discretion over which field methods, metrics, and parameters are used for a project. Users should complete the Parameter Selection Checklist and consult with the Corps prior to data collection on a project.

- The same parameters must be used in the existing condition and all subsequent condition assessments (i.e., proposed, as-built, and monitoring) within a project reach, otherwise the relative weighting between metrics and parameters changes and the overall scores are not comparable over time.
- For metrics that are not selected (i.e., a field value is not entered), the metric is not included in the scoring. It is NOT counted as a zero.
- The overall scores should not be compared or contrasted between sites when parameters and metric selection varies between project sites. To evaluate multiple sites, the same suite of parameters and metrics would need to be collected at all sites.
- The reach runoff, floodplain connectivity, lateral migration, riparian vegetation, and bed form diversity parameters should be evaluated at all sites. These parameters are important indicators of the stability and resiliency of stream systems. The 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.
- Field methods in Appendix A are focused on single-thread, wadeable streams. Some metrics may be difficult to sample in non-wadeable or multi-thread systems and may require alternate field methodologies. For CWA 404 projects, sampling plans in these systems should be discussed with the Corps prior to data collection efforts.
- Reference curves to assign index values have been primarily derived from data within perennial, wadeable, single-thread stream systems. When applying metrics in other stream situations, such as multi-thread systems or ephemeral channels, the user should note this and select only applicable parameters and metrics (Table 6). While a parameter and associated metrics may be applicable to ephemeral and multi-thread channels, the user should understand that the reference curves are not from these systems. Therefore, more focus should be placed on the difference in functional condition rather than the absolute value.

Table 6: ***Applicability of metrics across flow type and in multi-thread systems. An 'x' denotes that one or more metrics within a parameter is applicable within these stream types.***

Applicable Parameters	Perennial	Intermittent	Ephemeral	Multi-thread Channels
Reach Runoff	x	x	x	x
Base Flow Dynamics	x	x		x
Floodplain Connectivity	x	x	x	x
Large Wood	x	x	x	x
Lateral Migration	x	x	x	x
Bed Material	x	x	x	x
Bedform Diversity	x	x		
Planform	x	x		
Riparian Vegetation	x	x	x	x
Temperature	x	Where baseflows extend through index period		x
Dissolved Oxygen	x	Where baseflows extend through index period		x
Nutrients	x	Where baseflows extend through index period		x
Macroinvertebrates	x	Where baseflows extend through index period		x
Fish	x	x		x
Flow Alteration Module	x			

SPECIFIC GUIDANCE ON PARAMETER SELECTION:

Reach Runoff Parameter: This parameter should be evaluated at all project sites. Users can select from the following options:

1. The land use coefficient and concentrated flow point metrics are recommended for projects in agricultural or low-development watersheds.
2. The impervious cover and concentrated flow point metrics are recommended in urban or rapidly developing watersheds.
3. The Water Quality Capture Volume (WQCV) metric is recommended in urban or developing areas where stormwater best management practices can be applied to address altered hydrology from land use change.

Baseflow Dynamics Parameter: This parameter is optional and should only be applied in single-thread intermittent and perennial cold-water streams (CS; see Stream Temperature in Section 2.4). This parameter is recommended where hydraulic conditions during summer/fall baseflow periods may not support trout assemblages under existing or proposed conditions due to flow or channel alteration. Both metrics should be evaluated together.

Floodplain Connectivity Parameter: This parameter should be evaluated at all project sites. Users must evaluate either the return interval and entrenchment ratio (ER) metrics or the bank height ratio (BHR) and ER metrics. The percent side channels metric is optional and is applied in valley settings that support side channels. Additional guidance on metric selection follows:

1. The return interval metric is recommended where the bankfull feature cannot be identified, flow alteration has changed the return interval associated with the bankfull feature, or the practitioner is more experienced with hydrologic modeling than field determination of the bankfull stage. This should be applied in combination with the ER metric.
2. The BHR and ER metrics are complimentary, as each of these metrics contributes differently to an overall understanding of floodplain connectivity; therefore, they should be applied together. The only exception is in multi-thread systems, where the BHR should be applied, but the ER is not applicable.
3. The percent side channel metric is optional and should be applied in alluvial valley types that naturally support secondary channels.

Large Woody Debris (LWD) Parameter: This parameter is optional and is recommended where the upstream watershed or adjacent land area naturally support, or historically supported, trees large enough to produce LWD. This parameter is not applicable to streams that lack forested catchments, riparian gallery forests, or otherwise naturally have a limited supply of LWD. Users can evaluate either the Large Woody Debris Index (LWDI) or large wood piece count metric, but not both. The LWDI metric better characterizes the complexity of large wood in streams but takes more time to assess.

Lateral Migration Parameter: This parameter should be evaluated at all project sites. Users must evaluate either the Greenline Stability Rating (GSR) metric or the dominant BEHI/NBS and percent erosion metrics together. The percent armoring metric is optional. Additional guidance on metric selection follows:

1. The GSR metric is applicable in all streams with less than 4% slope and is an alternative to dominant BEHI/NBS and percent erosion.
2. The dominant BEHI/NBS and percent erosion metrics are applicable in single-thread channels. These metrics are not recommended in systems that are naturally in disequilibrium, like some braided streams, ephemeral channels, alluvial fans, or other systems with naturally high rates of bank erosion.
3. The percent armoring metric is applicable only when armoring techniques are present or proposed in the project reach. If a user is proposing to armor an eroding bank, the user would substitute this metric for dominant BEHI/NBS in calculating the proposed condition score; the user would not apply the BEHI/NBS metric to an armored bank.

Bed Material Characterization Parameter: This parameter is optional and is recommended for alluvial or confined stream reaches where altered sediment transport processes have shifted the grain-size distribution away from the reference condition. This parameter is only applicable in gravel and cobble bed streams. Selection and sampling of a reference reach is required.

Bedform Diversity Parameter: This parameter should be evaluated at all perennial and intermittent project sites. Users must evaluate pool spacing ratio, pool depth ratio, and percent riffle metrics together. The aggradation ratio metric is optional. Additional guidance on metric selection follows:

1. The pool spacing ratio metric should be evaluated at all sites except natural bedrock systems, ephemeral streams, or multi-thread systems, where the metric is not applicable.

2. The pool depth ratio and percent riffle metrics should be evaluated together at all sites except ephemeral streams or multi-thread channels.

3. The aggradation ratio metric is recommended for meandering single-thread stream types where the riffles are exhibiting signs of aggradation.

Planform Parameter: This parameter is optional and is only applicable in perennial and intermittent streams where the project reach is at least 20 times the bankfull width. This parameter is most applicable in restoration projects that require a reduction in sinuosity to achieve functional improvement.

Riparian Vegetation Parameter: This parameter should be evaluated at all project sites. Users must evaluate all metrics within this parameter.

Temperature, Dissolved Oxygen, and Nutrients Parameters[11]: These parameters are optional and are recommended for projects with goals and objectives related to water quality improvements or projects where improvements to these parameters are anticipated based on restoration potential. One or more parameters can be applied at a project site. These parameters are applicable in perennial (including multi-thread) and intermittent streams where baseflows extend through August.

Macroinvertebrates Parameter[13]: This parameter is optional and is recommended for perennial (including multi-thread) and intermittent stream projects with goals and objectives related to biological improvements or projects where improvements in biological condition are anticipated based on restoration potential.

Fish Parameter[12]: This parameter is optional and is recommended for perennial (including multi-thread) and intermittent stream projects with goals and objectives related to fisheries improvements. Consultation with an area fish biologist at CPW is highly recommended prior to selecting this parameter. Selection and sampling of a control/reference reach is required for the wild trout biomass metric. Users can either apply the native species and SGCN metrics together or the wild trout biomass metric. Additional guidance on metric selection follows:

1. The native species richness and SGCN metrics should be applied together at sites where project goals and CPW management objectives relate to native fish species restoration.

2. The wild trout biomass metric should be applied at sites where project goals and CPW management objectives relate to game fish species restoration.

Flow Alteration Module: This module is optional and is recommended in perennial streams where a proposed project will alter or improve hydrology within a specific length of stream. Metric selection within the module is discussed in Section 2.9.

[11] Without evaluating the physicochemical and biological parameters, the maximum overall score in the CSQT will be 0.60. Selecting and assessing parameters in both physicochemical and biological functional categories will increase the maximum overall score to 1.0 in the CSQT.

[12] Without evaluating the Physicochemical and Biological Parameters, the maximum overall score in the CSQT will be 0.60. Selecting and assessing parameters in both functional categories will increase the maximum overall score to 1.0 in the CSQT.

2.4. Data Collection for Site Information and Reference Selection

The Quantification Tool worksheet quantifies the change in condition using reference curves to translate measured field values into index scores. For some metrics, these curves are stratified by physical stream characteristics like stream type, temperature, and ecoregion. The Site Information and Reference Selection section of the Quantification Tool worksheet 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. It may not be necessary to complete all fields, depending on parameter selection. Metrics will not be scored or may be scored incorrectly if necessary 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 Colorado. Additional information on how reference curves are stratified is included in the Scientific Support for the CSQT (CSQT SC 2019).

Project Name – Enter the name of the project.

Reach ID – Each project reach within a project area should be assigned a unique identifier (see Section 2.1 for guidance on delineating project reaches).

Restoration Potential (restoration and mitigation projects only) – Restoration potential should be determined for the reach (not the sub-reach) 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.

Existing Stream Type – The existing stream type is determined through a field survey of the project reach. This stream classification system and the basic fluvial landscapes in which the different stream types typically occur are described in detail in *Applied River Morphology* (Rosgen 1996). The stream type is determined using entrenchment ratio, width depth ratio, sinuosity, and slope (Figure 15). The existing stream type is not used to select the appropriate reference curve or determine index values but is provided for communication and to inform channel evolution scenarios and restoration potential, refer to Section 3.2.

In the Debit Calculator workbook, 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.

Figure 15: Rosgen Stream Classification Summary (Rosgen 1996)

<table>
<tr><th colspan="6">Quick Rosgen Stream Classification Guide (Rosgen 1996)</th></tr>
<tr><td colspan="3">ER < 1.4</td><td>1.4 < ER < 2.2</td><td colspan="2">ER > 2.2</td></tr>
<tr><td colspan="2">WDR < 12</td><td>WDR > 12</td><td>WDR > 12</td><td>WDR < 12</td><td>WDR > 12</td></tr>
<tr><td>K<1.2</td><td>K>1.2</td><td>F</td><td>B</td><td>E</td><td>C</td></tr>
<tr><td>A</td><td>G</td><td colspan="4">ER = Entrenchment Ratio; WDR = Width Depth Ratio; K = Sinuosity</td></tr>
</table>

Reference Stream Type – The CSQT relies on the stream type to stratify reference curves for the entrenchment ratio, pool spacing ratio, and sinuosity metrics.

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 CSQT, 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 (Cluer and Thorne 2013) 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.

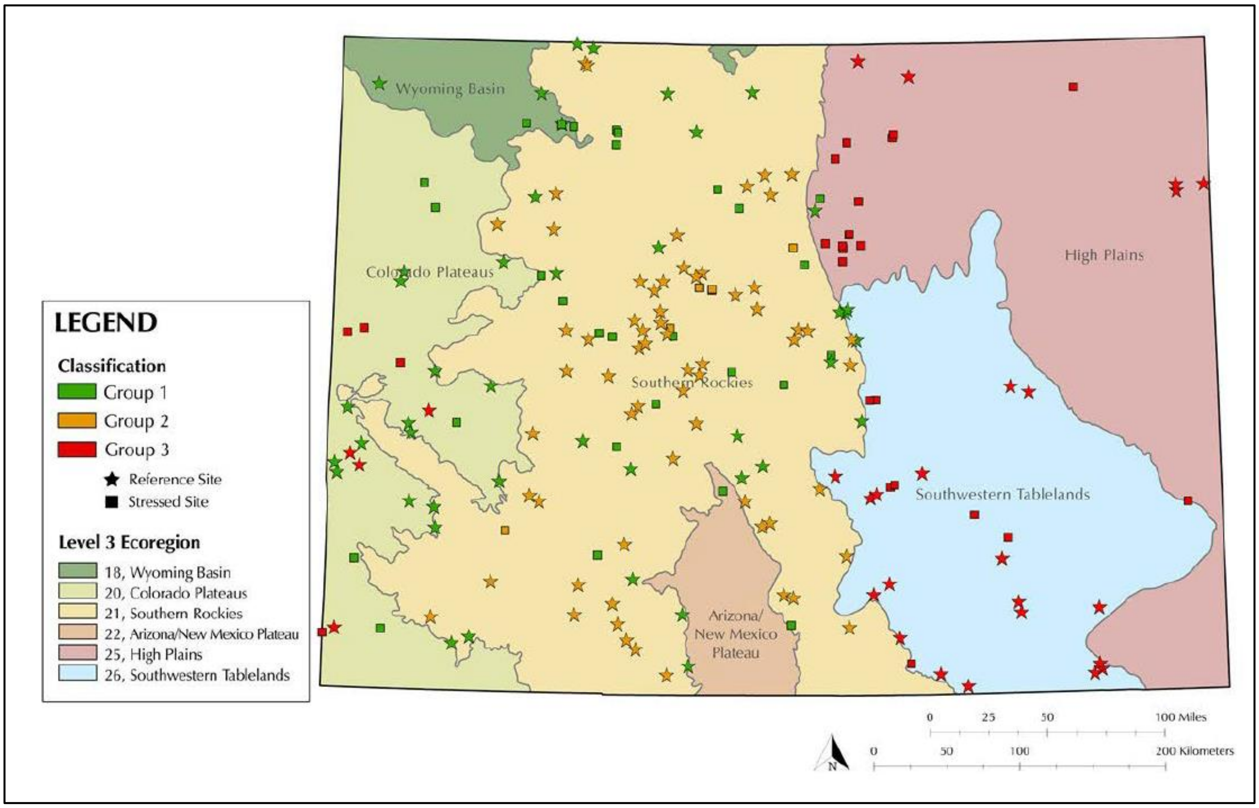
Historic, geomorphic, and even stratigraphic evidence and research may be needed to determine reference stream type. For example, DA (stream/wetland) complexes were historically common in alluvial valleys with low energy and sediment supply while alluvial valleys with gravel/cobble bed streams and ample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

Ecoregion – The CSQT uses the project’s ecoregion to stratify reference curves for the woody vegetation cover metric. EPA Level III ecoregion data from Colorado and Wyoming were grouped into broader classifications, as shown in Table 7. The ecoregions of Colorado are depicted in Figure 16.

Table 7: EPA Level III Ecoregion Groupings for Colorado and Wyoming

Mountains	Basins	Plains
Southern Rockies	Wyoming Basin	High Plains
Middle Rockies	Colorado Plateau	Northwest Great Plains
Wasatch/Uinta Mountains	Arizona/New Mexico Plateau	Southwestern Tablelands

Figure 16: Colorado Biotypes and EPA Level III Ecoregions (reproduced from Appendix A of CDPHE 2017)



<u>Biotype</u> – Biotype is similar to, but distinct from the ecoregions described above. Biotypes are defined by CDPHE to classify groups of streams with similar physical and biological traits (CDPHE 2017; “groups” as shown in Figure 16). Biotype is determined based on EPA Level IV ecoregion, elevation, and stream slope as shown in Table 8. This selection is used to determine the correct reference curves for the chlorophyll a and macroinvertebrate metrics.

Table 8: Site Biotype Classification Rules (reproduced from Appendix A of CDPHE 2017)

Criteria	Biotype 1	Biotype 2	Biotype 3
EPA Level IV Ecoregions:	21d, 21h, 21i, 21j, 25l, 26i	21a, 21b, 21e, or 21g	All 25 and 26 Level IV Ecoregions except 25l and 26i
Slope:	21c and slope < 0.04 ft/ft	21c and slope > 0.04 ft/ft	-
Elevation:	21f and elevation < 8,202 ft	21f and elevation > 8,202 ft	Any ecoregion, elevation < 5,085 ft

Drainage Area (sq.mi.) – The drainage area is the land area draining water to the downstream end of a project reach and is delineated using available topographic data (e.g., StreamStats, USGS maps, USGS Stream Stats, 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 Bankfull Width (ft) – The bankfull width is the design width of a riffle feature. It is used for stratification of the baseflow depth metric. Bankfull, or design, dimensions can also be calculated using the discharge associated with a 1.5-year return interval. Refer to methods for the return interval metric in Section 2.5.c.

Proposed Bed Material – The bed material characterization metric in the CSQT 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.

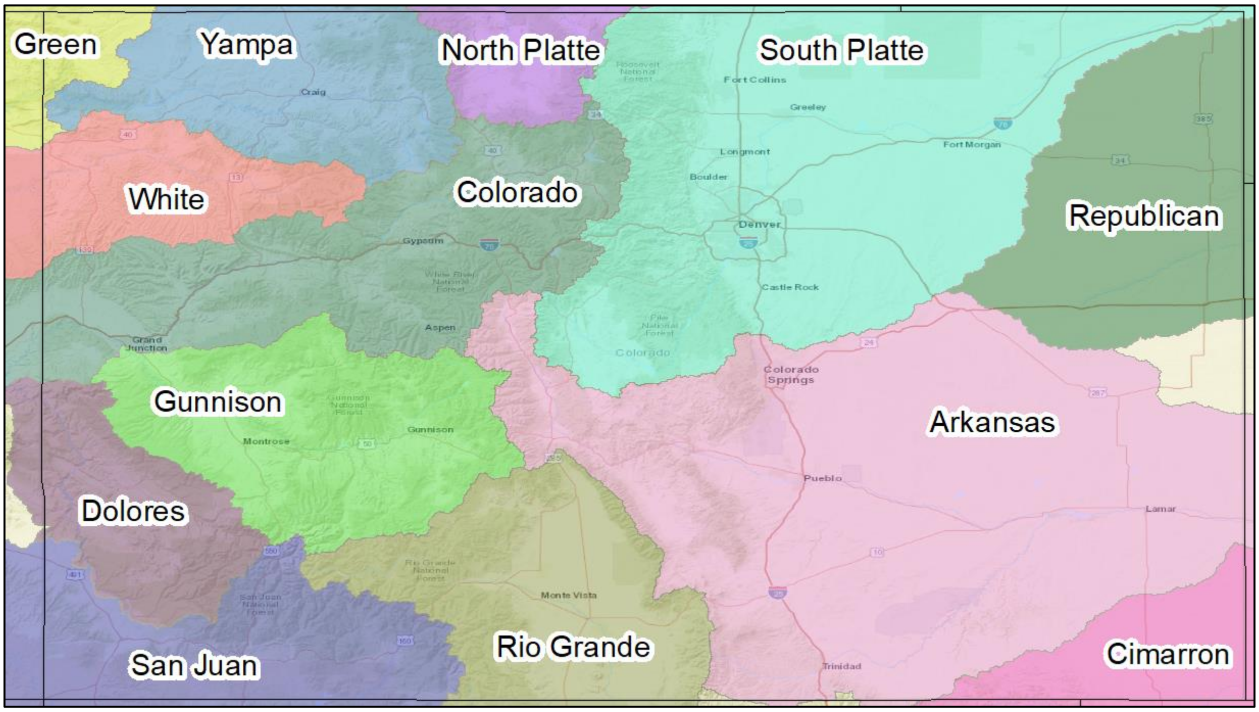
Project Reach Stream Length – Existing (ft) – Project reach stream length extends from the upstream to the downstream end of the project reach. This can be determined by surveying the profile of the stream, stretching a tape in the field, or remotely by tracing the stream centerline pattern from aerial 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 CSQT 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., a riffle. Field methods to determine stream slope are outlined in Appendix A.

River Basin – Colorado is subdivided into thirteen major river basins (Figure 17): Arkansas River, Colorado River, Republican River, Rio Grande River, South Platte River, North Platte River, Gunnison River, Cimarron River, Yampa River, Dolores River, Green River, San Juan River, and White River. Select the river basin that the project reach falls within. This input is not used in the scoring but is used to select an appropriate fish species list for the number of native fish species metric.

Figure 17: Colorado River Basins



<u>Stream Temperature</u> – The stream temperature tier is used to determine the correct reference curve for the temperature parameter and the baseflow depth metric. Streams in Colorado are identified as cold streams (CS) or warm streams (WS) and classified by thermal tiers based on the most thermally-sensitive species expected to occupy the reach in summer (Table 9). All streams in Colorado have assigned temperature tiers (see Regulations 32 – 38). If the applicable temperature standard is not appropriate for the reach, a temperature tier should be selected based on the most thermally sensitive species that occupies the reach and justification provided for the alternate tier.

Table 9: Stream Temperature Classes based on Expected Species

Tier	Species Expected to be Present
CS-I $_{MWF}$	Mountain whitefish early life stages (applied to spawning grounds only)
CS-I	Brook trout and cutthroat trout
CS-II	Brown trout, rainbow trout, mottled sculpin, mountain whitefish, and longnose sucker
WS-I	Common shiner, johnny darter, orangethroat darter, and stonecat
WS-II	Brook stickleback, central stoneroller, creek chub, longnose dace, northern redbelly dace, finescale dace, razorback sucker, white sucker, and mountain sucker.
WS-III	Other Warmwater Species (Arkansas darter, bigmouth shiner, black bullhead, bluegill, bluehead sucker, bonytail, brassy minnow, brown bullhead, channel catfish, Colorado pikeminnow, common carp, fathead minnow, flannelmouth sucker, flathead catfish, freshwater drum, green sunfish, horneyhead chub, Iowa darter, plains killifish, plains minnow, plains topminnow, orangespotted sunfish, pumpkinseed sunfish, quillback, red shiner, Rio Grande chub, Rio Grande sucker, river carpsucker, roundtail chub, sand shiner, smallmouth bass, smallmouth buffalo, southern redbelly dace, speckled dace, spotail shiner, western mosquitofish, yellow bullhead)

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 Class – The CSQT uses the stream productivity class to select the correct reference curves for the wild trout biomass metric. The stream productivity class is based upon existing fish biomass data. Baseline data from the project site can be used; or the user can consult with CPW fisheries biologists to determine if other recent biomass data is available.

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 and anastomosed 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.

2.5. Reach Hydrology and Hydraulics Functional Category Metrics

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

2.5.A. Reach Runoff

The reach runoff parameter evaluates the infiltration and runoff processes of the land that drains laterally into the stream reach. The lateral drainage area (Figure 18) is the portion of the reach catchment that drains directly to the reach from adjacent land uses. The reach runoff parameter consists of four metrics: land use coefficient, impervious cover, concentrated flow points, and water quality capture volume (Figure 19).

Figure 18: ***Lateral Drainage Area for Reach Runoff.*** *The purple line delineates the upgradient extent of the land draining to the project reach (i.e., 1.6 mi2).*

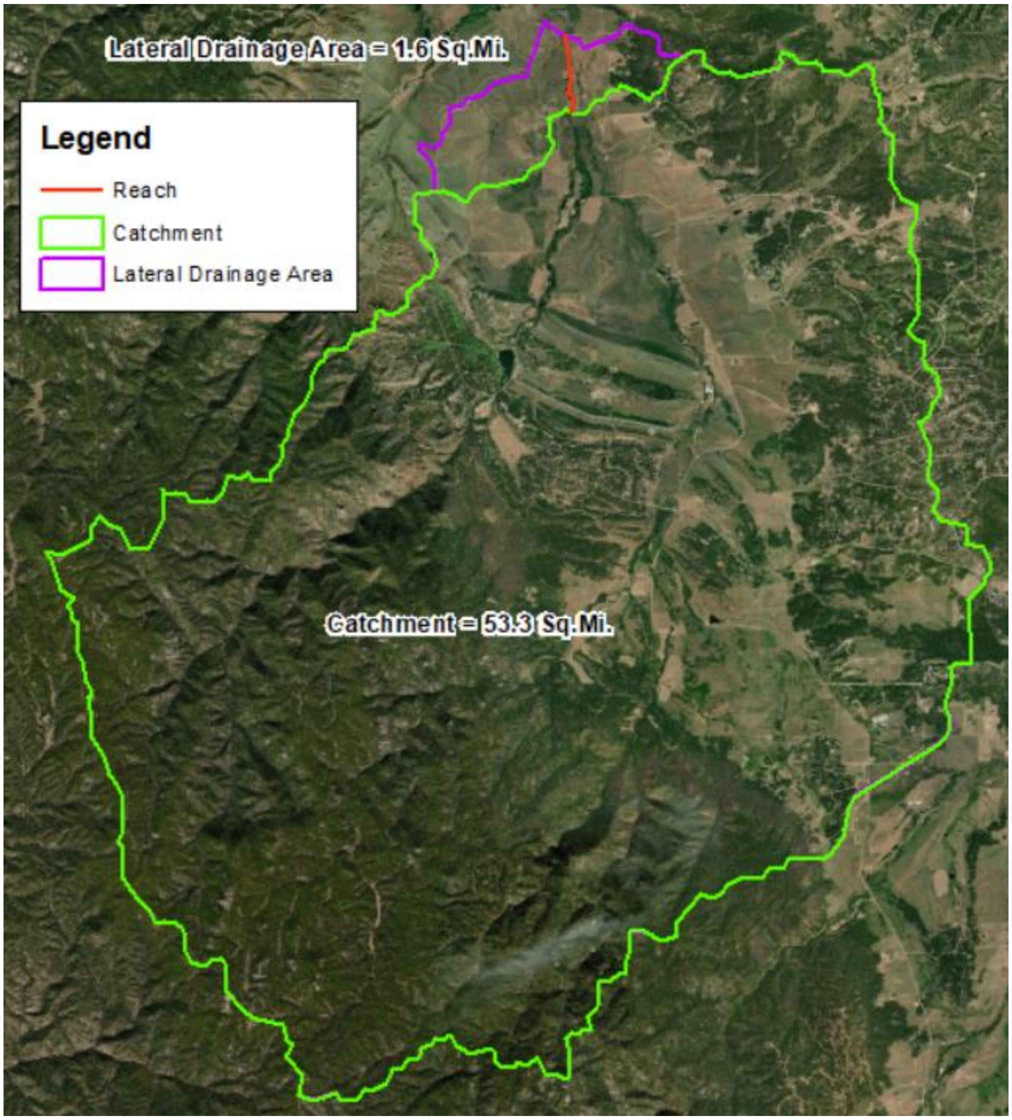
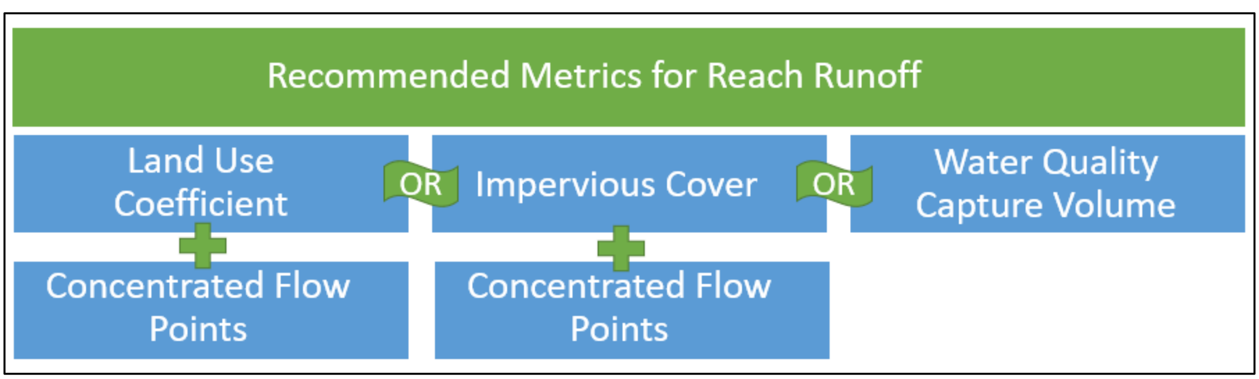


Figure 19: ***Metric Selection Guidance for Reach Runoff Parameter***



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 end points. Land use coefficients are shown in Table 10. Higher values, nearer 100, indicate more runoff potential while lower values, nearer 0, indicate less runoff.

Table 10: Land Use Descriptions and Associated Land Use Coefficients. Adapted from NRCS (1986).

Land Use Description (From TR-55)	Land Use Coefficient
Natural Land Cover	
Forested or scrub-shrub vegetation communities	35
Herbaceous – mixture of grass, weeds, and low-growing brush, with brush the minor element	62
Desert scrub-shrub – major plants include saltbush, greasewood, creosotebush, blackbrush, bursage, yucca, 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
Farmsteads – buildings, lanes, driveways, and surrounding lots	74

<u>Data Collection Method</u>:

1. Delineate the lateral drainage area adjacent to the project reach and calculate the total lateral drainage area (see Figure 18).
2. Using the USGS National Land Cover Database (NLCD), delineate the different land use types within the lateral drainage area and calculate the area occupied by each type.
3. Using Table 10, 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).

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

PERCENT IMPERVIOUS COVER

The impervious cover metric requires the user to determine the percent of the lateral drainage area that is impervious. Land use imperviousness is based on the rational method outlined in the Urban Storm Drainage Criteria Manual Volume 1 (UDFCD 2016). The field value reflects the total impervious cover and does not require any evaluation of whether the impervious surface is directly connected to the waterway.

The impervious cover is calculated by either: 1) delineating all impervious surfaces within a lateral drainage area; or, 2) assuming impervious cover for different land use types and estimating total impervious cover. The former is not practical in larger catchments. Both methods are described below.

<u>Data Collection Method</u>:

1. Delineate the lateral drainage area for the project reach and calculate the area (see Figure 18).
2. Using the most recent aerial imagery, delineate the different land use types within the lateral drainage area and calculate the area occupied by each type.
    a. Where lateral drainage areas are small, the user can delineate all impervious surfaces within the lateral drainage area (e.g., roofs, driveways, streets, parking lots).
    b. In larger lateral drainage areas, where delineating all impervious surfaces is impractical, the user shall delineate areas of different land uses (e.g., agricultural, single family residential, downtown business area, school). The NLCD can be used to delineate land uses.
3. Assign each land use type a percent imperviousness (Table 11).
4. Calculate the total percent impervious for the lateral drainage area. For each land use type, multiply the percent imperviousness by the area of that land use type; sum all products and divide by the total lateral drainage area (see equation below).

$$Percent\ Impervious\ Cover = \frac{\sum(Area_i *\ Percentage\ Imperviousness_i)}{Area_{total}}$$

Table 11: Percentage Imperviousness Values (from UDFCD 2016)

Land Use or Surface Characteristics	Percentage Imperviousness (%)
Business:	
Downtown Areas	95
Suburban Areas	75
Residential:	
Single Family	
2.5 Acres or Larger	12
0.75 – 2.5 Acres	20
0.25 – 0.75 Acres	30
0.25 Acres or Less	45
Apartments	75
Streets	
Paved	100
Gravel (packed)	40
Drive and walks	90
Roofs	90
Lawns, sandy or clayey soil	2
Industrial:	
Light Areas	80
Heavy Areas	90
Other:	
Parks, cemeteries	10
Playgrounds	25
Schools	55
Railroad yard areas	50
Greenbelts, agriculture	2

CONCENTRATED FLOW POINTS

Anthropogenic impacts can lead to concentrated flows that erode soils and transport sediment into receiving stream channels. 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.

Stream restoration projects can reduce concentrated flow entering the channel by dispersing flow in the floodplain and increasing ground cover near the channel. Combining multiple concentrated flow points into a single concentrated flow point does not count as an improvement. The restoration activity must diffuse or capture the runoff. Example activities include filling ditches, removing pipes, routing concentrated flow into created oxbow ponds, and stormwater BMP's.

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.

WATER QUALITY CAPTURE VOLUME

The water quality capture volume (WQCV) is defined as the volume that represents runoff from frequent storm events (e.g., the 80th percentile runoff producing event) that accounts for much of the annual pollutant loads in urban catchments (UDFCD 2011). This metric assesses how much of the WQCV coming from runoff source areas within the lateral drainage area is controlled through storage, infiltration, or evapotranspiration, and will typically be used in urban environments. The Urban Storm Drainage Criteria Manual Volume 3 (UDFCD 2011) serves as the primary resource in designing and assessing existing best management practices (BMPs). This manual provides instructions to users on designing BMPs based on the WQCV in order to improve runoff water quality and reduce hydromodification (UDFCD 2011).

The CSQT field value for the WQCV metric is calculated using the following formula:

$$Field\ value\ =\ \frac{\mathrm{Area}_{\mathrm{total}}\ -\ RSA + \sum(DA_{BMP} * WQCV_{treated}\ )}{\mathrm{Area}_{\mathrm{total}}}$$

Where:

- $\mathrm{Area}_{\mathrm{total}}$ is the lateral drainage area in acres,
- RSA is the runoff source area in acres,
- DA_{BMP} is the area of the sub-catchment draining to any BMP practice treating runoff from the RSA, and
- $WQCV_{treated}$ is the fraction of the WQCV from the DA_{BMP} that is controlled through storage, infiltration, or evapotranspiration. This value must be less than or equal to 1.

In order to calculate the field value the user must determine how much of the lateral drainage area is considered a runoff source area (RSA). A runoff source area consists of both agricultural and urban land uses that increase runoff and generate pollutants. By identifying the RSA, the area of natural land use within the lateral drainage area of a project reach is not counted as contributing to functional loss within the project reach. This is similar to the concept of excess urban runoff volume from UDFCD (2011) in that the metric represents the difference between the developed and pre-developed runoff volume. Unlike the excess urban runoff volume, the storm event is the WQCV storm rather than the two-year plus storm.

For BMPs that are installed within a Municipal Separate Storm Sewer System (MS4) community, the applicant shall coordinate with the local stormwater program or local government responsible for stormwater management regarding BMP design.

Data Collection Method:

1. Delineate the lateral drainage area ($\mathrm{Area_{total}}$) for the project reach and calculate the area (see Figure 18).
2. Using recent aerial imagery, delineate the runoff source area (RSA) within the lateral drainage area. Runoff source area consists of both agricultural and urban land uses that increase runoff and generate pollutants.

The results of steps 1 and 2 are sufficient to calculate the field value for this metric for any project with no BMPs in place to treat WQCV. This metric can capture lift associated with land use changes that reduce the runoff source area. This can include removing impervious cover within the lateral drainage area or planting a native riparian community on agricultural land.

For projects with BMPs in place that treat urban or agricultural runoff, the following steps are applicable.

3. Delineate the sub-catchment draining to a BMP treating runoff.
4. Determine the WQCV for the sub-catchment.

According to UDFCD (2011) the WQCV for the Denver area is produced from a precipitation event of 0.6 inches, corresponding to the 80th percentile storm event. Assuming depression storage within urban watersheds is 0.1 inch, the WQCV storm required would be equal to 0.5 inch over the sub-catchment area.

5. Determine the fraction of the WQCV that is treated by the BMP.

This requires a field investigation to determine whether runoff source areas are directly connected to the receiving waters and to quantify the storage, infiltration, and/or evapotranspiration capacity of any practices that treat runoff from the RSA. While this kind of assessment typically requires hydrologic modeling, depending on the project and the BMP, it may not be necessary to perform hydrologic modeling to determine the field value for this metric. For example, the RSA within a sub-catchment draining to a maintained and functioning sand filter BMP with a surface retention volume greater than the WQCV can be considered treated.

For filtration BMPs that are not sufficient to retain the sub-catchment WQCV, an assessment of watershed routing and BMP infiltration rate would indicate whether the WQCV is treated. For BMPs that use sedimentation rather than filtration, a user would need to assess whether the hydraulic residence time is adequate to treat the WQCV. While land use changes can lead to functional lift through the reduction of RSAs within the lateral drainage area, a user could also perform percolation tests and modeling to quantify infiltration of runoff water volumes coming from RSAs that drain to the riparian buffer.

6. Repeat steps 3 through 5 for each BMP.
7. Calculate the field value using the equation above.

2.5.B. BASEFLOW DYNAMICS

Baseflow is the flow within an intermittent or perennial stream that is sustained between precipitation events. The objective of this parameter is to characterize habitat conditions within the reach during baseflow. Baseflow ($Q_{baseflow}$), measured in cubic feet per second (cfs), is defined as the average of the mean daily flow values during the low flow period, typically in the late summer and early fall of the monitoring year. For the CSQT Beta Version, reference curves have only been developed for use in cold-water streams. As such, this metric should not be applied in warm-water streams. Stream temperature tiers are defined in Table 9, Section 2.4.

There are two metrics to assess baseflow dynamics: average velocity and average depth. These metrics are assessed at riffle features within the reach. Both metrics should be used in combination to quantify this parameter.

AVERAGE VELOCITY

This metric uses hydraulic geometry to determine the average cross section velocity (V) at riffles within the reach for the baseflow discharge ($Q_{baseflow}$).

$$Velocity = {Q_{baseflow}}/{A_{wetted}}$$

Where A_{wetted} (sf) is the wetted cross-sectional area of the cross section at $Q_{baseflow}$ (cfs).

To determine the field value for velocity (measured in feet per second; ft/s):

1. Determine baseflow Q using existing stream gage data or monitoring stream flow during the late summer and early fall of the monitoring year.
2. Survey cross-sections at a minimum of three riffles within the reach.
3. Process survey data to determine the cross-sectional area wetted at baseflow at each riffle cross section using R2Cross or another single cross section hydraulic tool.
4. Calculate the average velocity for each cross section using the equation above. The field value for the velocity metric in the CSQT is the average of the velocity values calculated for each riffle cross section in the reach.

Detailed steps for data processing and calculating field values are provided below.

Data Collection Method:

Field methods for data collection are described in Appendix A. Field methods for this metric include deploying gages, surveying cross section(s) and riffle water surface slope, and measuring velocity using a current meter.

Before deploying stream gages to monitor discharge in the reach, the user should review *Best Practices for Continuous Monitoring of Temperature and Flow in Wadeable Streams* (USEPA 2014). Existing stream gage data can be used where the gage is nearby and where no change in the baseflow Q is expected between the existing and proposed condition. When using data from a nearby gage, perform steps 2, 5, 6 and 7.

1. Deploy stream gage(s) to collect data throughout the late summer and early fall of the monitoring year. The sensors should be set to record point stage measurements at intervals that do not exceed one hour.
2. Measure discharge at or near baseflow and relate the discharge measurement to the measured stage at the stream gage as described in EPA (2014). Multiple flow measurements are preferred but one measurement is sufficient provided that baseflow is within a range of 0.4 to 2.5 times the measured flow (Espegren 1996). Due to turbulent flow, these measurements are not required to be recorded in riffle features, refer to section 3.8.3 of EPA (2014) for site selection considerations in measuring discharge.
3. Create a stage-discharge rating curve for the gage and convert recorded stage values to flow values. This can be accomplished using R2Cross or another single cross section hydraulic tool that applies Manning's equation (Excel, HEC-RAS, RiverMorph, etc.).
4. Use the monitored stream stage data to calculate the mean daily flow for each day in the period of record.
5. Determine the baseflow discharge observed in the monitoring period. Baseflow is defined as the average of the mean daily flow values during the low flow period.
6. Survey at least three riffle cross sections within the reach. Instructions for surveying cross sections are provided in Appendix A. If the reach is short and does not contain three riffle features, survey a single representative cross section of reach conditions or record dimensions in order to perform hydraulic calculations.
7. Process survey data to determine the wetted area and top width of the cross section at $Q_{baseflow}$. Use R2Cross or another single cross section hydraulic tool that applies Manning's equation.

Use the $Q_{baseflow}$ and wetted area at baseflow to calculate average velocity at each surveyed riffle. The field value for the velocity metric is the average velocity of all surveyed riffle cross sections.

AVERAGE DEPTH

This metric uses hydraulic geometry to determine the average cross section depth (d) at riffles within the reach for the baseflow discharge ($Q_{baseflow}$).

$$d = {}^{A_{wetted}}/_{W_{wetted}}$$

Where A_{wetted} (sf) is the wetted cross-sectional area of the cross section at $Q_{baseflow}$ (cfs) and W_{wetted} (ft) is the top width of the cross section at $Q_{baseflow}$.

To determine the field value for average depth:

1. Determine $Q_{baseflow}$ using existing stream gage data or monitoring stream flow during the late summer and early fall of the monitoring year.
2. Survey cross-sections at a minimum of three riffles within the reach.

3. Process survey data to determine the wetted area and top width at baseflow at each riffle cross section using R2Cross or another single cross section hydraulic tool.
4. Calculate the average depth for each cross section using the equation above.The average depth values for each cross section should be averaged to calculate the field value for this metric..

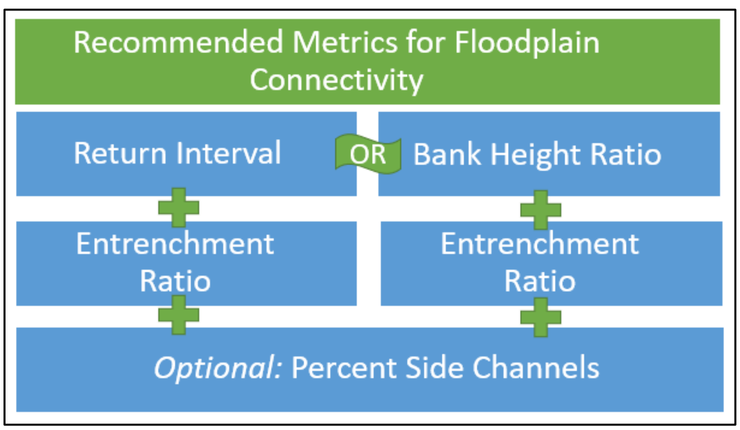
Data Collection Method:

See Data Collection Method for Velocity above. Use the wetted area and top width at baseflow to calculate average depth at each surveyed riffle. The field value for the depth metric is the average depth of all surveyed riffle cross sections.

2.5.C. FLOODPLAIN CONNECTIVITY

There are four metrics to assess floodplain connectivity: return interval, bank height ratio (BHR), entrenchment ratio (ER), and percent side channels. It is recommended to use entrenchment ratio in combination with either bank height ratio or return interval. Entrenchment ratio characterizes the horizontal extent of the floodplain while return interval and BHR characterize the frequency of floodplain inundation. Every project reach must assess floodplain connectivity using bank height ratio and entrenchment ratio or return interval and entrenchment ratio (Figure 20). Percent side channels is an optional metric that may be used with the other floodplain connectivity metrics where appropriate.

Figure 20: Metric Selection Guidance for Floodplain Connectivity Parameter



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. This metric is described in detail by Rosgen (2014). The bank height ratio compares the low bank height to the maximum bankfull riffle depth. The lower the ratio, the more frequently water can access the floodplain. The low bank height is defined as the left or right streambank that has a lower elevation, indicating the minimum water depth necessary to inundate the floodplain. The most common calculation for the BHR, and the one used in the CSQT, is low bank height divided by the maximum bankfull riffle depth (D_{max}). Typically, the minimum bank height ratio is 1.0 meaning that bankfull is equal to the top of the streambank.

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

To improve consistency and repeatability, this measurement is taken at the approximate mid-point of every riffle within the representative sub-reach. The approximate mid-point is stated to provide some flexibility in the specific location with the intent being to select a location where the BHR best represents the full length of the riffle. The riffle length corresponding to the BHR is also measured and the weighted BHR is calculated and input into the CSQT. 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 CSQT.

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

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			

Data Collection Methods:

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

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 perpendicular to the valley and at the same location as the riffle cross section. The flood prone width is also measured at as the cross-section width at an elevation of 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). However, if the valley width is uniform, it is unnecessary to assess every riffle. The ER should be measured at the midpoint of the riffle, halfway between the head of the riffle and the head of the run or pool if there is not a run. 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 cross-sectional survey methods or the rapid survey method. Field methods are described in Appendix A.

RETURN INTERVAL

The return interval metric is a measure of the discharge and associated return interval that completely fills the stream channel. This metric can be used instead of bank height ratio in cases where the bankfull feature cannot be identified, flow alteration has changed the return interval associated with the bankfull feature, or the practitioner is more experienced with hydrologic modeling than field determination of the bankfull stage. If bankfull features are evident and/or flow alterations have not changed the return interval range of the bankfull feature, the bank height ratio metric is preferred. If the return interval metric is selected, the entrenchment ratio must still be calculated. Field identification of the bankfull elevation is described in Appendix A.

There are two basic steps to determine the return interval. First, the discharge that completely fills the channel must be estimated. Second, the return interval associated with the discharge must be determined. Methods range from single cross-section analyzers and USGS flood frequency regression equations to more complicated hydrologic and hydraulic modeling. Simple approaches are appropriate for sites that are being considered for stream mitigation (e.g., during the prospectus stage of a mitigation bank). More sophisticated modeling may be appropriate during project design and monitoring phases, especially in watersheds with complex hydrology.

Data Collection Method:

1. Estimate the discharge that fills the channel.

Field data collection consists of surveying one or more riffle cross sections, calculating the average channel slope, and sampling the bed material following the procedures in Appendix A. The cross section(s) should best represent the channel width and depth for the reach. If width and depth vary to the point that a different return interval value would be calculated, then multiple cross sections (and multiple bed material samples) are needed, and the return interval is averaged. Bed material samples must be collected from the same riffle that includes the cross-section survey; these values are used to estimate bed roughness.[13]

A variety of single-section analyzers are available for calculating discharge using the cross-section survey, average slope, and bed material data collected from the field survey. The Reference Reach Spreadsheet version 4.3 developed by Dan Mecklenburg with the Ohio Department of Natural Resources (DNR) is a free, user-friendly tool that will calculate discharge, entrenchment ratio, and several other hydraulic variables.[14] See Example 9 for use of the Reference Reach Spreadsheet to determine the return interval metric. Another free single-section spreadsheet program is WinXSPRO for streams steeper than 1%.[15] Note that a hydraulic model can also be used to determine the discharge that fills the channel throughout a project reach. The Hydrologic Engineering Center – River Analysis System (HEC-RAS) is a free hydraulic modeling software commonly used across the U.S.[16]

2. Flood Frequency Estimation

The standard procedure for estimating flood frequency uses the log Pearson frequency analysis as described in Bulletin 17B (Interagency Advisory Committee on Water Data 1982). The program PeakFQ implements the Bulletin 17C procedures for flood-frequency analysis of streamflow records.[17]

One of the simplest methods to use in Colorado is StreamStats.[18] This tool allows the user to select the downstream end of the project reach, and then calculates the drainage area and provides a range of watershed characteristics such as land cover, degree of flow regulation, and peak flow statistics. Example 9 illustrates how to calculate the field value for the return interval metric for West Plum Creek, CO.

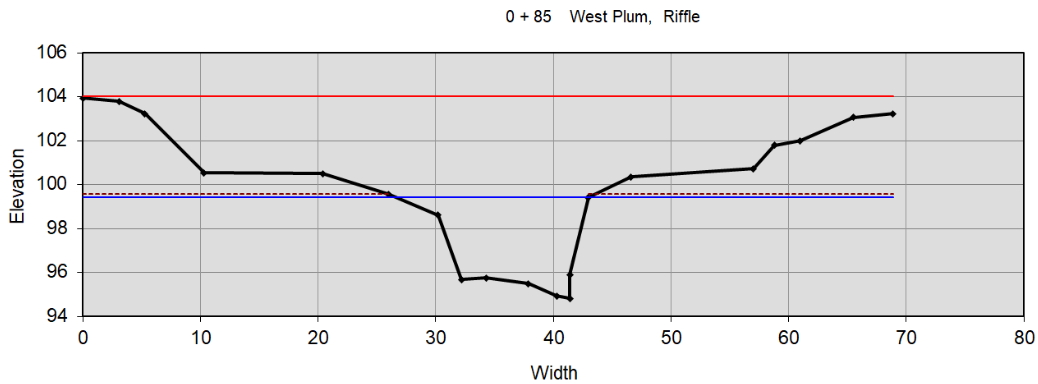
Projects that have complicated watershed hydrology cannot use StreamStats and should include more robust hydrologic analyses. This may include the use of hydrologic models to estimate peak flow discharges and return intervals and/or developing empirical relationships from a nearby gage station.

[13] Bed material samples can be used to calculate a Manning's 'n' roughness value. Where possible, field measurements of discharge can be used to calculate a Manning's 'n'. Field data should be collected during a flow event at or near the bankfull discharge.
[14] The spreadsheet is available at https://stream-mechanics.com/stream-functions-pyramid-framework/ under spreadsheet tools.
[15] https://www.fs.fed.us/biology/nsaec/products-tools.html
[16] https://www.hec.usace.army.mil/software/hec-ras/
[17] https://water.usgs.gov/software/PeakFQ/
[18] https://streamstats.usgs.gov/ss/

Example 9: Return Interval for West Plum Creek, CO

Below is the Reference Reach Spreadsheet output for West Plum Creek, which includes a cross section plot with discharge, entrenchment ratio and other hydraulic calculations. In this example, the top-of-bank and bankfull are the same stage, and the bankfull / top-of-bank discharge is approximately 198 cfs.

Cross Section 1



Bankfull Dimensions	
45.4	x-section area (ft.sq.)
16.4	width (ft)
2.8	mean depth (ft)
4.6	max depth (ft)
21.4	wetted parimeter (ft)
2.1	hyd radi (ft)
5.9	width-depth ratio

Flood Dimensions	
129.0	W flood prone area (ft)
7.9	entrenchment ratio
4.8	low bank height (ft)
1.0	low bank height ratio

Materials	
4	D50 Channel (mm)
25	D84 Channel (mm)
28	threshold grain size (mm):

Bankfull Flow	
4.4	velocity (ft/s)
197.9	discharge rate (cfs)
0.53	Froude number

Flow Resistance	
0.037	Manning's roughness
0.12	D'Arcy-Weisbach fric.
11.6	resistance factor u/u*
33.9	relative roughness

Forces & Power	
0.43	channel slope (%)
0.57	shear stress (lb/sq.ft.)
0.54	shear velocity (ft/s)
3.2	unit strm power (lb/ft/s)

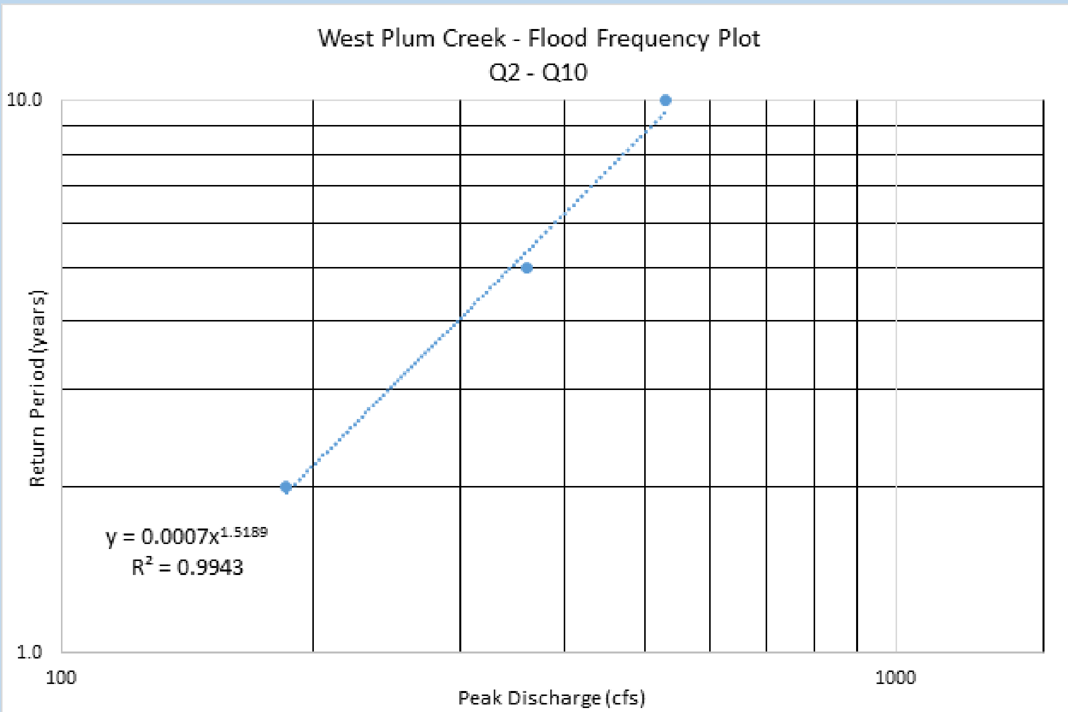
Below is the Peak Flow statistics output from StreamStats for West Plum Creek:

Peak-Flow Statistics Flow Report [Area-Averaged]

Statistic	Value	Unit
2 Year Peak Flood	186	ft^3/s
5 Year Peak Flood	362	ft^3/s
10 Year Peak Flood	530	ft^3/s
25 Year Peak Flood	800	ft^3/s
50 Year Peak Flood	1070	ft^3/s
100 Year Peak Flood	1400	ft^3/s
200 Year Peak Flood	1770	ft^3/s
500 Year Peak Flood	2350	ft^3/s

Example 9 continued: Return Interval for West Plum Creek, CO

The calculated top-of-bank discharge of 198 cfs from the Reference Reach Spreadsheet is slightly greater than the 2- year return interval discharge of 186 cfs from the StreamStats output. To determine the specific return interval associated with top-of-bank discharge for West Plum Creek, the 2 to 10-year peak discharges from StreamStats were plotted in Excel (shown below) to create a return interval versus discharge relationship. The 2, 5, and 10-year values are used rather than the entire range because values over a 10-year interval may be considered very incised, so including the full range of flows is unnecessary.



Using the equation from the return interval vs. discharge plot, the return interval associated with a top-of-bank discharge of 198 cfs is 2.2 years. This is the field value for the return interval metric that is entered into the CSQT.

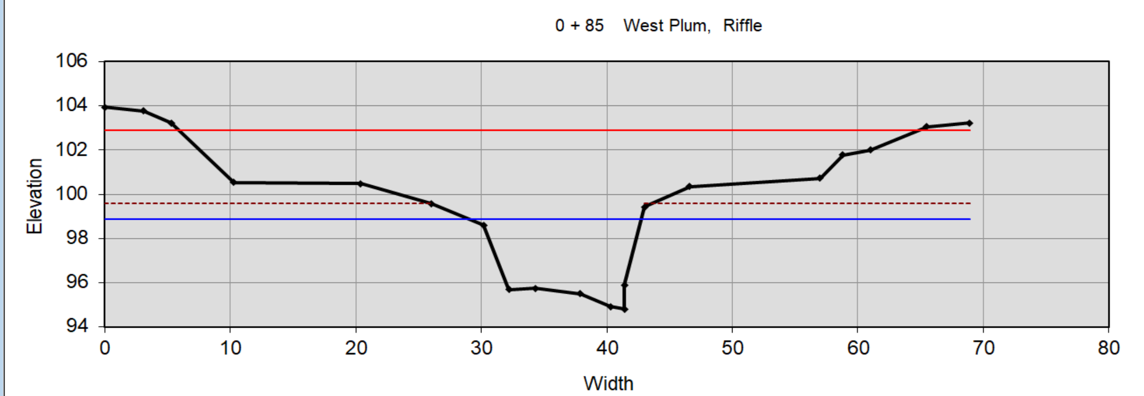
<u>Calculating Bankfull Dimensions without Bankfull Field Indicators</u>:

As discussed in previous sections, the return interval metric may be used instead of the bank height ratio metric. However, dimensionless ratios are included elsewhere in the CSQT that use bankfull dimensions to scale measurements. A maximum bankfull depth, mean bankfull depth, and bankfull width are needed to calculate the entrenchment ratio, pool depth ratio, and pool spacing ratio respectively. To calculate these bankfull values, the user should rely on the return interval versus discharge plot. The user should use the average bankfull return interval of 1.5 years and the representative cross section for the reach to determine the bankfull dimensions and scale dimensionless ratios as shown in Example 10. Note that the representative cross section may differ from the return interval cross section; refer to Appendix A for direction in identifying the representative riffle.

Example 10: Calculating Bankfull Dimensions Based on Return Interval for West Plum Creek, CO

The West Plum Creek Flood Frequency Plot in Example 9 was used to determine the 1.5-year discharge for West Plum Creek as 156 cfs. The bankfull elevation in the Reference Reach Spreadsheet tool was adjusted until a discharge of 156 cfs was contained within the 'bankfull' channel as shown below. The bankfull dimensions of width, mean depth, and max depth are calculated in the tool under Bankfull Dimensions and can be used in calculating field values for other metrics. Additionally, the Reference Reach Spreadsheet calculates the entrenchment ratio (under Flood Dimensions) which is equal to 4.3 for this cross section.

Cross Section 1



Bankfull Dimensions	
37.0	x-section area (ft.sq.)
13.7	width (ft)
2.7	mean depth (ft)
4.1	max depth (ft)
18.3	wetted parimeter (ft)
2.0	hyd radi (ft)
5.0	width-depth ratio

Flood Dimensions	
59.0	W flood prone area (ft)
4.3	entrenchment ratio
4.8	low bank height (ft)
1.2	low bank height ratio

Materials	
4	D50 Channel (mm)
25	D84 Channel (mm)
27	threshold grain size (mm):

Bankfull Flow	
4.2	velocity (ft/s)
156.2	discharge rate (cfs)
0.52	Froude number

Flow Resistance	
0.037	Manning's roughness
0.13	D'Arcy-Weisbach fric.
11.4	resistance factor u/u*
33.0	relative roughness

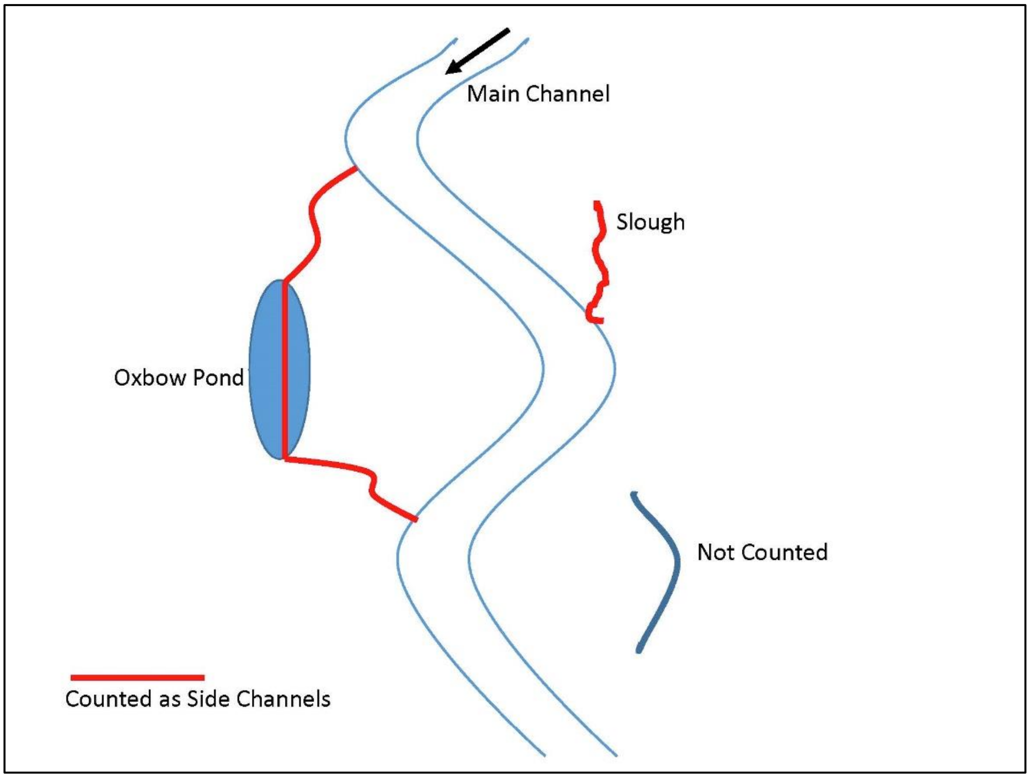
Forces & Power	
0.43	channel slope (%)
0.54	shear stress (lb/sq.ft.)
0.53	shear velocity (ft/s)
3.1	unit strm power (lb/ft/s)

PERCENT SIDE CHANNELS

Percent side channels is an optional metric for single-thread channels having perennial flow in valley types and gradients that would naturally support side channels. For example, this metric would not be applicable in moderate and high gradient confined streams. It is the responsibility of the practitioner to determine if side channels are appropriate for the given valley setting. Justification for including this metric should be provided to the Corps.

Side channels are small open channels that are connected to the main channel at one or both ends. A slough is an example of a side channel connected at one end. Floodplain channels can be included in this metric when one or both ends are connected to the main channel and the depth is at least one-half the bankfull stage. For example, if the bankfull riffle depth equals two feet, the floodplain side channel depth must equal at least one foot where the side channel intersects the main channel. Floodplain channels that have filled with sediment to the bankfull stage at both ends are not counted as side channels. Islands and mid channel bars do not create side channels; they simply split the flow within the main channel (see Figure 21).

Figure 21: Examples of Side Channels



The percent side channels metric is calculated by measuring the total length of all side channels and dividing by the total length of the main channel. It is reported in percent as the field value.

$$Field\ Value = 100 * \frac{\sum Side\ channel\ length\ (ft)}{Reach\ Length\ (ft)}$$

Data Collection Method:

Side channels can be assessed from aerial photos and field reconnaissance. The lengths can be measured on aerials if they are visible or measured in the field with a tape measure or range finder and then recorded on the Project Reach field form (Appendix B).

2.6. Geomorphology Functional Category Metrics

The CSQT contains the following function-based parameters to assess the geomorphology functional category: large woody debris, lateral migration, bed material characterization, bed form diversity, plan form, and riparian vegetation. Not all geomorphic parameters will be evaluated for all projects. Refer to Section 2.3 of this manual for guidance on parameter and metric selection.

2.6.A. Large Woody Debris

There are two metrics used to assess large woody debris (LWD), including a LWD piece count and a large woody debris index (LWDI). Either metric can be used to inform this parameter but both metrics should not be used at a single reach. LWD should be assessed for all projects that are in ecoregions that support forested riparian areas.

LWD is defined as dead and fallen wood over 3.28 feet (1m) in length and at least 3.9 inches (10 cm) in diameter at the largest end.[19] The wood must be within the stream channel or touching the top of the streambank. Both metrics use data from a 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.

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 lies in the floodplain but is not at least partially in the active channel is not counted. 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, which is included in the *Application of the Large Woody Debris Index: A Field User Manual Version 1* (Harman et al. 2017). When data are entered digitally into the field form workbook, the LWDI score calculates automatically. The LWDI score is entered as the field value in the CSQT.

Data Collection Method:

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

Piece Count

For this metric, all pieces of LWD within the 328 feet (100 meters) 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 CSQT. No additional calculation is required.

Data Collection Method:

The field procedure is outlined in Appendix A; data is recorded on the Project Reach form (Appendix B).

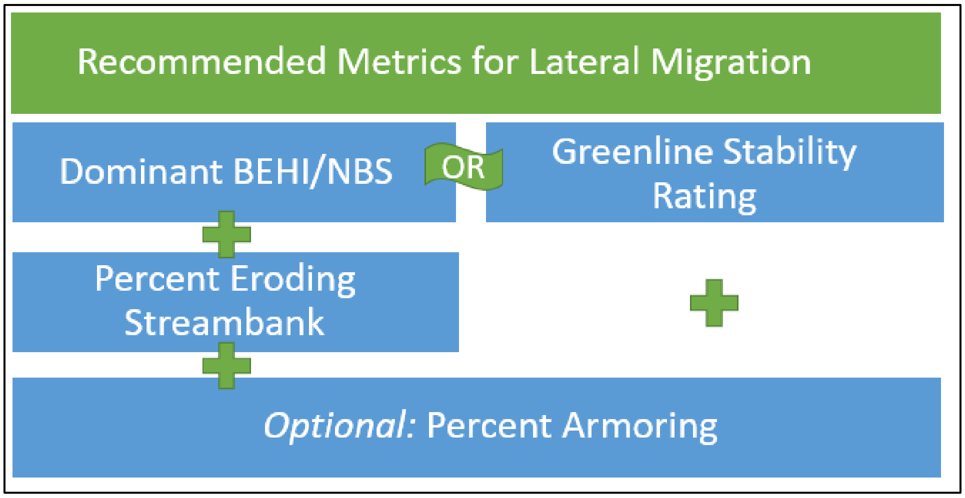
2.6.B. Lateral Migration

Lateral migration is a parameter that assesses the degree of streambank erosion relative to natural rates of erosion and is recommended for all projects. There are four metrics for this parameter (Figure 22): dominant bank erosion hazard index (BEHI)/near bank stress (NBS),

[19] Note: Standing dead material is not included as LWD. 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.

percent streambank erosion, armoring, and greenline stability rating (GSR). When using the BEHI/NBS assessment, the percent of bank erosion is also assessed. The dominant BEHI/NBS characterizes the magnitude of bank erosion and the percent of erosion 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. Armoring is an optional metric that may be used where bank armoring is present.

Figure 22: Metric Selection Guidance for Lateral Migration Parameter



DOMINANT BANK EROSION HAZARD INDEX/NEAR BANK STRESS (BEHI/NBS)

The Bank Erosion Hazard Index (BEHI) is a method 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). In the CSQT, 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** outside meander bend. The outside of the meander bend is assessed whether or not it is eroding. In addition to all meander bends, any other bank that is actively contributing sediment is also assessed. 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 CSQT BEHI/NBS survey. However, they are included in the percent of erosion.

Banks that are armored should not be assessed with the dominant BEHI/NBS metric. Instead, they should be assessed with the armoring metric.

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 for each assessed bank length within that category (see Example 11). 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 CSQT, a drop-down list of BEHI/NBS categories is provided in the Quantification Tool worksheet.

Example 11: 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 are included 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).

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 a BEHI/NBS score indicating an actively eroding bank (Table 12) should be summed together to calculate this metric.

Table 12: 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

VL = Very Low, L=Low, M = Moderate, H = High, VH = Very High, Ex = Extreme

This metric is calculated by dividing the total length of eroding bank by the total length of streambank within the sub-reach, refer to Example 12. 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 and reach length determination are used to calculate percent erosion. Methods are included in Appendix A and datasheets are included 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 12: 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**

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. GSR is not applicable in steeper (i.e., greater than 4 percent gradient) streams or highly modified streams where natural and artificially hardened banks are less susceptible to vegetation influences; or in large rivers where landform features play the dominant role in regulating hydrologic influences.

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.

<u>Data Collection Method</u>:

Data collection should occur throughout the representative sub-reach. The CSQT relies on either of two methods to measure the GSR:

- 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.

PERCENT ARMORING

Bank armoring is any rigid human-made stabilization practice that permanently prevents lateral migration processes. Examples of armoring include rip rap, gabion baskets, concrete, boulder toe and other engineered materials that covers the entire bank height. Bank stabilization practices that include toe protection to reduce excessive erosion are not considered armoring if the stone or wood does not extend from the streambed to an elevation that is beyond one-third the bank height and the remainder of the bank height is vegetated.

This metric should only be used if bank armoring is present or proposed in the project reach. 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) within the project reach 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 CSQT.

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

<u>Data Collection Method</u>:

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

2.6.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 over gravel bed material. Projects that implement bank stabilization 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).[20]

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 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 would represent a good reference reach. 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.

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 4 mm or 8 mm) should be entered 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 pebble count procedures described in Bevenger and King (1995).

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

2.6.D. BED FORM DIVERSITY

Bed forms include the various channel features that maintain heterogeneity in the channel form, including riffles, runs, pools, and glides (Rosgen 2014). 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.

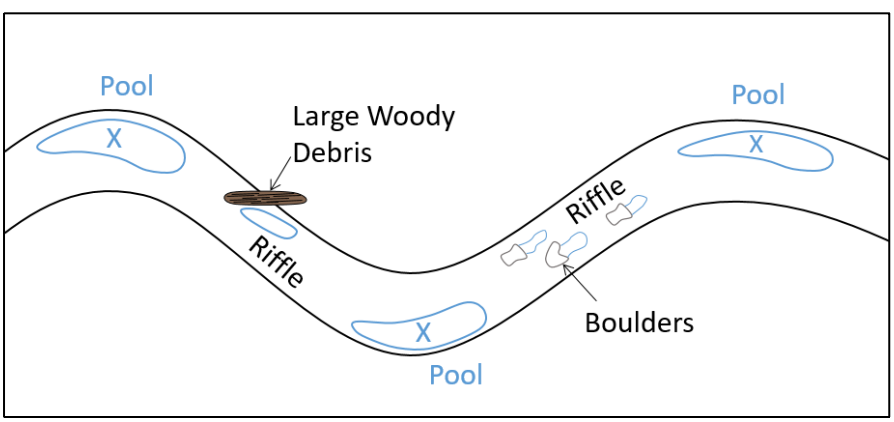
POOL SPACING RATIO

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 under 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 23 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.

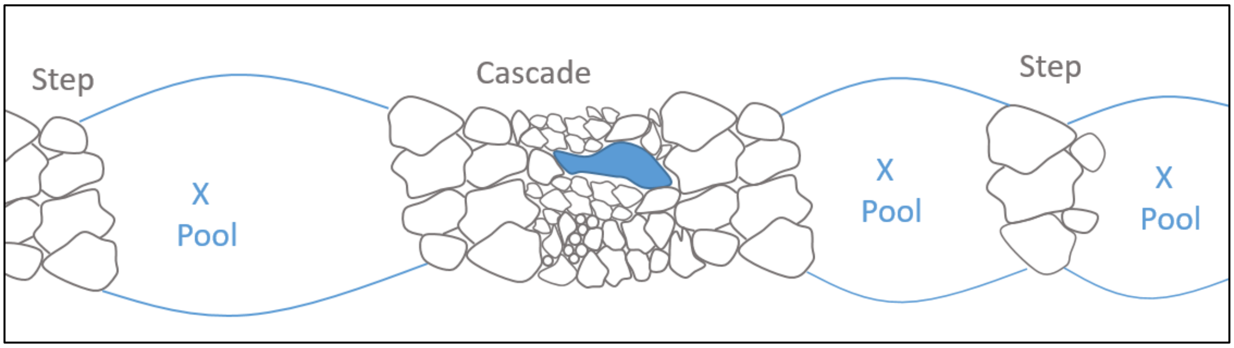
Figure 23: Pool Spacing in Alluvial Valley Streams



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, riffle, or 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 24. For these bed forms, pools are only counted at the downstream end of the riffle or cascade, micro-pools within the feature are not included.

Figure 24: 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. In a meandering stream, a moderate ratio is preferred over very low (near 1) or very high (near 10) ratios. In other words, having too many or too few pools can be detrimental to channel stability and geomorphic function. As streams transition from steep step-pool channels to low gradient meandering streams, the frequency of pools decreases.

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

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

Data Collection Method:

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.

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 (i.e., meander bend or riffle/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 and 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 CSQT.

<u>Data Collection Method</u>:

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.

PERCENT RIFFLE

The percent riffle is the proportion of the representative sub-reach containing riffle bed form 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 (i.e., meander bend or riffle/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, have a concave shaped bed surface and a 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.

<u>Data Collection Method</u>:

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.

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).

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

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. The reference WDR can come from the representative riffle cross section at, or adjacent to the project reach or through the design process. Hydraulic and sediment transport models, such as Torizzo and Pitlick (2004), may be used to select a channel dimension and slope that yields a stable WDR. Justification for the selected WDR should be provided.

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.

2.6.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 entire project reach. If recent aerial imagery is not available or the stream channel is not visible on the imagery, then sinuosity should be measured in the field per the method outlined in Appendix A.

2.6.F. RIPARIAN VEGETATION

Riparian vegetation is a critical component of stream ecosystem structure and function 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, and physicochemical and biological processes, and is thus is included in the geomorphic category of the CSQT.

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 selected to provide repeatability and consistency and to allow for extrapolation of species information to draw inferences on vegetation composition and/or to apply additional regulatory performance standards at mitigation sites.

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 CSQT.

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 CSQT and is calculated using the following equation:

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

Data Collection Method:

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

Expected Riparian Width:

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 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). Hydrologic and substrate 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, or floodplain mapping).

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 is not uniform, 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.

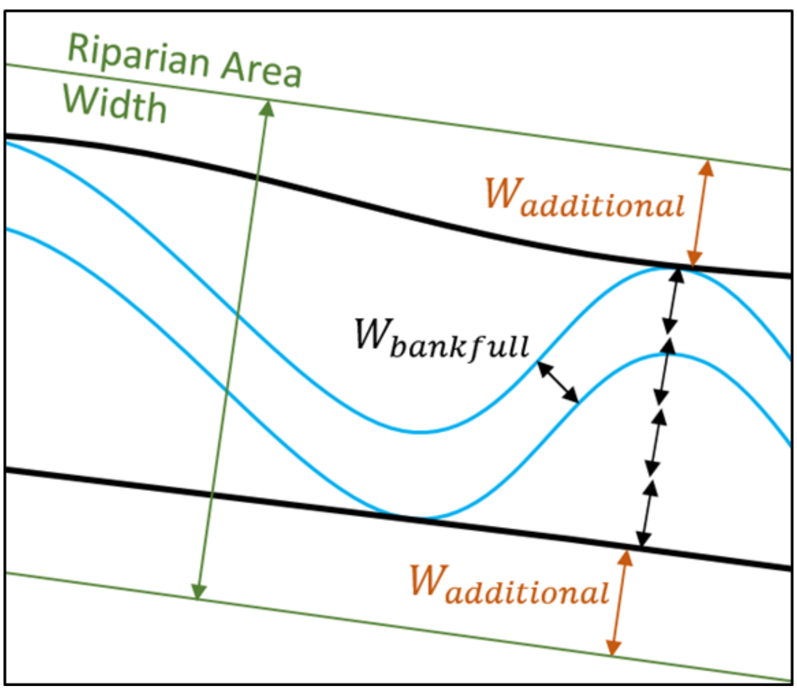
4. Where significant incision or anthropogenic modification of the riparian area has occurred (e.g., development, grading) and aerial imagery, spatial data and/or field indicators cannot be used to delineate the expected riparian extent, the meander width ratio (MWR) may be used to calculate expected 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 13). 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 25). 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 13: MWR by Valley Type adapted from Harman et al. (2012) and Rosgen (2014)

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

Figure 25: 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 CSQT value for riparian width (%).

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 CSQT 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 26). 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 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. These 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 2008b, 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.

HERBACEOUS VEGETATION COVER

This metric characterizes herbaceous vegetation cover, which 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 to the instructions provided in Appendix A. The herbaceous vegetation cover field value for the CSQT is the sum of absolute percent herbaceous plant cover from herbaceous species averaged across all plots within the representative sub-reach.

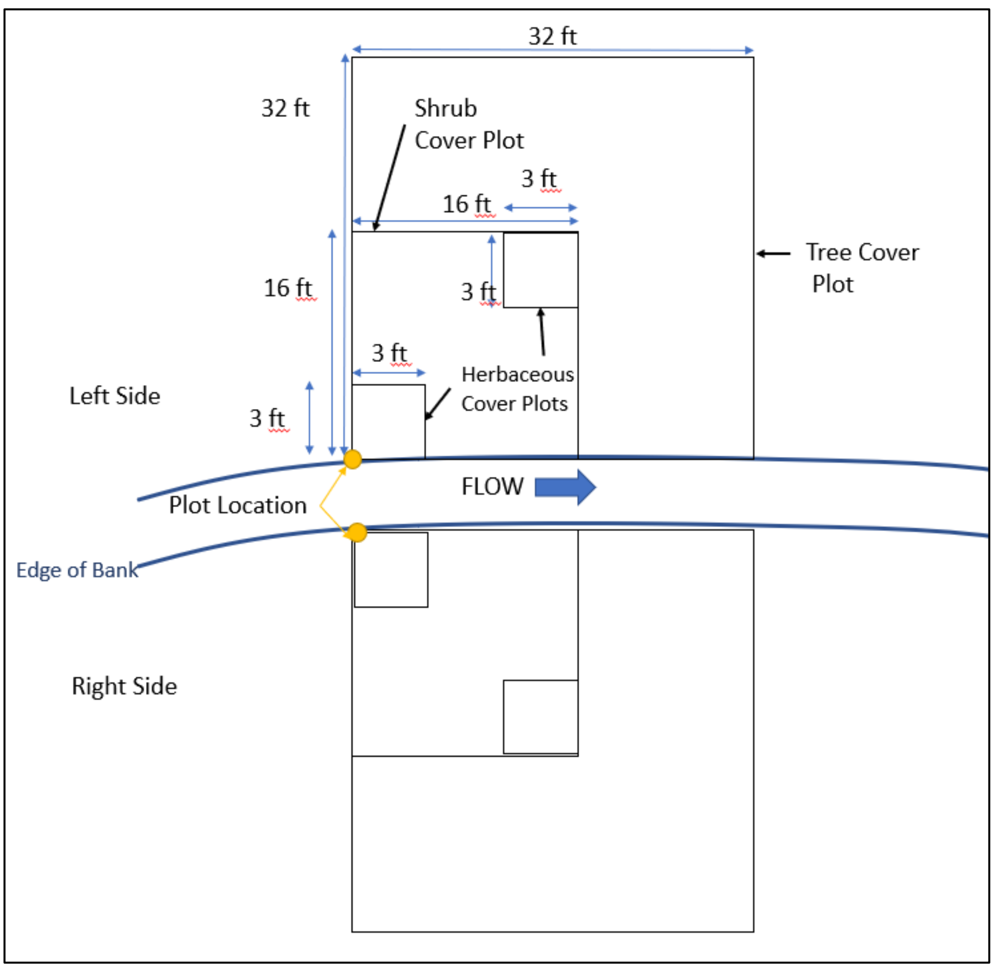
$$Herbaceous\ vegetation\ cover = Herbaceous_{\ Ground\ Cover}$$

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%.

Data Collection Method:

See Data Collection Method for Woody Vegetation Cover above.

Figure 26: Riparian Vegetation Sample Plot Layout



PERCENT NATIVE COVER

This metric helps characterize the composition and condition of the riparian communities. Data from riparian plots is collected according to the instructions provided in Appendix A. The percent native cover metric for the CSQT 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 CSQT.

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

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

Data Collection Method:

See Data Collection Method for Woody Vegetation Cover above.

2.7. Physicochemical Functional Category Metrics

The CSQT contains three function-based parameters to assess the physicochemical functional category: temperature, dissolved oxygen, and nutrients.

2.7.A. TEMPERATURE

There are two metrics included in the CSQT for the temperature parameter; (1) the daily maximum temperature and (2) the maximum weekly average temperature (MWAT). Chronic and acute temperature criterion are defined in State regulation 31 (5 CCR 1002-31) by stream temperature tier. Both metrics are stratified by temperature tier; species with similar thermal requirements are grouped into tiers shown in Table 9 in Section 2.4.

DAILY MAXIMUM TEMPERATURE

As defined by State regulation 31 (5 CCR 1002-31) the daily maximum (DM) temperature is the highest two-hour average water temperature recorded during a given 24-hour period. The daily maximum temperature is determined based on monitoring throughout the summer months of July and August with a maximum sampling interval of 30-minutes.

To determine the field value for the daily maximum temperature (measured in degrees Celsius):

1. Using the individual temperature readings, calculate the 2-hour average temperatures on a rolling basis for the sampling period.
    a. For a sampling interval of 30-minutes, this means the average of 4 consecutive measurements. For a sampling interval of 15-minutes, it would be the average of 8 consecutive measurements.
2. Identify the maximum of the rolling 2-hour average temperatures and enter as the field value in the CSQT.

Data Collection Method:

Placement and use of in-water temperature sensors should follow *Best Practices for Continuous Monitoring of Temperature and Flow in Wadeable Streams* (USEPA 2014) or USFS's *Measuring Stream Temperature with Digital Data Loggers: A Field Guide* (Dunham et al. 2005). These procedures cover sensor selection, calibration, sensor placement, and data QAQC. Note that the USEPA 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 CSQT, the minimum sample period consists of the summer months of July through August for the sampling year. The sensors should be set to record point temperature measurements at intervals that do not exceed 30 minutes and should be located in comparable habitats for pre and post-project data collection.

MWAT

As defined by state regulation 31 (5 CCR 1002-31) the Maximum Weekly Average Temperature (MWAT) is the largest weekly average stream temperature in the period of interest. The temperature is monitored throughout the summer months of July and August and the weekly average temperature is the average of daily average temperatures over a seven-day consecutive period.

To determine the field value for the MWAT (measured in degrees Celsius):

1. Calculate the average temperature recorded for each day in the sample period (July to August; minimum 62 days). These are the mean daily temperatures.
2. Using the mean daily temperatures, calculate the weekly average temperatures on a rolling seven-day basis for the sampling period.
3. Identify the maximum of the rolling weekly average temperatures and enter as the field value in the CSQT.

Data Collection Method:

Follow the data collection methods for the daily maximum temperature metric described above.

2.7.B. Dissolved Oxygen

This parameter evaluates dissolved oxygen (DO), which plays a key role in supporting aquatic life. There is one metric included in the CSQT for this parameter, the dissolved oxygen concentration, measured in milligrams per liter (mg/L). Measurements are collected in-situ during summer and in the afternoon when temperatures are highest and dissolved oxygen levels are lowest. Sampling events may coincide with chlorophyll a or biological sampling where sampling periods overlap.

Data Collection Method:

Measuring dissolved oxygen concentration should be conducted according to the WDEQ Standard Operating Procedure (WDEQ/WQD 2018).[21] DO sampling for use in the CSQT requires a DO logger be deployed for at least one week during the summer months of July or August and set to record daily measurements between one and three in the afternoon. Loggers should be located in comparable habitats for pre and post-project data collection.

2.7.c. Nutrients

There is one metric for the nutrient parameter, chlorophyll a. Chlorophyll a is the pigment that allows plants (including algae) to use sunlight to convert simple molecules into organic compounds via the process of photosynthesis 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 a data should be expressed as milligrams of chlorophyll a per square meter of sampled rock substrate (mg/m^2).

Data Collection Method:

Methods for collecting chlorophyll a are included in Appendix A. Chlorophyll sample collection and processing should be conducted according to the CDPHE Standard Operating Procedure procedures outlined in CDPHE (2015). Samples must be collected at times of normal, stable flows when the benthic algal community has peaked for the season, typically mid-summer to early fall (CDPHE 2015).

2.8. Biology Functional Category Metrics

The function-based parameters included in the CSQT for the biology functional category are macroinvertebrates and fish. The macroinvertebrate parameter is informed by the multi-metric index developed by CDPHE. Since there is no existing biological index used for fish in Colorado, metrics for fish were modified from the WSQT (USACE 2018a) in consultation with Colorado Parks and Wildlife (CPW).

2.8.a. Macroinvertebrates

Macroinvertebrates are an integral part of the food web and are commonly used as indicators of stream ecosystem condition. One metric is included in this parameter, the Colorado Multi-Metric Index (CO MMI) of macroinvertebrate communities, which was developed by CDPHE to assess the biological condition of Colorado streams. The CO MMI is a statewide regionally-calibrated macroinvertebrate-based multi-metric index stratified by three biotypes, Mountains, Transition, and Plains & Xeric. While the CDPHE (2017) approach is intended for use in perennial streams, it can be applied in intermittent streams when standing or flowing water is present

[21] The CSQT SC reviewed the WDEQ/WQD methods and compared them to the CO SOPs (CDPHE 2016) and found the Wyoming methods were comparable and provided more detail.

during the index period. Spatial and interannual variability may be greater within these systems, and sampling may have more limited repeatability.

According to CDPHE (2017), "[w]ithin the benthic macroinvertebrate assemblage, metrics are selected that represent some measurable aspect of the community structure and function. These measurements are grouped into five metric categories: taxa richness, composition, pollution tolerance, functional feeding groups, and habit (mode of locomotion). Combining metrics from these categories into a multi-metric index transforms taxonomic identifications and individual counts into a unitless score that ranges from 0-100." The assessment of biological condition is made by evaluating the departure of CO MMI scores from an expected or reference condition within each biotype. Note that there are limitations in applying the threshold values in larger rivers (exceeding 2,700 mi^2 watershed area) in the South Platte River, Arkansas River, Purgatoire River, and Rio Grande River basins (CDPHE 2017).

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 Policy Statement 10-1 and its appendices (CDPHE 2017).

Once taxa are identified from the sample following standard operating procedures outlined in Appendix C of CDHPE (2017), CO MMI values can be calculated by inputting data into the EDAS database (see Appendix D of CDPHE (2017)). Laboratories providing taxonomic identification services may also calculate CO MMI scores upon request. Note that midges (family Chironomidae) must have sufficient taxonomic resolution to calculate an MMI score. Some labs charge a separate fee for higher taxonomic resolution for this group. A public version of EDAS and EDAS User Manual is available for use; contact the Environmental Data Unit at CDPHE for a copy. Contact CDPHE for questions on macroinvertebrate sampling and assistance with calculating CO MMI scores, if needed.

The CO MMI score is entered as the field value for the CSQT.

2.8.B. FISH

Fish are an integral part of functioning river ecosystems. Three metrics for fish are included in the CSQT: native fish species richness (%); absence of Species of Greatest Conservation Need (SGCN); and wild trout 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. Project specific consultation with an area fish biologist from CPW is recommended, as they 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 identified management objectives. A CPW permit is required prior to collecting fish samples.

In the CSQT, 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 (i.e., proposed, as-built, and monitoring). Since all metrics for the fish parameter recommend data be collected across two consecutive years, the average value should be entered for both monitoring events. For example, for As-Built condition, the average of the year 1 and year 2 data collection should be entered into the As-Built Condition Assessment as well as year 1 and year 2 monitoring events (as shown in Example 13). Fish populations may take five or more years to respond to restoration projects, and this should be considered when developing a monitoring plan. Long-term monitoring events should be also be averaged across two consecutive years (e.g., years 3 and 4, 5 and 6, etc.)

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 thirteen major river basins in Colorado based on differences in stream temperature tiers. These assemblages were developed by CPW 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 CSQT and is calculated using the following equation:

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

<u>Expected Fish Community</u> – 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 an area fish biologist at CPW to further refine the expected species assemblage. The area 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.

<u>Observed Fish Community</u> – Fish community data may be requested from CPW, and where proximate and representative data have been collected within the previous 3 years, these data may serve as a preliminary estimate of the number of native species present. Detailed fish surveys must be conducted prior to the initiation of a project to refine this preliminary estimate. An average of at least two sampling events is needed to calculate the field value for the CSQT.

<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 in two consecutive years are needed to establish the observed fish community. To verify fish identification, practitioners should collect and preserve voucher specimens of fish species not readily identified in the field. Results from two sampling events should be used to calculate the field value in the CSQT – if a native species is present in one of the two sampling events, the species should be considered present.

Absence of Species of Greatest Conservation (SGCN)

Species of Greatest Conservation Need (SGCN) are identified in the SWAP (2015) as those species whose conservation status warrants increased management attention and funding, as well as consideration in conservation, land use, and development planning in Colorado. For any project where this metric is used, the practitioner should consult with the regional fish biologist at CPW 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, Appendix C and the SWAP (2015) 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 2 species have less of a conservation need than tier 1. The number of species with natural potential to occur at the site in each tier is used to calculate the field value for the CSQT (Table 14). 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 14: How to Calculate the Field Value for SGCN Metric

SGCN Species *(A)*	Multiplier *(B)*	Equation
# Tier 1 Species Absent	2	$\boldsymbol{C_1 = A_1 * B_1}$
# Tier 2 Species Absent	1	$\boldsymbol{C_2 = A_2 * B_2}$
Field Value for the CSQT =		$\boldsymbol{C_1 + C_2}$

<u>Data Collection Method</u>:

Fish community data may be requested from CPW, and where proximate and representative data have been collected within the previous 3 years, these data may serve as a preliminary estimate of the observed presence or absence of SGCN. Detailed fish surveys should be conducted prior to the initiation of a project to refine this preliminary estimate. An average of at least two sampling events should be used to calculate the field value for the CSQT.

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 two consecutive 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 2 times as much as tier 2 species (Table 14). Note that if there are no species in a tier expected at the site then there are no species absent for that tier. The weighted number of SGCN species absent is the field value for this metric. Results from two sampling events should be used to calculate the field value in the CSQT – if a species is present in one of the two sampling events, the species should be considered present. (see Example 13 for how multiple year data is entered into the CSQT).

Example 13: Calculation of the SGCN metric

A project is proposed in a warm-water stream in the Arkansas River Basin. According to Appendix C, seven tier 1 SGCN species (Arkansas Darter, Flathead Chub, Northern Plains Killifish, Orange spotted Sunfish, Plains Minnow, Southern Redbelly Dace, and Suckermouth Minnow) may be expected in the stream under pristine conditions. Upon coordination with the regional fish biologist, it is determined that only six have the natural potential to occupy that catchment. The practitioner then determines whether those species are present by sampling using standard methods over at least two sampling events. Only one species is detected. The field value in the CSQT would be 10 since there were 5 Tier 1 SGCN species expected but absent.

WILD TROUT BIOMASS (% INCREASE)

This metric focuses on native or non-native trout species and should only be applied in streams where CPW management objectives relate to native or non-native wild trout species. This metric should not be applied to functional loss or impact projects, or in streams where management objectives relate to non-trout native species. This metric is focused on wild trout populations, so should not be applied to stocked trout populations. Consultation with the area fish biologist is important to determine whether certain species or age classes should be excluded from biomass estimates because of stocking efforts within the watershed.

This metric measures the increase in wild trout 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 have a similar elevation and geomorphic setting as the project reach and should be of reference quality (to the extent practicable). 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 Wild Trout Biomass percent increase for the CSQT:

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 and determine the productivity class used to stratify reference curves.

2. Conduct at least two sampling events in consecutive years at both the project reach and the control reach post-construction. Sampling events should occur at a similar time of year and should avoid spawning season.
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. Average two years of sampling data; this average percentage difference is the field value to be entered into the CSQT. See Example 14.

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.

The change in biomass metric is stratified by productivity ranges, recognizing that streams with an already productive fishery may be less likely to see large additional increases in productivity following a restoration project. The high productivity class includes streams where current biomass is equal to or greater than 60 pounds per acre, which is the biomass criteria for a Gold Medal fishery in Colorado. The moderate productivity class ranges from 30-60 pounds per acre and the low productivity class includes streams that currently have less than 30 pounds per acre. Baseline pre-project biomass data should be used to determine the productivity class.

<u>Data Collection Method</u>:

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 trout populations communities, at least two sampling events occurring in different seasons (at least 60 days between sampling occurrences) or ideally in two consecutive years are needed pre-project. Note: this metric requires selection and sampling of a control reach *in addition* to sampling of the project reach.

Example 14: Calculation of Wild Trout Biomass

Example data and calculations are provided for a medium productivity trout stream where data are collected across multiple years.

Baseline Data for Wild Trout Biomass in a Medium Productivity Trout Stream:

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

Monitoring data for wild trout biomass in a medium productivity trout stream:

Monitoring Event	Sampling Event Yield (lbs/acre)		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%
Post Construction Year 3	100	95	33%	-5%	38%
Post Construction Year 4	105	105	40%	5%	35%
Average Year 1 and 2					**16.5%**
Average Year 3 and 4					**36.5%**

Field Values for Wild Trout Biomass in a Medium Productivity Trout Stream:

Condition Assessment	Biomass Field Value
Existing	0
Proposed	30
As-Built	
Monitoring Year 1	
Monitoring Year 2	16.5
Monitoring Year 3	
Monitoring Year 4	36.5

2.9. Flow Alteration Module

The primary purpose of the Flow Alteration Module is to determine the functional change associated with activities that affect the magnitude, frequency, duration, timing, and rate of change of environmentally relevant flow events (Poff et al. 1997). This module is intended to calculate the functional feet value related to changes in operational commitments, acquisition/ change of existing water rights, or new facilities that enable the proposed hydrology to occur.

Prior to using this module, users should coordinate with the Corps and other appropriate entities. For restoration projects, users should ensure that water is available in the reach to restore one or more aspects of the flow regime, that flow protections can be applied within a specified length of stream, and the restoration of flow in the reach will not have secondary adverse effects elsewhere. On a case-by-case basis this module could also be applied to calculate debits where flow alteration is anticipated. In general, use of this module related to any CWA 404 activities should be determined on a case-by-case basis after consultation with the Corps.

2.9.A. Affected Stream Length

Where flow alteration will occur, the reach affected by the flow altering activities may be shorter or longer than the reach assessed using the Quantification Tool worksheet. The affected stream length in the Flow Alteration Module is defined at the upstream end by where impacts or flow protection would initiate, and at the downstream end by the location of the next water rights user, tributary junction, or terminus beyond which the flow modification has no material effect on SQT parameters. When used for CWA 404 compensatory mitigation projects and impact sites, the Flow Alteration Module is applicable where impacts from flow alteration or improvements associated with flow protection can be evaluated within a specific length of stream, referred to as the affected stream length.

2.9.B. Metric Selection

The Flow Alteration Module includes a 7-day minimum metric to characterize extreme low flows; August (Aug), September (Sept) and January (Jan) mean flow (aka discharge, Q) metrics to characterize baseflows; a mean annual peak Q metric to characterize high flow pulses, and a mean annual Q metric to provide a general characterization of flow volume.

The field value for each metric is the ratio of the observed value over an expected value (O/E) and requires monthly or daily stream flow data to characterize both the observed and expected condition for the affected reach. Data requirements and possible data sources are discussed in more detail below. Table 15 summarizes the metrics and data requirements.

Table 15: Flow Alteration Module Metrics

Metric	Description	Aspect of Hydrologic Alteration Characterized	Data Requirements
Mean Annual Q (O/E)	The average of mean monthly flows (cfs) for each water year in the period of record.	Changes in annual flow volume	Daily or Monthly Average Flow Data
Mean Aug Q (O/E)	The average flow rate (cfs) for the calendar month of August in each water year in the period of record.	Baseflow alteration	Daily or Monthly Average Flow Data
Mean Sept Q (O/E)	The average flow rate (cfs) for the calendar month of September in each water year in the period of record.	Baseflow alteration	Daily or Monthly Average Flow Data
Mean Jan Q (O/E)	The average flow rate (cfs) for the calendar month of January in each water year in the period of record.	Baseflow alteration	Daily or Monthly Average Flow Data
Mean Annual Peak Daily Q (O/E)	The average of the peak daily discharge (cfs) for each water year in the period of record.	High flow pulses	Daily Flow Data
7-Day Minimum (O/E)	The minimum of the 7-day moving average mean for each water year in the period of record.	Extreme low flows	Daily Flow Data

For projects where the Flow Alteration Module is applicable, all six metrics should be evaluated. However, the availability of data may limit the metrics selected in the Flow Alteration Module. For example, the annual peak daily flow and 7-day minimum metrics require daily flow data, and where this data is not available, these metrics cannot be evaluated. The remaining four metrics can be calculated with monthly average flow data, although daily flow data should be used if it is available.

Where these six metrics may not be representative of a critical aspect of the flow regime within a specific reach or watershed, substitution of flow metrics may be considered where sufficient information is available to demonstrate a metric's importance to the local native flow regime.

2.9.C. CALCULATING FIELD VALUES

All metrics in this module are calculated from hydrologic analyses of flow records. While several approaches are available to perform the necessary analyses, these procedures are beyond the scope of this manual. Users should have prior experience with hydrologic analysis and modeling before applying these methods in the Flow Alteration Module.

For each metric, the value of interest (e.g. mean annual Q) is calculated for each water year in the flow record. Then the median value for the flow record is calculated. For most analyses, the distribution of the value of interest within the flow record will be non-normal and the median value should be used (TNC 2009). Justification will need to be provided to use the mean value (parametric analysis). The field value input to the CSQT is the ratio of the observed value to the expected value (O/E). For each metric in the CSQT field values are calculated as the deviation from a reference condition (refer to Table 1 on page 14). Therefore, the user needs to calculate the value of interest for three scenarios:

1. Native Flow – This is the expected (E) condition in the O/E calculations. For the purposes of the CSQT, native flows are the estimates of the stream flows that would result from natural hydrologic processes such as rainfall-runoff and snowmelt-runoff without anthropogenic influence at a given location.
2. Pre-project condition – The amount of flow seen by the system prior to the project taking place. Ideally characterized using a gage record of at least 20 years in length.
3. Post-project condition – The amount of flow seen by the system as a result of the project taking place. The post-project condition reflects changes to the operating rules or modeling parameters that reflect the implementation of the project. Ideally, this value is determined through modeling that uses the same period of record as the pre-project condition.

The pre-project condition is compared to the native flow to calculate the **existing** condition O/E field value for all six metrics and quantifies the flow alteration within the system **before** the project (impact or restoration) is implemented. The post-project condition is compared to the native flow to calculate the proposed condition O/E field values and quantifies the flow alteration within the system **after** the project is implemented.

The Indicators of Hydrologic Alteration (IHA; Richter et al. 1996) is a commonly applied approach for evaluating flow alteration in rivers (Richter et al. 1997; Mathews and Richter 2007; Poff et al. 2010). IHA is a standalone software application that can be used to evaluate hydrologic alteration and develop environmental flow targets using daily stream gage records or modeled daily flows. Users should refer to the IHA Version 7.1 User's Manual for more detail (TNC 2009). Example 15 shows how IHA can be used to generate field values for the CSQT.

Note, the CSQT does not require the use of IHA. Other software or tools can be used to calculate streamflow statistics and generate field values, for example, there is also an R package called EFlowstats.[22] Where USGS stream gages are at or near the project site, some of the metrics may be calculated directly on the USGS NWIS webpage.[23]

[22] http://adsabs.harvard.edu/abs/2013AGUFM.H43E1508T
[23] https://maps.waterdata.usgs.gov/mapper/index.html

Example 15: Flow Alteration in the Fraser River

Average daily flows for the Fraser River near the Winter Park stream gage were used to develop and test the Flow Alteration Module. Flow alteration began in 1936 when the Moffat Tunnel began diverting water from the Fraser basin to the Colorado Front Range. Historical data from 1911-1935 were used to represent native hydrology. Native flows were compared to current hydrology using data from 1988-2017. The comparison of native vs. current flows was used to create an existing condition score for the flow alteration reach, which extends 10.5 miles (55,213 ft) from the Fraser River near Winter Park stream gage to the confluence of the Fraser and Colorado rivers.

Sample IHA output are shown on the following page with the values used to calculate field values for the Flow Alteration Module highlighted in yellow. Example field value calculations are provided below for the mean January Q and mean annual Q metrics. The flow record was evaluated, and a parametric analysis was found more appropriate and means are reported below. Typically, a non-parametric analysis is preferred.

The existing condition field value for the mean January Q metric = O/E = 5.496 cfs /7.772 cfs = 0.71

The existing condition field value for the mean annual Q metric = O/E = 20.04 cfs /44.28 cfs = 0.45

The existing condition assessment in the Flow Alteration Module is shown below. The existing condition score of 0.61 indicates that the affected reach is functioning-at-risk with respect to flow alteration.

Metric	Field Value	Index Value	Module
Mean Annual Q (O/E)	0.45	0.50	0.61
Mean Aug Q (O/E)	0.39	0.43	
Mean Sept Q (O/E)	0.46	0.51	
Mean Jan Q (O/E)	0.71	0.79	
Mean Annual Peak Daily Q (O/E)	0.55	0.62	
7-Day Minimum (O/E)	0.74	0.83	

A hypothetical flow alteration scenario that added 10 cfs to each daily value from August to November comprised the proposed condition. The mean annual peak daily Q, 7-day minimum, and mean Jan Q were unchanged; the mean annual Q, mean Aug Q, and mean Sept Q showed lift as shown below.

Metric	Field Value	Index Value	Module
Mean Annual Q (O/E)	0.45	0.50	0.73
Mean Aug Q (O/E)	0.64	0.71	
Mean Sept Q (O/E)	0.85	0.95	
Mean Jan Q (O/E)	0.71	0.79	
Mean Annual Peak Daily Q (O/E)	0.56	0.62	
7-Day Minimum (O/E)	0.74	0.83	

The Functional Foot value is calculated by multiplying the affected stream length (55,213 LF) by the change in condition scores (0.73-0.61 = 0.12) and applying a 20% weight factor, for a gain of 1,325 FF. This Functional Foot value is added to the Functional Foot value calculated in the Quantification Tool worksheet.

Example 15 Continued: Sample IHA Output from the Fraser River

IHA Parametric Scorecard		
Fraser River at Winter Park Two-Period Parametric Analysis		
	Pre-impact period: 1911-1935 (25 years)	Post-impact period: 1988-2017 (30 years)
NormalizationFactor	1	1
Mean annual flow	44.28	20.04
Non-Normalized Mean Flow	44.28	20.04
Annual C. V.	1.52	1.97
Flow predictability	0.68	0.6
Constancy/predictability	0.44	0.63
% of floods in 60d period	0.88	0.89
Flood-free season	272	242

	MEANS	
	Pre	Post
Parameter Group #1		
October	18.170	8.647
November	13.920	6.344
December	9.708	5.730
January	7.772	5.496
February	6.967	5.449
March	7.422	6.108
April	16.480	9.682
May	90.670	29.210
June	204.500	96.520
July	89.490	39.950
August	40.250	15.810
September	25.360	11.650
Parameter Group #2		
1-day minimum	5.388	4.086
3-day minimum	5.601	4.187
7-day minimum	5.787	4.302
30-day minimum	6.229	4.722
90-day minimum	7.030	5.224
1-day maximum	316.600	175.500
3-day maximum	299.200	167.500
7-day maximum	280.800	152.400
30-day maximum	217.900	108.200
90-day maximum	131.900	56.760
Number of zero days	0.000	0.000
Base flow index	0.137	0.262

FLOW RECORDS

Flow records for hydrologic analyses must be sufficiently long to account for inter-annual variability, and typically this consists of at least 20 years of data (TNC 2009). Flow records for hydrologic analyses can be obtained from sources such as USGS gages, state-operated streamflow gages, or the State of Colorado's Stream Simulation Model (StateMod). Each of these data sources is discussed below. Note, IHA requires daily streamflow data and the software performs linear interpolation over any gaps in the datasets loaded into the software (TNC 2009). All datasets should be checked for data gaps prior to analysis to determine if sufficient data are available to calculate each flow metric. All interpolated data should be reviewed as well.

Gages: When stream gages are present within or near the project site, these data are invaluable. Empirical relationships from a nearby gage station can be developed to produce flow records for the affected stream reach (TNC 2009; Archfield and Vogel 2010; Gianfagna et al. 2015). Any flow datasets should be evaluated to identify data gaps, or data quality outliers or anomalies, and then compared to historic documentation to determine whether the native flow condition can be determined.

The most common source of continuous stream flow data is the USGS gage network.[24] There are also State operated stream gage networks.[25,26] Note that the State of Colorado Division of Water Resources network of stream gages is operated for administration purposes which generally exclude non-irrigation season data (Nov - March).[17] Thus the mean annual and January mean Q may not be available metrics for sites without these data unless flow can be modeled for the missing values.

StateMod: StateMod is a surface water allocation and accounting model that can be used to simulate various water management approaches in Colorado (StateMod 2016).[27] StateMod can be used to simulate flows after accounting for flow alteration within the river system. The user would need to apply the Base Flow[28] module and the simulation module to generate the data to characterize the native flow, i.e. expected values. StateMod generally estimates average monthly flows but an advanced StateMod user can generate daily time step data. Users should consult the StateMod User Manual for instructions and limitations (StateMod 2016).

Hydrologic Models: Where streamflow data are not available or sufficient in length, the user can create a hydrologic model of the reach catchment and use precipitation data to generate stream flows. Note that watershed hydrologic models can be very inaccurate due to their need to parameterize entire watersheds. Records such as daily diversion records and reservoir volumes may be required for modeling existing, pre-project conditions and are available through HydroBase.[29] Precipitation datasets used in hydrologic modeling, similar to flow datasets

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[24] https://nwis.waterdata.usgs.gov/nwis/sw
[25] http://www.dwr.state.co.us/Surfacewater/default.aspx
[26] https://dnrweb.state.co.us/cdss/
[27] https://www.colorado.gov/pacific/cdss/statemod
[28] Base Flow is defined in StateMod as representing "…basin streamflows absent man's influence including diversions, return flows, reservoir operations and pumping. If 100% of man's influence is removed, baseflows are often called virgin flows or natural flows." (StateMod 2016)
[29] https://www.colorado.gov/cdss

mentioned above, should be evaluated to identify data gaps, or data quality outliers or anomalies.

The Urban Storm Drainage Criteria Manual (UDFCD 2016) promotes the use of the EPA Stormwater Management Model (EPA SWMM) for performing hydrologic assessment associated with major drainageways or outfall systems. The USACE Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS; USACE 2016) can also be used to generate flow records. Existing hydrologic analyses performed in Colorado that may be useful can be found in Barlow et al. (2014) and Sanderson et al. (2012).

Data Collection Method:

The Existing Condition Assessment field values are derived from data collection and analysis methods outlined above. The Proposed Condition Assessment field values are generated through altering the pre-project condition flow record to reflect the proposed hydrology according to operational commitments, acquisition/ change of existing water rights, or new facilities that enable the proposed hydrology to occur. The Flow Alteration Module contains ten condition assessments for monitoring to verify that the proposed hydrology. For the monitoring condition assessments in the Flow Alteration Module, the user *must* incorporate measured flow data or otherwise verify the proposed hydrology.

Field data collection needs will vary depending on the data source for flow records. Prior to using this module, users should coordinate with the Corps and other appropriate entities. Individual flow measurements may be sufficient to validate empirical relationships that convert flow values from a nearby gage to the affected stream length. Installing stream gage(s) and taking multiple flow measurements is recommended but ultimately, the data requirements and study design must be developed based on project specific needs.

Field data collection will include surveying cross section(s) and measuring discharge in the field using a current meter. Field data collection may also include installing stream gages, calculating the average channel slope, and sampling the bed material. Field data collection procedures are provided in Appendix A. Placement and use of stream gages should follow Best Practices for Continuous Monitoring of Temperature and Flow in Wadeable Streams (USEPA 2014).

Chapter 3. Calculating Functional Lift

This chapter outlines the process and concepts that should be considered during restoration project planning using the CSQT, including projects providing mitigation under CWA 404 (i.e., mitigation banks, in-lieu fee projects, or on-site/off-site permittee responsible mitigation projects). The sections of the CSQT workbook that should be completed for restoration and mitigation projects are summarized in Table 16. See Chapter 1.2.c. for information on how the CSQT calculates functional lift.

Table 16: CSQT Worksheets Used for Restoration Projects

Worksheets	Relevant Sections
Project Assessment (Section 1.2.a)	• Programmatic Goals • Reach Description • Aerial Photograph of Project Reach • Restoration Approach
Catchment Assessment (Section 1.2.b)	• Complete entire form • Determine restoration potential
Quantification Tool (Section 1.2.c)	• Site Information and Reference Selection • Existing Condition field values* • Proposed Condition field values*
Flow Alteration Module* (Section 1.2.d)	• Site Information • Existing Condition field values* • Proposed Condition field values* • Field values for up to 10 monitoring events*
Monitoring Data (Section 1.2.f)	• As-Built Condition field values* • Field values for up to 10 monitoring events*
Data Summary	No data entry in this worksheet
Reference Curves	No data entry in this worksheet

**Guidance on parameter selection is provided in Section 2.3. 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 CSQT can be used to assist with selecting or ranking the priority of a potential stream restoration or mitigation site. While 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 CSQT.

In the CSQT, 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 CSQT can be used to rank sites based on the amount of functional lift available. 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. The user could model a variety of design approaches to see how much lift is reasonable for each parameter. 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 COMP (USACE 2019) or consult with the Corps for further guidance on site selection.

3.2. Restoration or Mitigation Project Planning

3.2.A. Restoration Potential

Users will need to determine the restoration potential of the project reach, which includes the completion of the Catchment Assessment form. Once the restoration potential has been determined, the results are provided in the Site Information and Reference Selection section of the Quantification Tool worksheet. The Catchment Assessment worksheet is described in Sections 1.2 and 2.2 of this manual. The information below provides guidance on how to determine restoration potential using the results from the Catchment Assessment.

Restoration potential is the highest level of restoration that can be achieved based on an assessment 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 categories to a reference standard. Partial restoration would improve some, but not all functions to reference standard. For example, partial restoration might mean restoring stability and aquatic habitat to a reference standard by implementing activities that manipulate processes in the Reach Hydrology & Hydraulics and Geomorphology categories, but not restoring temperature or fish communities 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, to a reference standard (see Table 1, page 14). 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 biological 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 may allow for some functions, such as floodplain connectivity, dynamic equilibrium, and in-stream habitat to be restored but may limit the restoration of physicochemical and/or biological functions to reference standard. For partial restoration projects, improvements in all functional categories may be observed, but these improvements may not reflect a reference standard.

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

<u>Procedure for Determining Restoration Potential</u>:

1. Determine the project reach limits and delineate the catchment area to the downstream end of the project reach (See reach delineation in Chapter 2).
2. Complete the Catchment Assessment worksheet (see 2.2 of this manual). Review the scores for each category to determine if an identified stressor can be overcome or if it will prevent the project reach from achieving even partial restoration. A stressor that prohibits partial restoration may constitute a “deal breaker” that could affect site selection until catchment-scale stressors can be improved.
    a. Upon completing the Catchment Assessment worksheet, 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 individual category ratings can change from fair or poor to good, then full restoration may be possible.
    b. Compare the reach size to the catchment size (length and/or area). 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.
    c. 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. 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.

3. 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, utility easements, 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 that natural conditions are not constraints. For example, while hillslopes constrain the lateral extent of meandering, that is 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 habitat diversity. They are not considered constraints in this methodology and would therefore not limit the restoration potential.

4. Use the Quantification Tool worksheet to determine the baseline condition of the reach. The Quantification Tool worksheet will quantify functional capacity by parameter and functional category.

5. Determine the current and future potential Stream Evolution Model (SEM) and/or Rosgen Channel Succession Stage (Table 17). 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 CSQT and is described in Chapter 2.

   The future SEM stage (Cluer and Thorne 2013) and/or Rosgen Stream Type (Rosgen 1996) can be determined by considering the reach-scale constraints, Catchment Assessment results in combination with the baseline existing condition data. 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 SEM provides more detail for systems that historically existed started as stream/wetland complexes or multi-thread systems than the Rosgen method and provides functional descriptions for each stage. Table 17 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 and responses to a wider range of disturbances.

Table 17: 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
Stage 8 - Anastomosing	DA

Based on Steps 1-5, 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) and which may not. The restoration potential of the project reach is recorded on the Catchment Assessment worksheet and described on the Project Assessment worksheet. Results are also entered in the Site Information and Reference selection Section of the Quantification Tool worksheet.

3.2.B. Function-Based Design Goals and Objectives

After the restoration potential has been determined, users should develop function-based goals and objectives. This information is also entered into the CSQT Workbook on the Project Assessment worksheet. Guidance on developing function-based goals and objectives is provided below.

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 migration, and riparian vegetation will be changed to meet the goals. Design goals and objectives can be used to inform parameter selection within the CSQT (see Example 16).

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 wild 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 trout, a partial restoration goal that matches the restoration potential. If wild trout populations in the project reach are to be monitored, increasing wild trout biomass could be possible even with partial restoration potential; however, restoring wild trout biomass to reference standard would not be expected or possible. If catchment-level improvements are implemented to address stormwater runoff and temperature issues, full restoration could be achieved. This outcome would require reach-scale *and* catchment-scale restoration efforts.

Example 16: Project with Partial Restoration Potential

Partial Restoration Potential: The catchment draining to the project is mostly rangelands or irrigated pasture. The overall catchment health is fair and 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 bed form 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 Active Restoration Approach Examples

The CSQT evaluates the functional lift of restoration activities through changes in function-based parameter scores and not by the scale of restoration activities, e.g., the amount of heavy equipment used in a project or the number of in-stream structures installed. Therefore, the tool can evaluate lift across a range of restoration approaches that require varying amounts of effort. While an active approach that includes significant earthwork and modification may be needed in some streams, this is not always the case. For less intensive projects, it is recommended that key parameters (i.e., floodplain connectivity, bed form diversity, lateral migration, and riparian vegetation) are already in a functioning condition or have the potential to trend in that direction without significant manipulation.

This section includes hypothetical examples of three restoration approaches and the potential lift that can be captured using the CSQT. The three example approaches include: Passive, Moderately Active, and Active, which relate to the amount of landscape and in-channel modification needed to achieve reference standard. All three examples evaluate the following parameters:

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

To illustrate the benefit of monitoring physicochemical and biological condition, it was assumed the projects could show modest improvements in temperature, nutrients, macroinvertebrate and fish parameters.[30]

Passive Restoration Approach

In this hypothetical example, 1,000 linear feet of stream is flowing through open rangeland. An existing condition assessment showed that the stream had not been channelized in the past and meanders within an alluvial valley. Cattle have access to the stream; however, due to the meanders and corresponding lateral-scour pools, bed form diversity was functioning. Most of the riparian vegetation was removed by grazing, which led to moderate erosion on several outside meander bends. Since the stream had not been channelized, the slope didn't change, and the stream did not incise. Erosion was not higher because bank heights were low, and energy could be dissipated by spreading flood waters across the floodplain.

Due to upstream agricultural land use practices, the project received a partial restoration potential determination. The nutrients parameter score is expected to improve slightly; however, it will remain not functioning and limit biological lift as well. The existing stream is a Rosgen C stream type with a single thread sinuous channel (Stage 1 of the SEM). While the stream is not incised, channel widening is likely to continue with cattle access to the stream. The stream will likely stay a C but could evolve into a D if sediment supply increases significantly.

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 bed form diversity are already within the reference standard range of condition (note, it often takes significant channel modification to fix these parameters). With these functions in place, a newly planted riparian corridor will improve lateral migration and support physicochemical and biology functions (Figure 27). For this example, it is likely that removing the cattle would result in measurable improvements to temperature, nutrients, macroinvertebrate, and fish parameters within the mitigation monitoring period of 5 years.

[30] Without evaluating the physicochemical and biological parameters, the maximum overall score in the CSQT will be 0.60. Selecting and assessing parameters in both functional categories will increase the maximum overall score to 1.0 in the CSQT.

Figure 27: Passive Restoration Approach CSQT Example. Red equals not-functioning, yellow equals functioning-at-risk, and green equals functioning.

Function-Based Parameters	Existing Parameter	Proposed Parameter
Reach Runoff	0.82	0.90
Baseflow Dynamics	0.86	0.86
Floodplain Connectivity	0.71	0.71
Large Woody Debris	0.00	0.00
Lateral Migration	0.60	1.00
Bed Material Characterization		
Bed Form Diversity	0.82	0.82
Plan Form		
Riparian Vegetation	0.14	0.68
Temperature	0.71	0.77
Dissolved Oxygen		
Nutrients	0.13	0.19
Macroinvertebrates	0.20	0.26
Fish	0.60	0.64

<u>Moderately Active Approach:</u>

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 and is now 800 linear feet in length. 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 bed form diversity is now in a not-functioning condition. The riparian vegetation has been substantially grazed, which has led to moderate bank erosion; however, floodplain connectivity has been largely maintained. In this scenario, the existing stream channel is a C but it is likely to incise and become a Gc stream type, followed by an F and finally back to a C, but only after many years of bank erosion and loss of pastureland.

In this scenario, the mitigation approach involves fencing out the cattle, riparian planting, and the addition of large wood and a few in-stream structures to create pools in the straightened channel. The addition of large wood will improve the large woody debris score and the in-stream structures will improve the bed form diversity score and reduce lateral migration (Figure 28).

Figure 28: Moderately Active Restoration Approach CSQT Example. Red equals not-functioning, yellow equals functioning-at-risk, and green equals functioning.

Function-Based Parameters	Existing Parameter	Proposed Parameter
Reach Runoff	0.82	0.90
Baseflow Dynamics	0.86	0.86
Floodplain Connectivity	0.71	0.71
Large Woody Debris	0.00	0.56
Lateral Migration	0.52	1.00
Bed Material Characterization		
Bed Form Diversity	0.40	0.82
Plan Form		
Riparian Vegetation	0.14	0.68
Temperature	0.71	0.77
Dissolved Oxygen		
Nutrients	0.13	0.19
Macroinvertebrates	0.20	0.26
Fish	0.60	0.64

Active Approach:

In this hypothetical example, the stream reach is in a setting similar to the previous two examples, except that the stream has been channelized (800 linear feet in length) and is incised (i.e., no floodplain connectivity). Riparian vegetation and bed form diversity are not functioning for reasons explained in the previous examples. Lateral migration is also not-functioning because the bank heights are high due to the floodplain disconnection and channel incision, which is exacerbated by the lack of riparian vegetation.

Since the channel is disconnected from its floodplain, a passive restoration approach is not likely to see improvements in channel condition during the monitoring period as flood flows will continue to erode and widen the channel. The current stream type is a Rosgen Gc, which will evolve into an F through bank erosion and aggradation. The channel will likely evolve back into a C channel. Significant modification is needed to establish a new meandering channel geometry (1,000 linear feet in length) and reconnect the stream to a floodplain, either by raising the bed or lowering the floodplain. Improvements in parameter scores are shown in Figure 29.

Figure 29: Active Restoration Approach CSQT Example. Red equals not-functioning, yellow equals functioning-at-risk, and green equals functioning.

Function-Based Parameters	Existing Parameter	Proposed Parameter
Reach Runoff	0.82	0.90
Baseflow Dynamics	0.86	0.86
Floodplain Connectivity	0.00	0.85
Large Woody Debris	0.00	0.56
Lateral Migration	0.24	1.00
Bed Material Characterization		
Bed Form Diversity	0.40	0.82
Plan Form		
Riparian Vegetation	0.14	0.68
Temperature	0.71	0.77
Dissolved Oxygen		
Nutrients	0.13	0.19
Macroinvertebrates	0.20	0.26
Fish	0.60	0.64

The functional lift for each of the three scenarios outlined above is summarized in Table 18, and is based on a proposed stream length of 1000 linear feet. Note that more functional lift was documented for each restoration approach because the projects were monitored for lift in the physicochemical and biology functional categories. Also note that even though the proposed condition scores are similar between all three scenarios because they had similar restoration potential, the most lift was achieved by the active approach since the existing channel was in the worst condition.

Table 18: 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	80	100
Moderately Active	120	144
Active	306	368

Chapter 4. References

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APPENDIX A:

Field Data Collection Methods for the Colorado Stream Quantification Tool and Debit Calculator Beta Version

Table of Contents

1. Introduction and Purpose

The purpose of this document is to provide a compendium of field methods that can be used to collect data for the Colorado Stream Quantification Tool and Debit Calculator (CSQT). Individuals collecting and analyzing these data should have experience and expertise in botany, ecology, hydrology, and geomorphology. Interdisciplinary teams with a combination of these skill sets are beneficial to ensuring consistent and accurate data collection and analysis. Field trainings in these methods and the Stream Functions Pyramid Framework are recommended to ensure that the methods are executed consistently.

This appendix serves as a compliment to Chapter 2 of the User Manual, which provides information on how to select parameters, calculate metrics from field data, and input these values into the CSQT and Debit Calculator workbooks. The CSQT and Debit Calculator are not themselves assessment methods, but instead consolidate data and results from many methods and use them to calculate changes in stream condition and determine functional lift and loss. Methods are provided in this Appendix for reference and use in the field. Few measurements are unique to the CSQT, and data collection procedures are often detailed in other instruction manuals or literature. Where appropriate, this appendix will reference the original methodology and explain differences in data collection or calculation methods needed for the CSQT. This document is based on the Field Document Collection Methods for the WSQT v1.0 (USACE 2018 Appendix A) and has been edited for Colorado with input from the Colorado Stream Quantification Tool Steering Committee (CSQT SC). The WSQT v1.0 served as the basis for the CSQT Beta Version and many Chapters in this document are reproduced with minor edits from USACE (2018) Appendix A.

A Parameter Selection Checklist and the data forms referenced in the relevant sections below are included in Appendix B. Prior to going into the field, the user should complete the Parameter Selection Checklist, which will assist in determining which field methods and forms are needed for data collection. Guidance on filling out the checklist is provided in Chapter 2 of the User Manual. Several of the data forms are available as Microsoft Excel Workbooks where data can be entered upon returning from the field.[1] Other data processing tools, such as Mecklenberg (2004) can be used to process field data and calculate metric values. There is a shading key on some of the field forms that indicates which cells are intended to be filled out in the office versus the field, and which cells perform calculations. The calculation cells will automatically calculate values from provided field data in the workbook version. These cells can also be filled out on a printed field form.

Note: Two metrics in the CSQT require data collection at a reference site *in addition* to data collection within the project area. For the bed material characterization metric, Bevenger and King (1995) provide a description of how to select and potentially combine reference reaches. For this metric, the reference reach should be located within the same stream and valley type, with a similar catchment area, gradient, and lithology. When possible, reference reaches should be located upstream of the project reach and upstream of the source of sediment imbalance.

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[1] Microsoft Excel version of the field forms and the Mecklenburg (2004) Reference Reach Spreadsheet tool are available from the Stream Mechanics website: https://stream-mechanics.com/stream-functions-pyramid-framework/

For the wild trout biomass metric, a control site should be sampled in conjunction with sampling of the project reach. Specific guidance is provided in the Fish Sampling section of this Appendix.

At a minimum, the following field gear will be needed:

- Field forms and maps
- Waders
- Stadia rod
- Standard survey equipment or hand level/line level depending on selected method
- Metric ruler
- 100' Tape
- Enough 300' tapes for the assessment reach length (note: a tape with feet on one side and metric on the other is recommended)
- GPS unit (helpful with lateral migration and sinuosity field measurements)
- Calipers large enough to measure 50 cm diameter logs (helpful for the LWD assessment)

For evaluating the following parameters and metrics, field methods are described briefly in this Appendix, however, users should be familiar with the following procedures and should review the following references prior to field sampling if that parameter will be assessed:

- Pebble Count:
  - River Stability Field Guide, Second Edition (Rosgen 2014)
  - Standard Operating Procedure for the Collection of Pebble Counts (CDPHE 2015a).
  - A Pebble Count Procedure for Assessing Watershed Cumulative Effects (Bevenger and King 1995).
- Large Woody Debris Index: Application of the Large Woody Debris Index: A Field User Manual Version 1 (Harman et al. 2017).
- Bank Erosion Hazard Index/Near Bank Stress:
  - Appendix D of Function-Based Rapid Field Stream Assessment Methodology (Starr et al. 2015), or
  - River Stability Field Guide, Second Edition (Rosgen 2014)
- Greenline Stability Rating:
  - Monitoring the Vegetation Resources in Riparian Areas (Winward 2000), or
  - Riparian Area Management: Multiple Indicator Monitoring (MIM) of Stream Channels and Streamside Vegetation (USDOI 2011).
- Temperature:

  - Best Practices for Continuous Monitoring of Temperature and Flow in Wadeable Streams (USEPA 2014), or
  - Measuring Stream Temperatures with Digital Data Loggers: A User's Field Guide (Dunham et al. 2005).

- Flow Alteration Module and potentially Baseflow Dynamics metrics: Best Practices for Continuous Monitoring of Temperature and Flow in Wadeable Streams (USEPA 2014).
- Macroinvertebrates: 10-1 Policy Statement Appendices B and C (CDPHE 2017).
- Fish: Standard Methods for Sampling North American Freshwater Fishes (Bonar et al. 2009)

2. Reach and Representative Sub-Reach Assessments

Prior to field work, the user should determine whether the project area should be delineated into multiple project reaches (see Section 2.1 of the User Manual). When multiple project reaches exist on the same stream, evaluate the most downstream reach first and work upstream. The following sequence of steps is recommended for all evaluations. Based on parameter selection (Section 2.3 of the User Manual), not all steps will need to be completed for all projects. The Parameter Selection Checklist can be used to indicate which parameters are included within the field evaluation.

Additionally, before going in the field check any sampling windows or index periods for field data collection. The procedure below outlines a comprehensive assessment of most metrics in the CSQT in a single day or visit but multiple days or visits may be required, depending on the metrics selected for analysis.

Procedure:

1. Conduct necessary pre-field desktop activities (see Chapter 2 of the User Manual). Complete the Parameter Selection Checklist and the Site Information and Reference Stratification section of the Project Reach form. All values in these sections should be filled in prior to completing fieldwork.
2. Walk along the stream throughout the project area to verify the delineation of project reaches. Determine whether additional segmentation is needed based on field conditions. Record the GPS location at the downstream end of the reach in Section I of the Project Reach form.
3. Within each project reach, walk along the stream length to view locations and character of riffles, presence of beaver dams or other impoundments, and bankfull indicators.
   a. Measure difference between bankfull stage and water surface elevation at multiple points along the project reach (See Bankfull Elevation – Field Identification). This data can be recorded in the Project Reach form. Use this data to come to a consensus on the difference between the bankfull (BKF) elevation and water surface (WS) elevation and record the value in Section II of the Project Reach form.
   b. Consider possible locations for the representative riffle cross section (see Representative Riffle Survey). The preference is for the riffle to be located within the representative sub-reach. However, in disturbed settings, this cross section may be located upstream or downstream of the sub-reach.
   c. Record number of concentrated flow points, length of any armored sections of bank, and length of any side channels on the Project Reach form (see Concentrated Flow Points, Armoring, and Side Channels sections below).
   d. Measure slope and sinuosity, if applicable (See Rosgen Stream Classification and Sinuosity, respectively).
4. If the project reach is long, determine the location of the representative sub-reach. The sub-reach is at least two meander cycles or 20 bankfull widths in length. The sub-reach should

be representative of the typical bed form diversity in the project reach and should include the stretch of channel with the greatest amount of large woody debris.

5. Record the GPS location at the downstream end of the representative sub-reach in Section III of the Project Reach form.
6. Select the location within the sub-reach for biological sampling (if applicable). Refer to Appendix B of the Policy Statement 10-1 (CDPHE 2017) for information on selecting a sample location.
7. Sample macroinvertebrates (see Macroinvertebrate Sampling in Section 9). Processed samples should be immediately preserved with ethanol or other appropriate preservative, and stored in a cool, shaded area for the remainder of data collection.
8. Sample chlorophyll a (see Chlorophyll a Sampling in Section 8). Chlorophyll a sampling can be done simultaneously during macroinvertebrate sample collection. Processed samples should be immediately transferred to a cooler with dry ice, and stored in a cool, shaded area for the remainder of data collection.
9. Survey the representative riffle cross section (see Representative Riffle Survey methods below). If located within the sub-reach, the same riffle used for biological sampling may be used for the cross section survey, or an alternative representative riffle can be selected. If the same riffle is used, locate the cross section in a portion of the riffle not substantially disturbed from biological sampling. Locate bankfull indicators using the Bankfull Elevation - Field Identification methods.
    a. Survey additional riffle cross sections as needed to quantify baseflow dynamics and return interval.
10. Conduct the Longitudinal Profile (see Section 3) or Rapid Survey (Section 4) for bed form diversity and floodplain connectivity data.
11. Conduct a large woody debris assessment (Section 5), lateral migration evaluations (Section 6), pebble counts, and riparian vegetation survey (Section 7), as applicable based on parameter selection.
12. Install stream gages, temperature sensors, and dissolved oxygen sensors as applicable based on parameter selection and complete the Sensor Log form.
    - Note: Users will need to survey cross sections and measure flow at any stream gages that will be used to determine stream flow (applicable to the baseflow dynamics, return interval, and metrics in the flow alteration module).

Concentrated Flow Points

This metric assesses the number of concentrated flow points caused by anthropogenic impacts that enter the project reach and is normalized per 1,000 linear feet of stream. Anthropogenic causes of concentrated flow include agricultural drainage ditches, impervious surfaces, storm drains, land clearing, and others.

Procedure:

1. During the initial reach walk, any observed concentrated flow points should be tallied and recorded on the Project Reach form. The reach walk should extend along the entire project reach and include both sides of the stream channel.
   - Field calculation: The number of concentrated flow points is normalized to a count per 1,000 linear feet of stream. Divide the count by the reach length provided in Section 1 of the form and multiply the result by 1,000 linear feet. Space is provided for this calculation on Line II.C of the form; the workbook version of the form will automatically calculate this value.

Armoring

Armoring is an optional metric that must be assessed on reaches where armoring is present or proposed. Examples of armoring include rip rap, gabion baskets, concrete, and other engineered materials that prevent streams from meandering and are located within, at, or extending beyond the channel banks. Typically, toe wood with transplants or bioengineering is not counted as armoring. However, if toe wood or stone-toe used for bioengineering extends from the bed to more than one-third the bank height, it is counted as armoring. Engineered log jams that are mechanically anchored to the bed/banks and extend to the top of the streambank are considered armoring. Armoring should be measured at the project reach-level.

Procedure:

1. During the initial reach walk, measure and record the length of each bank that is armored and record that length on the Project Reach form. The reach walk should extend along the entire project reach and include both sides of the stream channel.

Side Channels

Percent side channels is an optional metric for single-thread channels having perennial flow in valley types and gradients that would naturally support side channels. Side channels are small open channels that are connected to the main channel at one or both ends. A slough is an example of a side channel connected at one end. Floodplain channels can count when one or both ends are connected to the main channel and the depth is at least one-half the bankfull stage. For example, if the bankfull riffle depth equals two feet, the floodplain side channel depth must equal at least one foot where the side channel intersects the main channel. Floodplain channels that have filled with sediment to the bankfull stage at both ends are not counted as side channels. Islands and mid-channel bars do not create side channels; they simply split the flow within the main channel.

Procedure:

1. During the initial reach walk, measure and record the length of each side channel and record that length on the Project Reach form. The reach walk should extend along the entire project reach and include both sides of the stream channel.

Sinuosity

The sinuosity of a stream is calculated by dividing the channel distance by the straight- line valley length between the upstream and downstream extent of the project reach (measure the full project reach length rather than the sub-reach). Sinuosity can be calculated from recent aerial imagery, if available (see Chapter 2 of the User Manual). 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.

Procedure:

1. Measure the stream length for the entire project reach using a tape along the edge of channel, GPS or aerial imagery.
2. Measure a straight line following the fall-line of the valley using a tape, range finder, GPS or aerial imagery.
3. The stream length divided by the valley length equals sinuosity. Enter this value in the space provided on the Project Reach form.

Bankfull Elevation – Field Identification

Multiple parameters in the CSQT require bankfull dimensions to calculate metrics, including floodplain connectivity, large woody debris, lateral migration, and bed form diversity. Bankfull dimensions are also needed to determine the Rosgen stream type. Prior to making field measurements for these parameters and determining stream type, the user should identify and verify the bankfull stage and associated dimensions. Methods to establish and verify bankfull elevation in the field can be found in the Bankfull Elevation – Field Identification section of the Manual of Standard Operating Procedures for Sample Collection and Analysis (WDEQ/WQD 2018). The text is duplicated here with minor modifications; photographs from the original reference are not included.

Quality Control: Appropriate use of bankfull elevation indicators requires adherence to the following principles which can also serve as quality control for this method:

1. Seek indicators appropriate for specific Rosgen stream types.
2. Know the recent flood and drought history of the area to avoid being misled by spurious indicators. This includes conducting site reconnaissance during bankfull discharge events.
3. Use multiple indicators wherever possible as reinforcement of a common stage or elevation.
4. Exercise caution when identifying bankfull elevation in reaches of the stream that are subject to frequent inundation caused by beaver dams, diversion structures, etc.
5. Bankfull elevation above and below hydrologic anomalies that influence the entire active channel such as natural controls (boulders, bedrock), headcuts, dams, and similar features will likely be different. These breaks in bankfull elevation should be accounted for at all site visits.
6. Except in cases noted above, bankfull indicators should be at a consistent elevation relative to the water surface along an individual stream reach.

7. Reachwide bankfull slope should be similar to the reachwide water surface slope, assuming both variables were measured on the same day and rapid aggradation or degradation is not occurring. This can be determined from the longitudinal profile and difference in measurements between the bankfull indicator and water surface.

8. Bankfull indicators along pools, particularly along the outside of meander bends, may be at a higher elevation than indicators at riffles. However, there should still be consistency in elevation of bankfull indicators along the entire reach.

9. Where possible, calibrate field-determined bankfull stage elevation and corresponding bankfull channel dimensions to known recurrence interval discharges (refer to Section 2.6.c in Chapter 2 of the User Manual) and/or with applicable regional curves or hydraulic and sediment transport models (Torizzo and Pitlick 2004). [In using regional curves to verify bankfull, the bankfull area is typically used for the comparison. Lines E, F, and G of Section III of the Project Reach form should be populated with the bankfull area, width, and mean depth as calculated from these resources <u>before</u> going out in the field].

10. Persistent long-term drought conditions may create a false “bankfull” elevation that does not correspond to the actual bankfull elevation under the current climatic regime. See step 9.

Introduction: Bankfull discharge is a frequently occurring peak flow whose corresponding stage or elevation often represents the incipient point of flooding associated with a return period of 1-2 years. Bankfull elevation (and its associated discharge) serves as a consistent reference point which can be related to the formation, maintenance, and dimensions of the channel as it exists under the current climatic regime. Bankfull elevation often represents the break point between processes of channel and floodplain formation. Correctly identifying bankfull elevation is crucial and serves as the foundation for all subsequent geomorphic methods used in the determination of channel classification, dimension, pattern, and profile.

Bankfull discharge in Wyoming and Colorado generally occurs in the late spring or early summer, which coincides with snow-melt or the period of frequent and/or intense precipitation events. However, bankfull discharge can conceptually occur at any time during the year. Because site visits are often not conducted during a bankfull event, bankfull indicators must be relied on to correctly identify bankfull elevation. There are several bankfull indicators though no one indicator is suitable in all circumstances. Use the following common bankfull indicators to identify bankfull elevation, many of which have been adapted from Rosgen (2008). In all cases, multiple bankfull indicators should be used to identify bankfull elevation. Primary indicators should always be sought out at the site; secondary indicators should be used only as supplemental information to support primary indicators. Illustrated examples of bankfull elevation and associated bankfull indicators from Wyoming streams are provided in WDEQ/WQD (2018).

Primary Indicators:

1. Floodplains – Bankfull elevation is often associated with the point at which water begins to spread out onto the floodplain. This may or may not be the top of the bank. This is one of the best indicators of bankfull elevation for use on Rosgen C, D, DA and E stream types which often have well-developed floodplains. Floodplain indicators do not apply to entrenched Rosgen A, B, F and G stream types which generally do not have floodplains. Most streams in alluvial/colluvial valleys have three distinct terraces. Do not confuse the low

terrace with the floodplain, which may be close in elevation. The low terrace is an abandoned floodplain often characterized by upland or a mixture of upland and facultative riparian vegetation.

2. Breaks in Slope – A change in slope from a near vertical bank to a more horizontal bank is often the best indicator of the incipient point of flooding, or the transition from the bankfull channel to a floodplain. Such changes in slope often correspond to the "bankfull bench". However, streams that have undergone physical alterations in the past or are actively degrading or aggrading can have multiple slope breaks that represent abandoned floodplains or terraces, rather than the bankfull elevation. For incised channels with near vertical banks, the first substantial break in slope (example: transitioning from 90° to 45°) at the bottom of the near vertical bank can be the bankfull elevation.
3. Scour Lines – A scour line at a consistent elevation along a reach that lies below an intact soil layer can represent bankfull elevation. Scour lines may or may not have exposed root hairs.
4. Undercuts – On bank sections where the perennial vegetation forms a dense root mat, the upper extent or top of the undercut is normally slightly below bankfull elevation. Undercuts are best used as indicators in channels lacking obvious floodplains.
5. Depositional Features – The elevation on top of the highest depositional feature (point bar or mid-channel bar) within the active channel is often associated with the bankfull elevation. However, in streams that have experienced recent record flood events, the tops of the highest depositional features may be above bankfull elevation. In streams that are rapidly degrading (downcutting), the tops of the highest depositional features may also be above the bankfull elevation.
6. Particle Size Demarcation – The point at which there is a distinct change in particle size of the active channel bed at a consistent elevation along a reach is often associated with bankfull elevation. Changes in particle size can be from coarse to fine or from fine to coarse and may also correspond to a break in slope or the top of a depositional feature.

Secondary Indicators:

1. Vegetation - Using vegetation to identify bankfull elevation must be done cautiously. When vegetation is used as a sole indicator, bankfull is frequently underestimated. Common riparian species such as alder (*Alnus* sp.), dogwood (*Cornus* sp.) and redtop (*Deschampsia* sp.) can be used as supplemental indicators of bankfull elevation in Colorado streams. Generally, bankfull elevation is located at or just under the base of riparian vegetation often associated with a scour line. Willow (*Salix* sp.) and cottonwood (*Populus* sp.) should not be used as indicators as they can colonize within the bankfull channel. Mature woody species are generally found above the bankfull elevation and should not be used. Vegetation generally is not an appropriate indicator in streams where active degradation such as bank sloughing is occurring.
2. Lichens or Mosses – A noticeable change in color, pattern and/or species of lichens or mosses on boulders or bedrock at a consistent elevation along a reach may represent bankfull elevation.

3. Debris Lines - The top of a debris line consisting of leaf and woody litter, dead algae, fecal material, trash or other floating debris at a consistent elevation along a reach may represent bankfull elevation. However, do not confuse debris deposited by flow events larger than bankfull to represent bankfull elevation.

Procedure:

1. Determine whether hydrologic anomalies such as natural controls (boulders, bedrock), headcuts, dams, and similar features exist in the reach and account for their influence on bankfull elevation accordingly.

2. Using the bankfull indicators described above, walk the entire length of the reach, multiple times if needed, and identify primary and secondary bankfull indicators where applicable. Care should be taken to use only the best bankfull indicators that provide the strongest evidence of bankfull elevation.

3. Mark the locations of both primary and secondary bankfull indicators with pin flags.

4. Use a pocket rod or stadia rod to measure the distance from the current water surface to the estimated bankfull elevation at each of the best bankfull indicators. Bankfull indicators should follow a generally consistent elevation relative to the water surface throughout the reach. As such, distances from the current water surface to the estimated bankfull elevation should be similar among all measurements. Outlying distances will be evident and should be removed or revisited and verified.

5. Use a weighted (primary indicators have greater weight than secondary indicators) average distance between water surface and bankfull elevation as a reference point when conducting subsequent geomorphic survey procedures such as cross sections and longitudinal profiles on the same day the average value was measured.

6. If desired for future reference, photo document the location of the bankfull elevation using the pin flags as reference points, making sure the entire bankfull channel is visible in the photograph. If a measurement tape has been stretched longitudinally along the entire reach, record the distance along the tape where the bankfull indicator in the photograph is located.

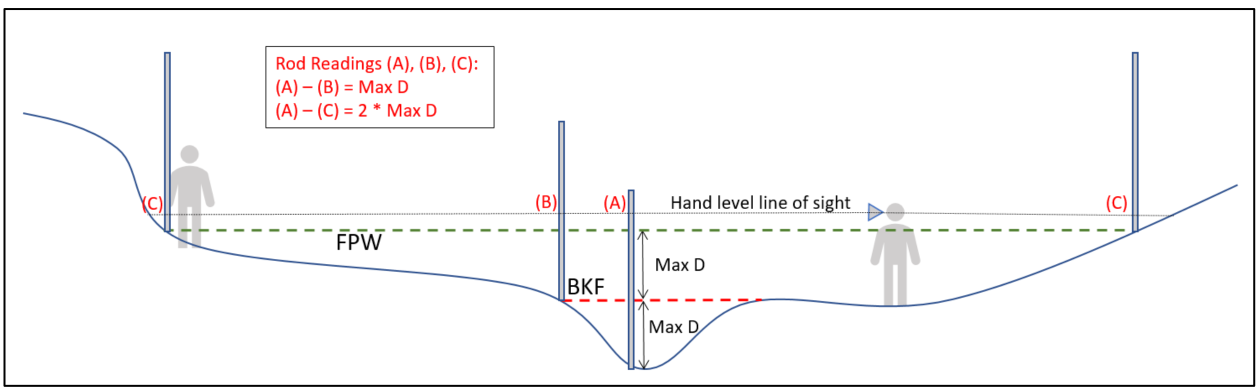
Representative Riffle Survey

A representative riffle should be surveyed to calculate the bankfull dimensions of area, width, and mean depth and to determine the Rosgen Stream Classification type (see following section). Bankfull dimensions from the representative riffle should be compared to estimated bankfull dimensions from other references such as return interval analysis or bankfull regional curves to verify the bankfull indicator (see Bankfull Elevation – Field Identification, Quality Control section). The bankfull width and mean depth from the representative riffle survey are used to calculate pool spacing and pool depth ratios, respectively. These are the primary reasons for surveying the representative riffle and the selection of the representative riffle should keep these objectives in mind. Two representative riffle cross sections may be required in severely degraded systems where the first cross section is a different stream type than the assessment reach. In this case, the two cross sections should be measured following the procedures below. The first is used for bankfull verification and to calculate dimensionless ratios for the bed form diversity parameter. The second riffle is measured within the assessment reach to characterize the Rosgen stream type.[2]

The representative riffle survey can be completed with either standard survey equipment or a stadia rod and level tape for rapid surveys. Methods to set up and measure the representative riffle cross section using standard surveying equipment are derived from the Channel Cross Section Survey methods outlined in the Manual of Standard Operating Procedures for Sample Collection and Analysis (WDEQ/WQD 2018). The text is duplicated here with minor modifications; information on quality control and photographs from the original reference are not included. A rapid method using a tape and stadia rod follow.

NOTE: The flood prone width should be recorded for all riffle cross sections and measured perpendicular to the fall line of the valley. Entrenchment ratio is a metric in the CSQT for the floodplain connectivity parameter and is necessary to determine the stream type. Independent of whether the representative riffle is surveyed following the WDEQ/WQD procedure or rapid survey methods, the cross section flood prone width is required. This means that either the cross section should extend far enough into the floodplain to capture the flood prone width OR the distance from the channel bank to the elevation that is twice the max bankfull depth should be recorded for each side of the channel. Where it is not feasible to survey the entire flood prone width, the cross section should span a width that is at least 3 times the width of the channel. Figure A.1 demonstrates how to measure the flood prone width with a hand level.

Figure A.1. Surveying Flood Prone Width



Procedure (WDEQ/WQD 2018):

1. Identify the riffle within the project area that will be used as the representative riffle. Where possible, the representative riffle should be located within the representative sub-reach. However, in a highly degraded reach, a stable riffle cross section from an adjoining upstream or downstream sub-reach may be used.
2. Following the procedure in Bankfull Elevation–Field Identification, identify bankfull elevation in the reach.

[2] The second riffle can also be used to characterize reach conditions for the return interval, average depth, and average velocity metrics if applicable. Additional cross sections may be necessary, refer to the User Manual instructions for these metrics.

3. Determine the location of the cross section within the representative riffle. Cross sections should not be placed over riffles or other features that have been substantially disturbed by biological sampling, animal or human activity or similar causes. Avoid placement of the cross section at the top or bottom of a riffle feature. In streams with active physical degradation and/or aggradation, features may migrate longitudinally within the reach from one year to another. Place the cross section across the mid-point of the feature to increase the likelihood that the facet type you measure will be the same type you measure in subsequent years. Make sure that the cross section is perpendicular to the direction of flow at bankfull. Where possible, cross section endpoints should be located above the bankfull elevation and preferably above the flood prone elevation (twice the maximum bankfull depth, see Figure A.1).

4. If possible, establish permanent markers at the cross section endpoint locations by driving rebar vertically in the ground. Attach either plastic or metal end caps on the tops of rebar for identification. This step is only needed if repeat surveys are anticipated.

5. Stretch the measurement tape or tag line (tape) across the channel with zero always beginning on the left bank as you are facing downstream. The zero mark on the tape should be placed over the left cross section endpoint. The tape can be secured to the ground with range pins. Make sure to stretch and secure the tape tight between both endpoints; sagging tapes are unacceptable. During windy conditions, flagging ribbon can be attached at regular intervals on the cross section tape to minimize tape “waving”.

6. Record the station ID of the cross section using the tape stretched along the length of the representative sub-reach (see Longitudinal Profile and Rapid Bed Form Survey Method) and sketch the cross section location as part of the site map with associated landmarks. Document as much information as possible about the cross section location on the datasheet so it can be relocated for future surveys or site visits.

7. Starting with the top of the left endpoint at 0, begin the cross section survey. Proceed with rod readings at breaks in slope; record important features such as terraces, top of bank, low bank, bankfull, edge of water, inner berm, and thalweg. If undercuts are present, use a combination of the stadia rod and pocket rod to accurately characterize the undercut. Otherwise, take survey readings at regular intervals of generally one to five feet, with wider intervals used for wider channels. Record any features along the cross section tape in the notes section of the datasheet. Complete the survey by taking rod readings at the right endpoint. Record all features on the datasheet next to their corresponding rod readings.

Rapid Cross Section Survey Procedure:

1. Follow steps 1-3 in the above procedure.

2. Stretch a tape from the left bankfull indicator to the right bankfull indicator. Use the primary bankfull indicator or the difference between water surface elevation and bankfull that has been recorded on the Project Reach form as the control.

3. Record the bankfull width. Space is provided on the Project Reach form.

4. Level the tape by attaching a line level or by measuring the distance from the water surface to the tape at the left and right edge of water surface; the location where the water meets the streambank. The distance should be the same on both sides.

5. Working from left to right, record the station from the tape and the depth from the tape to the ground using a stadia rod. Include bankfull, major breaks in slope, the thalweg, and other points along the channel bottom. Record this data on the Project Reach form.
6. Space is provided on the Project Field form to calculate the bankfull mean depth and area. These calculations are automatically performed in the Microsoft Excel Workbook version of the Project Reach form. A rough estimate of the mean depth can be calculated by adding all the depth measurements (except for zeros at bankfull) and dividing by the number of observations.
7. Compare the bankfull width, mean depth, and area to the regional curve values on the field form.
8. Measure the flood prone width on either side of the bankfull channel as shown in Figure A.1. The flood prone width should be measured perpendicular to the fall line of the valley.

Rosgen Stream Classification

The CSQT requires that the existing stream type be determined according to the Rosgen classification system (Rosgen 1996). Stream classification is based on entrenchment ratio, width depth ratio, sinuosity, slope, and channel material. Section V of the Project Reach form provides space to collect these data based on measurements from the sub-reach assessment.

Methods to determine Rosgen Stream Classification are derived from the Rosgen Stream Classification section in the Manual of Standard Operating Procedures for Sample Collection and Analysis (WDEQ/WQD 2018). The text below is modified from this reference. This section is included in the field data collection methods to ensure that sufficient data is collected to classify the existing stream type. As shown in the procedures below, determining the stream type is based on values derived from data collected as described elsewhere in this appendix. As such, determining the stream type can be done in the office after the data is collected and processed.

Field Measurements:

1. Entrenchment Ratio (ER): Measure of flood-prone area width (Wfpa) divided by bankfull width (Wbkf). Parameter is unitless.
   a. Values are measured or calculated from the Representative Riffle Survey.
2. Width to Depth Ratio (Wbkf / dbkf): Measure of bankfull width (Wbkf) divided by bankfull depth (dbkf). Parameter is unitless.
   a. Values are measured or calculated from the Representative Riffle Survey.
3. Channel Sinuosity. Parameter is unitless.
   a. Measurement procedures are provided in the Sinuosity section above.
4. Channel Materials (Particle Size Index) (D50): Measure the mean diameter of channel materials (D50) sampled within a reach at least twenty bankfull widths in length between the bankfull and thalweg elevations. Measure in millimeters.

   a. 105-Count Procedure section of the Standard Operating Procedure for the Collection of Pebble Counts (CDPHE 2015a)

5. Water Surface Slope (S): Measure of water surface slope from the top of a riffle to the top of another riffle at least twenty bankfull widths in length. This measurement is a surrogate for the water surface slope at bankfull stage. Measure in ft/ft.

   a. See Longitudinal Profile and Rapid Bed Form Survey Methods.

   b. Note if baseflow is not present, the bottom of the channel should be used. However, care must be taken to not create large elevation changes due to localized scour or fill. One method to avoid localized scour or fill is to use the edge of channel rather than the thalweg. In both cases (with and without baseflow), the measurements should be made at the top of a feature, e.g. the top or beginning of a riffle.

3. Longitudinal Profile

This method will provide data to inform the floodplain connectivity and bed form diversity parameters within the CSQT. Additionally, data from the longitudinal profile can be used to calculate average reach slope and riffle slopes. Average reach slope is part of stream classification and metric stratification, while riffle slopes are necessary to calculate discharge from stage data at riffle cross sections where stream gages are installed.

There are two methods that can be used to collect bed form diversity and floodplain connectivity data for the CSQT, the Longitudinal Profile (described in this section) and the Rapid Survey (described in Section 4). For CWA Section 404 projects, it is recommended the user coordinate with the Corps prior to selecting between these methods. The rapid survey techniques for collecting the bed form diversity and floodplain connectivity data are considered more rapid than surveying the longitudinal profile and require little post-processing of the field data.

Field forms for the longitudinal profile include the Longitudinal Profile form and the Cross Section form and are provided in Appendix B. Data collected using these forms will require post-processing to calculate CSQT metric field values for pool spacing ratio, pool depth ratio, percent riffle, and bank height ratio. Data analysis should follow the methods described in Chapter 2 of the User Manual. The Reference Reach Spreadsheet version 4.3 developed by Dan Mecklenburg with the Ohio Department of Natural Resources (DNR) is a free, user-friendly tool for entering survey and pebble count data and can be used to calculate these metrics.[3] Users should provide the raw survey data, longitudinal profile plots at legible scales, and bed form identification callouts that indicate where measurements were taken to calculate field values.

Quality Control: Following the process described in Harrelson et al. (1994), no longitudinal profile is complete without checking the accuracy of the survey with a survey closure. To close the survey, take a foresight reading at the benchmark, compute the elevation, and compare the difference to the original benchmark elevation at the start of the survey. Typically, a closure of no more than 0.05 feet is acceptable when conducting stream surveys. The survey closure error shall be documented on the longitudinal profile datasheet.

Introduction: The longitudinal profile documents the existing water surface, bankfull, low bank, terrace, and thalweg elevations of a stream reach. Longitudinal profile data is used to calculate average bankfull and water surface slopes of a reach, along with maximum, minimum, and average slopes of features such as riffles, runs, pools, and glides (also known as facet slopes). Maximum, minimum, and average bankfull depths and spacing measures are obtained from longitudinal profile data. These data are useful in geomorphic assessments of streambed stability and sediment supply and may be useful for design objectives. Longitudinal profiles require basic surveying skills and equipment. Survey basics such as establishing benchmarks, foresights, positioning the level, turning points, and others are not covered here. For more information on survey basics consult Harrelson et al. (1994).

[3] The spreadsheet is no longer available from the DNR web page, but is available at https://stream-mechanics.com/stream-functions-pyramid-framework/ under spreadsheet tools.

Procedure:

1. Establish a representative sub-reach within the project reach, generally at least two meander cycles or 20 bankfull widths in length. The sub-reach should be representative of the typical bed form diversity in the project reach and should include the stretch of channel with the greatest amount of large woody debris.
2. Beginning at the upstream end of the sub-reach, stretch the tapes along either the left or right bank as close to the edge of the channel as possible and should be threaded through riparian vegetation or other obstructions if necessary. Tape(s) can be secured to the ground with range pins, vegetation, or rocks. Stationing of features will be obtained from the tape.
3. If desired, establish permanent markers at the beginning and end of the longitudinal profile tape by driving rebar vertically in the ground. Attach either plastic or metal end caps on top of the rebar for identification.
4. The position of the longitudinal profile tape should be included on the site map along with associated landmarks, stream channel cross sections, and other relevant features. If desired, triangulate the top and bottom of the longitudinal profile between the benchmark and another permanent feature and record on the datasheet. GPS locations of the top and bottom of the longitudinal profile can be used in place of triangulation. Document as much information as possible about the longitudinal profile tape location on the datasheet so it can be relocated for future surveys.
5. Follow the procedure in Bankfull Elevation – Field Identification to identify bankfull elevation in the reach.
6. Follow the process described by Harrelson et al. (1994) to establish a benchmark and height-of-instrument.
7. Begin the longitudinal profile survey with a thalweg measurement at station 0 on the longitudinal profile tape. Obtain the rod reading and record the value as a foresight on the datasheet. Record (at a minimum) rod readings of water surface, bankfull and low bank (if greater than bankfull) perpendicular to the longitudinal profile tape at station 0. Only take rod readings of bankfull and low bank where indicators are present. Record the quality of the bankfull indicator(s) (good, fair, etc.) and the type of feature in the notes column of the datasheet.
8. Continue the same sequence as in step 7, working downstream, collecting readings at the top, mid-point and bottom of each feature (riffle, run, pool, and glide), along with any other major bed features (dams, weirs, etc.). For pools, take a reading at the maximum depth location and note whether the pool is a geomorphic pool (refer to Pool Identification below). For streams with long features or a homogeneous bed, take rod readings at regular intervals, generally spaced no more than one bankfull width.
9. Note the stationing of all cross section locations (if present) on the longitudinal profile tape and record on the datasheet. Take rod readings at the tops of all cross section endpoints located along the bank with the longitudinal profile tape and record on the datasheet.
10. Close the survey according to the process described in the Quality Control section of this document.

Pool Identification

Geomorphic pools are associated with planform features that create large pools and patterns 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 within riffles 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.

If a pool is not associated with a meander bend or cascade/step, it should still meet the following criteria: the pool must be deeper than the riffle, have a concave 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.

Cross Section Surveys

Data should be collected from cross sections at multiple riffles within the representative sub-reach to inform the baseflow dynamics metrics (average velocity and average depth), entrenchment ratio, return interval, and aggradation ratio metrics. The flow alteration module requires the collection of continuous flow data and cross section surveys are required to convert recorded stage data to flow values.

A Cross Section form is provided in Appendix B to collect these data. Data collected using these forms will require post-processing to calculate CSQT metric field values. Cross sections should be collected following the procedures described in the Representative Riffle Survey section. The WDEQ or rapid cross section survey method, or a combination of the two, can be used based on best professional judgement.

- For the entrenchment ratio, it is recommended that the entrenchment ratio be measured at each riffle unless the valley width is consistent throughout the representative sub-reach. The flood prone width should be measured perpendicular to the fall line of the valley.
- For the aggradation ratio, 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. Visual indicators of aggradation include mid-channel bars and bank erosion within riffle sections.

For cross sections where the data will be used to calculate discharge (as applicable for the average velocity, average depth, return interval, and the metrics in the flow alteration module), follow the procedures outlined in Best Practices for Continuous Monitoring of Temperature and Flow in Wadeable Streams (USEPA 2014) for developing stage-discharge rating curves. Users should provide the raw survey data, cross section plots at legible scales, and callouts for feature that indicate where measurements were taken to calculate field values.

4. Rapid Survey

This section outlines rapid survey methods to collect data to inform floodplain connectivity and bed form diversity parameters. There are two methods that can be used to collect bed form diversity and floodplain connectivity data for the CSQT, the Longitudinal Profile (described in Section 3) and the Rapid Survey (described in this section). For CWA Section 404 projects, it is recommended the user coordinate with the Corps prior to selecting between these methods. The rapid survey techniques for collecting the bed form diversity and floodplain connectivity data are considered more rapid than surveying the longitudinal profile and require little post-processing of the field data.

The Rapid Survey form is provided in Appendix B. There is a shading key on the field form that indicates which cells are intended to be filled out in the office versus the field, and which sections are for performing field calculations. The calculation cells can be filled out on a printed field form. In the workbook version, these cells will automatically calculate values from provided field data. Field values that can be entered directly into the Quantification Tool worksheet from this field form are bolded. These include: weighted BHR, weighted ER, maximum WDR, percent riffle, average pool depth ration, and median pool spacing ratio.

Procedure:

1. Establish a representative sub-reach within the project reach, generally at least two meander cycles or 20 bankfull widths in length, whichever is longer. The sub-reach should be representative of the typical bed form diversity in the project reach and should include the stretch of channel with the greatest amount of large woody debris.
2. Beginning at the upstream end of the sub-reach, stretch tapes along either the left or right bank as close to the edge of the channel as possible, and should be threaded through riparian vegetation or other obstructions if necessary. Tape(s) can be secured to the ground with range pins, vegetation, or rocks. Stationing of features will be obtained from the tape. Begin and end the representative sub-reach at the head of a riffle feature.
3. Record sub-reach length in Rapid Survey form.
4. Measure the slope of the sub-reach (see Reach Slope section below).
5. Working from upstream to downstream, take measurements at every riffle and pool within the sub-reach using a stadia rod and a hand level. A line level can be used instead of a hand level for small streams. NOTE: Review pool identification instructions provided below and in Section 2.6.d of the User Manual.
    a. Measure the following at every riffle within the sub-reach and record values in the Rapid Survey form. These data are used to calculate the bank height ratio, entrenchment ratio, aggradation ratio, and percent riffle metrics.
        i. Measure the length of the riffle, including runs, if present. Riffle length is measured by taking a station reading from the tape at the head (beginning) of the riffle and another station reading downstream at the head of the pool.

Field calculation: Percent riffle can be calculated by adding the length of all riffles within the sub-reach (total riffle length) and dividing by the total sub-reach length. Total riffle length is also used to calculate weighted entrenchment ratio and weighted bank height ratio below.

ii. Identify the middle of the riffle feature and bankfull elevation (see Bankfull Elevation – Field Identification).

iii. From mid-riffle, measure the difference in stadia rod readings from the thalweg to the top of the lower of the two streambanks. Record this value as the Low Bank Height on the rapid survey form. The low bank height is the lower of the left and right streambanks, indicating the minimum water depth necessary to inundate the floodplain.

iv. From mid-riffle, measure the difference in stadia rod readings from the thalweg to the bankfull indicator, and record this value as the bankfull maximum depth on the Rapid Survey form. Alternatively, measure the difference in stadia rod readings from the thalweg to the water surface then add the value recorded for the difference between bankfull stage and water surface (Section II on the Project Reach form).

Field calculation: bank height ratio can be calculated by dividing the low bank height by the bankfull maximum depth. Space is also provided to calculate the weighted bank height ratio: multiply the bank height ratio by the riffle length at each riffle and divide by the total length for the sub-reach.

v. From mid-riffle, measure the bankfull width and record this on the form.

vi. For sub-reaches with changes in valley width or a bank height ratio greater than 1.8, flood prone width should also be measured at each riffle. At mid-riffle, locate and flag the point along the cross section in the floodplain where the difference in stadia rod readings between the thalweg and that point is twice that of the bankfull maximum depth (see Figure A.1 for illustration). Record flood prone width on the rapid survey form.

Field calculation: entrenchment ratio can be calculated by dividing the flood prone width by the bankfull maximum depth. Space is also provided to calculate the weighted entrenchment ratio: multiply the entrenchment ratio by the riffle length at each riffle and divide by the total riffle length for the sub-reach.

vii. If evaluating the aggradation ratio, at the widest riffle in the sub-reach (or any riffle with aggradation features) the bankfull mean depth should also be measured and recorded. Visual indicators of aggradation include mid-channel bars and bank erosion within riffle sections. At candidate riffle features, estimate the mean depth as the difference between the edge of channel and the bankfull stage. This is measured by placing a stadia rod at the edge of channel, which is the breakpoint between the streambed and streambank. Measure the stadia rod height at the bankfull elevation and record as the mean depth. Note: It is recommended to collect data from 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.

Field calculation: width depth ratio can be calculated by dividing bankfull width by bankfull mean depth. The largest width depth ratio within the sub-reach is considered the maximum width depth ratio.

b. Measure the following at every pool within the sub-reach and record values in the Rapid Survey form. These data are used to calculate the pool spacing and pool depth ratio metrics.

   i. Determine the deepest point of the pool and record the station number from the tape on the form.

   Field calculation: The pool spacing ratio can be calculated by determining the distance between each pair of pools and dividing this distance by the bankfull riffle width (from Section IV of the Project Reach form). Space is provided to record the median pool spacing ratio on the Rapid Survey form.

   ii. Measure the maximum bankfull pool depth by placing the stadia rod at the deepest point in the pool and recording the depth to bankfull elevation. Alternatively, measure the difference in stadia rod readings from the deepest point in the pool to the water surface and then add the value recorded for the difference between bankfull stage and water surface recorded in Section II of the Project Reach form.

   Field calculation: The pool depth ratio can be calculated by dividing the bankfull pool depth by the mean bankfull riffle depth (from Section IV of the Project Reach form). Space is provided to record the average pool depth ratio on the Rapid Survey form.

Pool Identification

Pool-to-pool spacing is essentially a measure of how many geomorphic pools are present within a given reach and can be indicative of 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 and patterns 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 within riffles 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.

For the pool depth ratio and percent riffle metrics, all significant pools (geomorphic and micro-pools associated with wood, boulders, convergence, and backwater) are assessed. If a pool is not associated with a planform feature (ex. meander bend or cascade/step), it should still meet the following criteria: the pool must be deeper than the riffle, have a concave 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. If one or no geomorphic pools are observed in the representative sub-reach, the field value for this metric is 0.0.

Reach Slope

Average reach slope is part of stream classification and metric stratification. It is not used as a function-based parameter or metric, however is does inform the calculation of discharge contained within the channel for the return interval metric. If a longitudinal profile is performed, slope can be calculated from that data and does not also need to be collected using the procedure below. If the rapid method is used, data should be collected using the following field procedure.

Procedure:

1. Take a stadia rod reading of the water surface elevation at the head of the first riffle and the head of the last riffle in the representative sub-reach. If limited by the line of sight and/or magnification of the hand level being used, take a stadia rod reading of the water surface elevation at the head of the first riffle and the head of the last riffle within a line of sight. Repeat as needed throughout project reach making sure that the total drop in elevation is recorded. Note, for streams with a uniform slope, a relatively short length of channel can be measured. For streams with large slope changes between riffles and pools, the entire sub-reach should be measured.

Field calculation: Calculate the difference in stadia rod readings, divide the difference in stadia rod readings by the channel length between these two points. Where multiple readings were taken, the sum of the elevation changes should be used in the numerator (total fall over the measured length). The denominator is the total stream length between the first and last measurement point. Space is available for calculations in the Project Reach form.

5. Large Woody Debris

Large Woody Debris Index

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. 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.[4] This index was developed by the USDA Forest Service Rocky Mountain Research Station (Pg. 73-77 in Davis et al. 2001). This method informs the large woody debris parameter in the CSQT. It can be used instead of the large woody debris piece count. Both metrics should not be used at a site. The LWDI has a greater level of field effort but captures more information about large wood in the reach.

The Large Woody Debris Index data collection procedure is not included here. Users should download the *Application of the Large Woody Debris Index: A Field User Manual* prior to going out in the field (Harman et al. 2017).[5] Large Woody Debris Index data forms are included in Appendix B; or a fillable excel workbook that calculates LWDI is available with the User Manual.

Large Wood Piece Count

This method informs the large woody debris parameter in the CSQT. It can be used instead of the LWDI metric. Both metrics should not be used at a site. The piece count has a reduced level of field effort but captures limited information about large wood in the reach.

Procedure:

1. Identify the 328-foot (100-meter) segment within the representative sub-reach that contains the most large woody debris. Record the station of the downstream end of the reach on the Project Reach form.
2. Count all pieces of large woody debris within this segment. Large wood is defined as dead wood over 3.3 feet (1m) in length and at least 3.9 inches (10cm) in diameter at the largest end. The wood must be within the stream channel or touching the top of the streambank. In a debris jam or dam, the number of individual pieces of large wood within the dam should be counted.   The number of pieces should be tallied and totaled on the Project Reach form.

[4] Note: In willow-dominated systems, willow branches that form debris jams are included in the assessment even if they do not meet the minimum piece size. Additional discussion is provided in the LWDI manual.
[5] The manual is available here: https://stream-mechanics.com/wp-content/uploads/2017/12/LWDI-Manual_V1.pdf.

6. Lateral Migration

BEHI/NBS and Percent Streambank Erosion

The dominant BEHI/NBS and percent streambank erosion metrics within the lateral migration parameter are informed by an assessment of bank erosion hazard index (BEHI)/near bank stress (NBS). Data forms are provided in Appendix B. **Detailed field procedures are not provided below**, but can be found in the following references:

- Appendix D of Function-Based Rapid Field Stream Assessment Methodology (Starr et al. 2015)
- River Stability Field Guide, Second Edition (Rosgen 2014)

Procedure:

1. Evaluate the outside bank of every meander bend whether or not it is eroding. In addition, assess all other areas of active erosion regardless of their location. Depositional zones and riffle sections that are not eroding should not be evaluated.
2. Give each study bank an ID, e.g. L1 for left side, bank number 1. Determine the BEHI/NBS rating for each study bank. Record data on the Lateral Migration form.
3. Measure and record the length of each bank assessed using the station numbers from the tape(s) stretched along the sub-reach for the Longitudinal Profile or Rapid Survey. A GPS unit can also be used to map assessed banks.

Note: If a bank is armored, do not apply the dominant BEHI/NBS metric. Instead, assess using the armoring metric, which is described near the beginning of Appendix A.

Data can be recorded on the Lateral Migration form found in Appendix B. These data can be used to determine the field values following the instructions in Chapter 2 of the User Manual for the following metrics: dominant BEHI/NBS and percent streambank erosion.

Greenline Stability Rating (GSR)

Data collection should occur throughout the representative sub-reach. The CSQT relies on either of two data collection methods. **Data collection methods are not provided here.** Users should download one or both methods referenced below prior to going out in the field. Data forms are provided within these references.

- The original greenline data collection procedures described *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).[6]

[6] USDOI (2011) 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).

7. Riparian Vegetation

There are four metrics to assess the riparian vegetation parameter in the CSQT: Riparian Width, Woody Vegetation Cover, Herbaceous Vegetation Cover, and Percent Native Vegetation. Field data should be collected during the growing season at the same time of year for pre- and post-project evaluations. A Riparian Vegetation form and a Riparian Width form are provided to record data (Appendix B). The calculation cells can be filled out on a printed field form. In the workbook version, these cells will automatically calculate values from provided field data. Field values will need to be averaged across plots before entering into the Quantification Tool spreadsheet (see Section 2.6.f in Chapter 2 of the User Manual). All riparian vegetation metrics are assessed at plots located at equally spaced intervals along the assessment sub-reach. To begin, the location of the first plot must be determined as follows:

1. Determine the number of riparian plots using the representative sub-reach length as shown in Table A.1. Plots should be systematically distributed along each bank such that the minimum number of plots are evenly spaced along the known length of the sub-reach. Fewer plots may be considered (and approved by the Corps) if the representative sub-reach is short or if the riparian vegetation is very uniform in structure and composition throughout the sub-reach. Additional plots may be added at sites with variable riparian vegetation.
2. Calculate the spacing interval of the plots by dividing the sub-reach length by the number of plots per side.
3. Select a random starting point within the first 20 feet of the sub-reach length.

Table A.1. Minimum Number of Sampling Plots Per Sub-Reach

Sub -Reach Length	Number of Plots per Side	Number of Plots per Sub-Reach
300-400 ft	3 plots	6 plots
400-600 ft	4 plots	8 plots
600-900 ft	6 plots	12 plots
900 -1300 ft	8 plots	16 plots

<u>Riparian Width – Field Verification</u>

Procedure:

1. Observed and Expected riparian width measurements should be collected from four locations within the reach using aerial imagery prior to going out into the field and entered on the Riparian Width field form (see Section 2.6.f in Chapter 2 of the User Manual).
2. Field data can be used to verify expected riparian width measurements obtained from aerial imagery. Examine the reach and landscape. Where practicable or possible, measure the expected riparian width from the station ID recorded for each sampling plot location using tape or a range finder. Alternatively, the GPS location of the expected riparian extent can also be recorded, and measurements determined later in the office. On the Riparian Width form, record the expected riparian width measurement and indicate which field indicators were used to verify this extent.

Expected riparian width includes the width across the stream in each direction, landward to the extent of substrate and hydrologic indicators. Field indicators such as 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, etc.) can be used to delineate the expected riparian width. Where significant incision or anthropogenic modification of the riparian area has occurred (e.g., development, grading, etc.) and aerial imagery and/or field indicators cannot be used to delineate the expected riparian extent, the meander width ratio may be used to calculate expected riparian width (See Chapter 2 of the User Manual).

3. At the station ID recorded for each plot location, measure the observed riparian width from the edge of the bank landward to the edge of the existing riparian area using tape or a range finder. Alternatively, the GPS location of the observed riparian extent can also be recorded, and measurements determined later in the office.

   The observed riparian width should extend from the edge of the bank landward to the extent of riparian vegetation. This area should be free from urban, utility-related, or intensive agricultural land uses and development. The edge of the existing riparian area should be determined using vegetation attributes, including the presence of riparian vegetation, distinctly different vegetation species than adjacent upland areas (e.g., species with wetland indicator ratings of OBL, FACW, FAC and some FACU; Lichvar et al. 2016), and species similar to adjacent upland areas but exhibiting more vigorous or robust growth forms (USFWS 2009). On the Riparian Vegetation form, record the observed riparian width measurement.

4. Measure the channel width at the location of riparian width measurements and record on the Riparian Vegetation form. Where plots have been relocated, measurements for riparian width should be taken on both sides of the channel at the station ID of the left side plots.

<u>Herbaceous, Woody, and Percent Native Vegetation Cover</u>

Setting up Riparian Plot Locations:

1. Set up the first plot at the random starting point on the left-hand side of the stream (looking downstream). The plot should begin at the edge of bank (where bed-meets-bank; BLM 2017) and extend landward and downstream from this point. All vegetation sampling is conducted within the reach’s expected riparian area width, and thus may extend into developed or modified upland areas (see Riparian Width - Field Verification). In narrower or colluvial valleys, square plots may need to be reshaped (to a rectangular plot of the same area) to keep the plots within the expected riparian area width of the reach. This could affect the location of subsequent plots, and subsequent plots may need to be relocated to avoid overlap. Plots should be located adjacent to the primary channel if high flow secondary channels exist, and outside active intricately braided channels, mid-channel bars, and beaver ponded areas.
2. Subsequent sampling plot locations should be identified using the spacing interval identified in step 2 above. Locations should be determined using the station reading from the tapes set up for the Longitudinal Profile or Rapid Survey. Plot locations on the right side of the

stream should use the same station locations as identified on the left unless they need to be relocated. Consecutively number the plots down the left bank and up the right bank.

3. If a riparian plot needs to be relocated, adjust the location to the minimum extent possible upstream or downstream from the designated station to avoid the problem (e.g., overlap of tight meander bend plots or reshaped plots; inaccessible locations; or at the confluence of a large secondary channel or tributary, etc.). If necessary, vegetation plots may extend beyond the downstream end of the representative sub-reach but should not extend outside the project reach. Relocation of a plot on the left side of the channel does not necessarily require relocation on the right side as well. Record the new station location and note the reason for relocation.

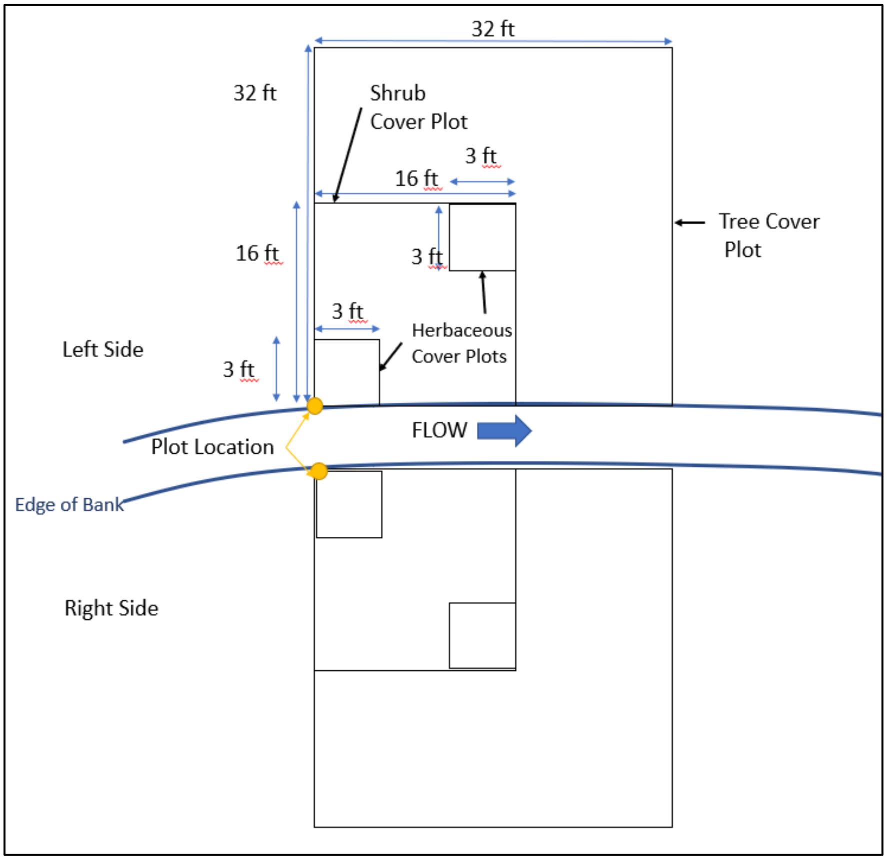
4. It is recommended that riparian data sampling start at the most upstream plot on the left side of the stream and move downstream. After data from the last plot is collected on the left side, cross the stream and place the first plot on the right side and move upstream collecting data on the remaining number of evenly spaced plots. However, plots may be sampled in any order once plot locations are identified.

Riparian Plot Establishment

1. On the left side of the stream (looking downstream), for each plot, place the lower left corner of the plot at the appropriate station reading where it intersects the edge of the bank; this is the starting point in Figure A.2. The plot should extend landward and downstream from this point and contain the nested sub-plot configuration according to the diagram provided in Figure A.2. When sampling the right side of the stream place the lower right corner of the plot at the same station reading where it intersects the edge of the bank. The plot should extend landward and downstream from this point such that the plots are mirror images across the channel at each designated station (Figure A.2).

   From the starting point, measure or pace out the bounds of a 32-ft x 32-ft (10m^2) tree (canopy) plot and a 16-ft x 16-ft (5 m^2) shrub (understory) nested plot and mark corners with pin flags as depicted in Figure A.3. Then mark two 3-ft x 3-ft (1 m^2) herbaceous ground cover nested plots at the starting point and the diagonally opposite corner of the shrub plot.

Figure A.2. Standard Riparian Plot Layout for Riparian Vegetation Cover



Data Collection

1. All data should be recorded on the Riparian Vegetation field form.
2. Take a photo of the riparian plot so that the near-stream herbaceous plot is visible in the foreground and a good portion of the remaining riparian plot is in the background. Note the photo number on the data form or include the plot number in the photograph.
3. Note the geomorphic location of the 32-ft x 32-ft plot as inside meander, outside meander, or straight/riffle. If this changes over the length of the plot, record the geomorphic location of the majority of the plot.
4. 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 (USACE 2008, 2010a, 2010b; Kittel et al., 1999). Practitioners should be able to identify at least 80% of the species within a plot. Absolute cover is the percentage of the ground surface that is covered by the aerial portions (leaves and stems) of a plant species when viewed from above. It can also be described as an estimate of the amount of shadow that would be cast by a particular plant species if the sun were directly over the plot area.

a. Absolute herbaceous (herb) cover by species should be measured at every riparian plot location within each of two nested 3-ft by 3-ft herb plots (see Figure A.2), then averaged. This technique is helpful to sample variable understories and smaller sized species over a larger area. Alternatively, herb cover data may be collected in the 16-ft x 16-ft plot, but this method requires additional survey effort for plant species within a larger area and may be less precise and more time consuming. Consistent plot size should be used for all aspects of the project.

   i. Identify and record the herbaceous plant species that occur within the plot and visually estimate the portion of the plot each species covers.

   ii. Record total bare ground/litter and total embedded rock (> 15 cm diameter) as separate absolute values (out of 100 percent) to document uncovered or partially exposed substrate. Note that high flow or minor secondary channels are counted as bare ground.

   iii. If using nested herb plots, repeat the procedure for the second herb plot and average species values across herb plots for a combined list within each riparian plot.

   iv. Record the sum of all herbaceous species cover.

b. Absolute shrub cover by species includes woody plants less than 3 inches DBH and less than 16 ft (5 m) tall and is measured within a single 16-ft by 16-ft nested plot (see Figure A.2).

   i. Identify and record shrub plant species and visually estimate the portion of the plot each species covers.

   ii. Record the sum of shrub species cover.

c. Absolute tree cover by species includes woody plants greater than 3 inches DBH and greater than 16 ft (5 m) tall and is measured within a 32-ft by 32-ft plot.

   i. Identify and record tree species and visually estimate the portion of the plot each species covers.

   ii. Record the sum of tree species cover.

d. Record the sum of shrub and tree species cover as woody vegetation cover and record the sum of all plant species cover as total vegetation cover for the riparian plot.

e. Identify and record which species are native or introduced (i.e., non-native or naturalized). Use USDA PLANTS Database http://plants.usda.gov to verify. Record the sum of all native species cover.

5. Based on the data collected, determine the general vegetation cover type for the riparian plot area as herbaceous, scrub-shrub, or forested and record at the top of the form. The cover type is distinguished by the plant life form that constitutes the uppermost layer of vegetation and that possesses an aerial coverage of 30 percent or greater (Cowardin et al. 1979). For example, an area with 50% aerial coverage of trees over a shrub layer with a 60% aerial coverage would be classified as forested; an area with 20% aerial coverage of

trees over the same (60%) shrub layer would be classified as scrub-shrub. When trees or shrubs alone cover less than 30% of an area but in combination cover 30% or more, the area is assigned to the scrub-shrub cover type.

Additional notes on sampling procedure:

- Individual species aerial cover estimates cannot exceed 100% but can be less than 100%.
- Due to overlapping plant canopies, the sum of absolute cover values for all species in a community or stratum may exceed 100 percent. (In contrast, "relative cover" is the absolute cover of a species divided by the total coverage of all species in that stratum, expressed as a percent. This is how the percent native vegetation metric is determined.)
- Naturalized species are not considered native.
- Absolute cover for riparian and non-riparian (upland) species should be estimated.
- Plants over-hanging the plot do not need to be rooted in the plot to be counted as absolute aerial cover; however, species rooted outside of the expected riparian width that are overhanging the riparian plot would not be counted.
- Standing dead shrubs/trees should be included in aerial cover estimates but eliminated from percent native cover calculations.
- Additional data collected and not reported in the CSQT provides context for riparian area reporting.

Rapid Alternatives

Less intensive methods of collecting riparian cover information data will result in similar but less accurate data and would only be available for cursory characterization or planning estimates. These methods would not be appropriate for determination of functional lift or monitoring efforts.

1. Abundance-only data could be collected using the methods outlined above with the following exception. Abundance-only data for herbaceous and woody vegetation cover metrics would involve estimating absolute cover by species without taxonomic identification and summarizing information by life form (e.g., herbaceous species A, B, C and D; shrub species A, B, and C). Native cover could not be accurately determined using this method.

   or

2. Data could be collected from a reduced number of plots, e.g., one or two representative plots per bank. Plot locations would be selected using best professional judgment of representativeness based on the overall abundance and composition of riparian communities throughout the reach. Sampling methods would be the same as outlined above.

8. Physicochemical Parameters

Temperature

Placement and use of in-water temperature sensors should follow the methods outlined in *Best Practices for Continuous Monitoring of Temperature and Flow in Wadeable Streams* (USEPA 2014) or USFS's *Measuring Stream Temperature with Digital Data Loggers: A User's Field Guide* (Dunham et al. 2005). These procedures cover sensor selection, calibration, sensor placement, and data QAQC. **Methods are not provided in this section.** Note that the USEPA 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 CSQT, the minimum monitoring period consists of the summer months of July and August for the sampling year. The sensors should be set to record point temperature measurements at intervals that do not exceed 30 minutes and should be located in comparable habitats for pre and post-project data collection.

Record the time and date of temperature sensor deployment on the Sensor Log form in Appendix B.

Dissolved Oxygen

This metric is a direct measure of the concentration of dissolved oxygen (mg/L) in the project reach collected according to procedures outlined in WDEQ/WQD (2018).[7] DO sampling for use in the CSQT requires a DO logger be deployed for at least one week during the summer months of July or August and record daily measurements between one and three in the afternoon. Loggers should be located in comparable habitats for pre and post-project data collection. Refer to sensor instructions for deployment, calibration, and instrument cleaning instructions. **Methods are not provided in this section.**

Record the time and date of dissolved oxygen sensor deployment on the Sensor Log in Appendix B.

Chlorophyll a

Chlorophyll a sample collection and processing should be conducted according to the Standard Operating Procedures for the Collection of Periphyton Samples (CDPHE 2015b). A Physicochemical and Biological data form is provided in Appendix B.

Data collection procedures are duplicated below with minor modification. See CDPHE (2015b) for additional information on quality control procedures and an equipment list. Chlorophyll a data should be expressed as milligrams per square meter of sampled substrate (mg/m^2).

Sampling Restrictions:

Periphyton samples will be sampled at times of normal, stable flows and when the benthic algal community has peaked for the season. The optimal sampling season is mid-summer to early

[7] The CSQT SC reviewed the WDEQ/WQD methods and compared them to the CO SOPs (CDPHE 2016) and found the Wyoming methods were comparable and provided more detail.

fall. Earlier sampling may be performed at lower elevations, but only to the extent that normal flow conditions are present and algae is in a state of growing or has already matured.

In the event of light flooding or scouring, sampling shall be delayed for a minimum of one week to allow recolonization. Studies have shown recovery after high discharge can be as rapid as seven days if the scouring event was less severe (Stevenson 1990).

Sampling shall be delayed for three weeks following severe, bottom-scouring flows to allow for recolonization and succession to a mature periphyton community. This is based on a recommendation by Peterson and Stevenson (1990).

Sampling Method:

1. Five transects will be setup within the overall reach.
    a. Determine a representative stream length of 50 to 100 meters that contains at least one riffle or run habitat. This may not always be achievable, so as an alternative, choose 3 to 5 riffles and/or runs, so that 5 transects or cross sections can be established.
    b. Beginning at the most downstream position, extend a tape measure from one wetted edge to the other being careful not to disturb the substrate beneath or immediately downstream of the tape measure. Fasten the tape measure to each bank edge so the measuring tape is taut and does not dip into the stream.
    c. Moving in an upstream direction, establish the remaining four transects at equidistant locations within the selected stream length or at each chosen riffle/run. Note: Periphyton is typically collected in chorus with a pebble counting procedure. Transects may be shared between the two procedures but caution must be taken to prevent agitation to the substrate immediately below the tape measure. Also avoid establishing transects that overlap with macroinvertebrate sampling areas.
    d. Illustrate the area between the first and fifth transects on the site sketch section of the Project Reach field form.

    This procedure has been adapted to two different types of substrate common to Colorado. The first procedure (Step 2) is best applied to streams with pre-dominantly hard-bottomed substrate, such as cobble, pebble and gravel (herein referred to as “rocks”). The second type (Step 3) is applied to sandy, shifty bottom streams, as found in lower elevations of the Plains ecoregion or the far western Xerics ecoregion of Colorado.

2. The following procedure applies to hard-bottomed streams:
    a. Note the distance from one wetted edge to the other along the tape measure at the first transect. Collect three rocks from the first transect at the ¼, ½ and ¾ points along the tape measure.
    b. Place the cobble facing upwards in the plastic pan. Cover the rocks with a moist medium-sized hand towel to prevent exposure to sunlight.
    c. Continue to collect three rocks from the remaining four transects, as described in Step 1, carefully pulling rocks from the ¼, ½ and ¾ points along the tape measure and covering them with the hand towel as you proceed from transect to transect.

d. Proceed to a shaded location on the stream bank to begin scraping periphyton from the rocks. See Step 4.

3. The following procedures apply to soft-bottomed streams:

   Collecting periphyton in soft-bottomed streams allows periphyton from all available substrates and habitats to be sampled as long as they are representative of the overall reach. The purpose of this section is to collect 15 subsamples, each with an area of 0.785 in^2, from submerged, removable habitats or loose sediment depositional zones present along or near each transect.

   a. Sampling Method for Rocks (Cobble), Woody Snags or Submerged Vegetation

      i. If rocks are not available or are limited at the ¼, ½ and ¾ points along the tape measure, then select the nearest woody snag (debris) or submerged vegetation (mosses, microalgae, vascular plants, and root masses). If submerged woody snags or other vegetation are large or flexible enough, can be lifted above the water line, and have a relatively smooth surface then use the bottle cap method described in Step 4 making certain that scrapings and rinse water are flushed directly into the 1-liter Nalgene bottle. Otherwise, identify the part of the submerged woody snag or vegetation to be scraped later and carefully remove a 4-8 in. section with pruning shears or a small saw. Place the removed section into the plastic pan.

   b. Suction Method for Loose Sediments (Loose sediment may be defined as sand, silt, clay or fine particulate organic matter)

      i. At sampling points where depth/velocity are low and have a depositional zone consisting of any of the loose sediments listed above, place a PVC ring on top of the sediment. Press the ring into the sediment to a depth of one-half inch.

      ii. Use a suction bulb to remove the entire top layer of periphyton. It is acceptable to suction up some sediment in the process.

      iii. Squirt this medium of material into the 1-liter Nalgene bottle.

   c. Cover the rocks or other removable substrates <u>and</u> the 1-liter Nalgene bottle with the hand towel to prevent exposure to sunlight as you move from habitat to habitat in the stream channel.

   d. Once completed, proceed to a shaded location on the stream bank to begin scraping periphyton from the remaining rocks or other removable substrates placed in the plastic pan. See Step 4.

      Example: If 10 sub-samples are collected via siphoning or by instream bottle cap method, then the remaining 5 sub-samples must be removable substrate that are scraped on the stream bank later. All forms of sub-samples must add up to 15.

4. Scraping and rinsing. This procedure applies to all objects that were removed from the stream and need to be scraped but will be simply referred to as “rocks” in this section.

   a. Sit in a shaded location on the stream bank, within an arm’s reach of the water’s surface.

b. Rinse twice and then fill the spray bottle with stream water. Ensure that the spray head mechanisms are thoroughly rinsed by pumping water through the spray head several times.

c. Carefully pull back an edge of the hand towel and remove the first rock. Place the bottle cap (“cap”) on any section of the upside aspect (e.g. where algae are attached) of the rock. With the rock in hand, hold the cap firm with your thumb. With your free hand, vigorously scrape algae from the area not under but around the cap with the toothbrush. Rinse the rock, with the cap still firmly in place, and toothbrush bristles in the stream. Repeat the scrape and rinse process one more time.

d. Note: Based on the density of periphyton on the rock, you may have to use a spoon or putty knife to remove macroalgae from the area not under the cap.

e. Remove the cap and place to the side. Hold the rock directly above the 1-liter Nalgene bottle. Gently scrape the area that was under the cap with the toothbrush.

f. Use the spray bottle to rinse the dislodged scrapings directly into the 1-liter Nalgene bottle. Ensure that the slurry of algal material and rinse water runs off or drips into the 1-liter Nalgene bottle. Keep the rinse water to a minimum, just enough to rinse off the scrapings.

g. Scrape and rinse the area that was under the lid a second time.

h. Discard the rock back into the stream and rinse the toothbrush (or applicable scraping device) in the stream.

i. Repeat the scraping and rinse process for the remaining 14 rocks at sites with hard-bottomed substrate or the remaining number of rocks or removable objects pulled from soft-bottomed streams.

j. At this point, approximately 75-150 ml of scrapings and rinse water will be in the 1- liter Nalgene bottle. Remove the spray head from the spray bottle. Pour stream water from the spray bottle into the 1-liter Nalgene bottle until the mixture reaches the 500 ml graduated increment.

k. If applicable, discard the remaining stream water from the spray bottle.

l. Cap the 1-liter Nalgene bottle and invert several times to homogenize the composite of scrapings and rinse water.

m. Record the composite material volume on the Physicochemical and Biology field form.

5. Sample preparation (Chlorophyll a)

a. Rinse the filter funnel and holder in the stream. Using tweezers, center a single 47 mm Whatman glass microfiber filter directly on the filter funnel base. Then screw and tighten the filter funnel to the base.

b. Using a cap-less 50 ml conical centrifuge tube, measure 20-50 ml of composite material.

c. Pump the measured composite material through the filter using the hand-operated PVC vacuum pump. Do not let the vacuum pressure rise above 20 psi to prevent cell damage.

d. Note the volume filtered on the Physicochemical and Biology field form.

e. Remove the cap from a pre-labeled 50 ml conical centrifuge tube. Use the tweezers to remove and gently fold in half the glass microfiber filter. Slide the folded filter into the centrifuge tube. Screw the cap back on.

f. Wrap the centrifuge vial in a 6” x 6” sheet of aluminum foil. Fold close the ends in such a fashion to ensure the aluminum foil does not rip or come undone during transport to the laboratory. Note: It is okay to cover the label. This process ensures that the label will remain fixed to the centrifuge vial rather than on top of the aluminum foil and will prevent loss of the label during transport.

g. Place the wrapped centrifuge tube(s) in an ice chest containing blocks of dry ice. For proper preservation, immediately place the tubes in direct proximity to the dry ice.

h. Discard the filtered extract from the filter funnel holder. Rinse the entire filtering apparatus.

9. Biological Parameters

Macroinvertebrate Sampling

Methods to collect macroinvertebrate data can be found in Appendix B of Policy Statement 10-1 (CDPHE 2017). The methods outlined in Policy Statement 10-1 represent semi-quantitative methods for collecting a single sample from perennial, wadeable streams. Quantitative sample collection methods via a Hess Sampler may also be used (Rees and Kotalik 2018; CDPHE 2019). Information on these methods is also available on the CDPHE website.

While the CDPHE (2017) approach is intended for use in perennial streams, macroinvertebrate sample collection could also be completed in non-perennial streams when standing or flowing water is present during the index period. However, it is important to note that spatial and interannual variability may be greater within these systems, and sampling may have more limited repeatability.

Record information related to macroinvertebrate sampling on Physicochemical and Biology field form in Appendix B.

Index period: Samples should be collected during this period to minimize seasonal variation:

Biotypes 1 and 2: late June to November 30

Biotype 3: May 1 to November 30.

Whatever date is selected for the preliminary sampling, a similar time frame (within a week or two) should be selected for subsequent sampling to further minimize seasonal variability.

Sampling Procedure: An equipment list is included in CDPHE (2017) Appendix B, Section 6.1. Sampling procedures for riffle and multi-habitat approaches are provided in CDPHE (2017) Appendix B and are duplicated with minor edits below. Please see the original reference for additional information, including information on site selection, quality control procedures and invasive species management.

The riffle habitat method (CDPHE 2017 Appendix B, Sections 6.0 and 7.1), which focuses on sampling riffle habitats, should be applied in hard-bottomed streams (i.e., moderate to high gradient streams with a dominate substrate of particles gravel size or larger).

The multi-habitat method (CDPHE 2017 Appendix B, Sections 6.0 and 7.2), which focuses on sampling non-riffle habitats, such as vegetated bank margins, submerged woody debris or snags and aquatic macrophytes, should be applied in soft-bottomed streams (e.g., low gradient streams with a dominant substrate of sand, silt, clay or mud, often found in the Eastern Plains and in the far western xeric plateaus of Colorado, and dominated by glide/pool habitats).

Riffle Habitat Method Procedures (from CDPHE 2017):

1. Ensure that the sampling net and sieve bucket are clean prior to usage.
2. Select the dominant riffle habitat within the study reach according to Section 5.0 of CDPHE (2017).

3. Place the net frame flush to the streambed with the frame open to the upstream flow. Check that the nylon bag and sieve bucket are freely floating immediately downstream of the net frame. This will ensure that once the substrate is disturbed that specimens will be directed through the nylon bag and into the capture sieve bucket.
4. Carefully lower the handle forward in an upstream direction until the sampling net is nearly horizontal to the water surface but the net frame is still flush to the streambed. The point at which the tip of the handle extends along the streambed is the point at which the kicking activity will cease. This distance multiplied by the width of the net frame equals one square meter. Return the handle to its vertical position.
5. Position yourself next to sampling net and begin to disturb the substrate immediately upstream of the net. Disturb the substrate using the heel of your boot or entire foot by kicking to dislodge the upper layer of cobbles or gravel and to scrape the underlying bed. The area disturbed should extend no further than the point delineated and not exceed 1 minute. Approximately 0.25 meters should be disturbed for every 15 seconds.
6. Larger cobble may be scraped by hand, if necessary, to remove specimens. Cobble should be scraped clean quickly and efficiently as the scraping is counted within the one-minute time frame.
7. Transfer material (matrix of specimens and insubstantial amount of stream substrate/detritus) from the interior of the net and sieve bucket into the sample jar and wash or pick all specimens off the net interior. Specimens that cling to the exterior of the net are not considered part of the sample. They may be removed and placed back into the stream.
8. Release back into the stream any fish, amphibians, reptiles or crayfish caught in the net.
9. If excessive or large debris items are present refer to Sample Processing Procedures below. The kick-net should be rinsed clean by backwashing with site water before collecting additional samples.
10. Continue to Sample Processing.

Multi-Habitat Method Procedures:

1. Ensure that the sampling net and sieve bucket are clean prior to usage.
2. Sample multiple habitats, as defined below, using the following procedures. The design is to sample an equivalent of a one-meter sweep across multiple non-riffle habitats. Avoid dredging the kick net through mud or silt and clumps of leafy detritus or algal material. Also avoid hard-bottomed substrates as those habitats will be sampled separately according to the Riffle Habitat Method
    a. Woody Debris or Snag: Jab the kick net into an area of submerged and partially decayed woody debris to dislodge specimens, followed by 1-2 “cleaning” sweeps through the water column to capture specimens in the water column. Scrub larger debris by hand over the opening of the kick net. The area of the larger debris should be included in the one-meter unit effort.

b. Bank Margins: Locate an area of bank within the study reach. Jab the kick net vigorously into the bank for a distance of 1 meter to dislodge specimens, followed by 1 to 2 "cleaning" sweeps to collect specimens in the water column.

c. Aquatic Macrophytes: Sweep the kick net through submerged or emergent vegetation for a distance of 1 meter to loosen and capture specimens, followed by 1 to 2 "cleaning" sweeps to collect specimens in the water column.

3. Transfer material (matrix of specimens and insubstantial amount of stream substrate/detritus) from the interior of the net and sieve bucket into the sample jar and wash or pick all specimens off the net interior. Specimens that cling to the exterior of the net are not considered part of the sample. They may be removed and placed back into the stream.
4. Release back into the stream any fish, amphibians, reptiles or crayfish caught in the net.
5. If excessive or large debris items are present refer to Sample Processing Procedures below.
6. The kick-net should be rinsed clean by backwashing with site water before collecting additional samples.
7. Continue to Sample Processing.

<u>Sample Processing Procedure (On-site)</u>: Sample processing is characteristically conducted in the field. Sample processing consists of excessive material or large debris item removal and rinsing, elutriation (if necessary), preservation, and storage.

1. Remove Excessive and Large Debris Items: Picking and rinsing should be performed in a Number 30 (600 µm) or 35 (500 µm) standard sieve. Rinse off and remove any excessive debris such as algal clumps or large debris items such as leaves, sticks, or rocks that will not fit into a 1-liter sample jar or will lessen the effectiveness of the preservative. Calmly rinse the debris with stream water over the sieve opening using care not to cause unnecessary splattering of material. Examine larger debris to ensure that all specimens have been thoroughly rinsed or scraped into the sieve. Discard the material. Transfer the remaining sample matrix in the sieve to a 1-liter wide-mouth polyethylene sample jar. Each sample jar should be no more than half full of sample material. Consequently, splitting the sample into two or more sample jars is acceptable. If splitting the sample among several containers, label appropriately to indicate that the sample has been split (e.g., Sample 1 of 2 and Sample 2 of 2).
2. Elutriation: Elutriation is a technique used to extract specimens from excessive substrate that has been captured during the sample collection process. This technique works best when the substrate is comprised of fines, sands and pebbles and should be used in circumstances when the amount of substrate is disproportionate to the amount of the detritus/specimen matrix. Keeping the sample in the 5-gallon bucket, add stream water to the bucket. Gently swish the sample around in the bottom of the bucket to liberate organic material and macroinvertebrates from the substrate. Pour the water and all floating material and specimens into a Number 30 (600 µm) or 35 (500 µm) standard sieve. This process may not work for heavy invertebrates such as snails, larger annelids or case-building caddis flies that use sand. Continue rinsing in a similar fashion 2-3 more times to maximize retention of specimens collected. If it appears that the heavy invertebrates are not being separated from the substrate, pour the remaining sample in the bucket into a tray and

spread the sample homogenously across the bottom of the tray. Use forceps to remove remaining specimens and place them into the sieve. Transfer the remaining sample matrix in the sieve to a 1-liter wide-mouth polyethylene sample jar. Each sample jar should be no more than 1/2 full of sample material. Consequently, splitting the sample into two or more sample jars is acceptable. If splitting the sample among several containers, label appropriately to indicate that the sample has been split (e.g., Sample 1 of 2 and Sample 2 of 2).

3. Sample Preservation: Sample preservation is very important to ensure the integrity of the benthic organisms collected from the site. The sample is preserved by decanting as much remaining water as possible and then filling the jar with 95% ethanol (ETOH) so the ETOH is 1” above the detritus/specimen matrix. Gently invert the sample jar several times to thoroughly homogenize the sample and preservative. This will make certain that the entire sample is preserved. Poorly preserved specimens can impede the identification and enumeration process. Any liquid leaking from the jar lid with the bottle inverted indicates an incomplete seal. Allowing for dilution with water remaining in the sample container, the minimum ethanol concentration should always be greater than 70%. If in doubt, or with samples containing a large amount of organic material, the ethanol should be decanted after initial preservation and replaced with fresh 95% ethanol. In general, the volume of the container should contain no more than 50% of the sample.
4. Labeling: Add moisture resistant labels to both the inside and outside of the sample container. Affix the label to the outside using transparent packaging tape. Pull back a corner of the packaging tape prior to affixing the label so the tape/label can be easily removed later once the taxonomist returns the 1-liter jars. The following information should be recorded with a pencil on each label and placed in each sample container:
   a. Reach ID
   b. Stream name
   c. Date
   d. Collector’s initials
   e. Indicate if sample is split
5. Storage: Place the sample jars in a hard-cased ice chest or equivalent container for transport to the laboratory. Ensure that jar lids are thoroughly tightened to eliminate leakage and fumes from developing inside vehicle cargo holds or truck beds.

<u>Sample Processing</u>: Standard operating procedures for laboratory identification and enumeration are outlined in CDPHE (2017) Appendix C.

<u>Fish Sampling</u>

Detailed fish surveys should be conducted using standard methods (Bonar et al. 2009). **Specific fish sampling procedures are not provided in this section.** A CPW permit is required prior to collecting fish samples. Because of inter- and intra-annual variability in 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: the wild trout biomass metric requires selection and sampling of a control reach *in addition* to sampling of the project reach. The control reach should be at a similar elevation and be roughly similar to the project reach in all other aspects and should be of reference quality (to the extent practicable). 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.

Record information related to fish sampling on the Physicochemical and Biology field form in Appendix B.

10. Measuring Flow

Implementing the Flow Alteration Module requires continuous monitoring of stream flow, or discharge measured in cubic feet per second (cfs) within the reach. Additionally, the Baseflow Dynamics parameter requires, and the return interval metric recommends, a field measurement of discharge in order to calculate Manning's 'n'. A stream gage can also be deployed to monitor baseflow discharge during the low flow season, typically late summer through early fall. Detailed instructions for deploying stream gages, establishing a rating curve, and analyzing flow records are provided in EPA's *Best Practices for Continuous Monitoring of Temperature and Flow in Wadeable Streams* (2014). **Methods are not provided in this section.** These measurements will require current meters in addition to the surveying equipment listed in Section 1.

Multiple field measurements of discharge will be required for the Flow Alteration Module, where extremes and baseflow discharge values are calculated from the gage record. For baseflow dynamics and return interval metrics where the discharge of interest is a single stage in the cross section, multiple flow measurements are preferred but one measurement is sufficient provided that baseflow is within a range of 0.4 to 2.5 times the measured flow (Espegren 1996). R2Cross software (Espegren 1996) can be used to calculate Manning's 'n' from field measurements of flow.

Record the time and date of sensor deployment on the Sensor Log form in Appendix B.

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APPENDIX B:

Data Collection Field Forms for Methods Outlined in Appendix A

Project:
Reach ID:

Colorado Stream Quantification Tool
Parameter Selection Checklist

	Function-Based Parameter	Metric(s)	Datasheets for Field-based Metrics
☑	Reach Runoff*	☐ Land Use Coefficient (D) **AND** Concentrated Flow Points (F)	Project Reach Form Section II(b)**
		or	
		☐ Impervious Cover (D) **AND** Concentrated Flow Points (F)	Project Reach Form Section II(b)**
		or	
		☐ Water Quality Capture Volume (D)	
☐	Baseflow Dynamics	☐ ***Optional:*** Velocity **AND** Average Depth (D/F)	Cross Section Form
☑	Floodplain Connectivity*	☐ Bank Height Ratio **AND** Entrenchment Ratio (F)	Cross Section Form **OR** Rapid Survey Form**
		or	
		☐ Return Interval (D) **AND** Entrenchment Ratio (F)	Cross Section Form
		☐ ***Optional:*** Percent Side Channels (F)	Project Reach Form Section II(d)**
☐	Large Woody Debris (LWD)	☐ ***Optional:*** LWD Index (F)	LWDI Form or fillable workbook**
		or	
		☐ ***Optional:*** No. of LWD Pieces/ 100 meters (F)	Project Reach Form Section VI**
☑	Lateral Migration*	☐ Dominant BEHI/NBS **AND** Percent Streambank Erosion (F)	Lateral Migration Form**
		or	
		☐ Greenline Stability Rating (F)	Available in Winward (2000)
		☐ ***Optional:*** Percent Armoring (F)	Project Reach Form Section II(c)**
☐	Bed Material Characterization	☐ ***Optional:*** Size Class Pebble Count Analyzer (F)	Pebble Count Form
☑	Bed Form Diversity*	☑ Pool Spacing Ratio **AND** Pool Depth Ratio **AND** Percent Riffle* (F)	Longitudinal Survey **OR** Rapid Survey Form**
		☐ ***Optional:*** Aggradation Ratio (F)	Cross Section Form **OR** Rapid Survey Form**
☐	Plan Form	☐ ***Optional:*** Sinuosity (F)	Project Reach Form Section II(e)**
☑	Riparian Vegetation*	☑ Riparian Width (D/F) **AND** Woody Vegetation Cover (F) **AND** Herbaceous Vegetation Cover (F) **AND** Percent Native Cover (F)*	Riparian Width and Riparian Vegetation Forms**
☐	Temperature	☐ ***Optional:*** Daily Maximum Temperature (F) **AND** Maximum Weekly Average Temperature (F)	Sensor Log
		☐	
☐	Dissolved Oxygen	☐ ***Optional:*** Dissolved Oxygen Concentration (F)	Sensor Log
☐	Nutrients	☐ ***Optional:*** Chlorophyll a (F)	Physicochemical and Biology Form
☐	Macroinvertebrates	☐ ***Optional:*** Colorado Multi-Metric Index (F)	Physicochemical and Biology Form
☐	Fish	☐ ***Optional:*** Native Fish Species Richness **AND** SGCN Absent (F)	Physicochemical and Biology Form
		☐ ***Optional:*** Wild Trout Biomass (F)	Physicochemical and Biology Form
☐	Flow Alteration Module	☐ ***Optional:*** Mean Annual Flow	Sensor Log
		☐ ***Optional:*** Mean August **AND** September Flow	Sensor Log
		☐ ***Optional:*** Mean January Flow	Sensor Log
		☐ ***Optional:*** Mean Annual Peak Daily Flow	Sensor Log
		☐ ***Optional:*** 7-Day Minimum	Sensor Log

* Include in all assessments
** Field values can be entered directly from field forms into CSQT; all other metrics require additional post-processing or analysis to calculate values.
(D) indicates metrics are calculated using desktop methods
(F) indicates metrics are calculated or verified using field methods

Date:
Investigators:

Colorado Stream Quantification Tool
Project Reach Form

I. Site Information

Project Name:	
Reach ID:	
Drainage Area (sq. mi.):	
Flow Type:	
River Basin:	
Valley Type:	
Stream Reach length (ft):	
Latitude:	
Longitude:	

Shading Key
Desktop Value
Field Value
Calculation

II. Reach Walk

A.	Difference between bankfull (BKF) stage and water surface (WS) (ft)							
	Difference between BKF stage and WS (ft) *Average or consensus value from reach walk.*							

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

C.	Length of Armoring on banks (ft)							
	Total (ft)							
	Percent Armoring (%)							

D.	Length of Side Channels (ft)							
	Total (ft)							
	Percent Side Channels (%)							

E.	Valley length (ft)	
	Stream Length (ft)	
	Sinuosity	

III. Identification of Representative Sub-Reach

Representative Sub-Reach Length At least 20 x the Bankfull Width	
Latitude of downstream extent:	
Longitude of downstream extent:	

20*Bankfull Width	

Sub-Reach Survey Method

□ Longitudinal Profile & Cross Section
□ Rapid Survey

IV. Bankfull Verification and Representative Riffle Cross Section

Is Cross Section located within Representative Sub-Reach? ☐ Yes ☐ No

If no, explain why:

A.	Bankfull Width (ft)	
B.	Bankfull Mean Depth (ft) = Average of cross-section depths	
C.	Bankfull Area (sq. ft.) Width * Mean Depth	
D.	Regional Curve Bankfull Width (ft)	
E.	Regional Curve Bankfull Mean Depth (ft)	
F.	Regional Curve Bankfull Area (sq. ft.)	
G.	Curve Used	

NOTE: Space is provided here to survey a cross section using rapid survey methods. A cross section form is also available for cross section surveys.

Cross Section Measurements Depth measured from bankfull			
Station	Depth	Station	Depth

V. Stream Classification

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

Average slope from the representative sub-reach will be measured and calculated. Pebble count forms are available to aid in this determination.

VI. Large Woody Debris (100m (328 ft) assessment length within Sub-Reach)

A.	Number of Pieces	

NOTE: Complete this section only if the LWDI is not being used. Otherwise complete the LWDI Field Form.

VII. Representative Sub-Reach Sketch

VIII. Notes

Colorado Stream Quantification Tool
Longitudinal Profile Form

Date:	Rod Team:
Stream Name:	Instrument Team:
Reach I.D.	Notes Team:
Team Number:	

Longitudinal Profile Field Form

Key Codes:

Head of Riffle	R	Bankfull	BKF	Benchmark	TBM
Head of Run	N	Top of Bank	TOB	Turning Point	TP
Head of Pool	P	Edge of Channel	EC	Backsight	BS
Head of Glide	G	Inner Berm	IB	Foresight	FS
Thalweg	TW			Height of Instrument	HI

Survey:			**Thalweg**		**Water Surface**		**Bankfull**		**Top of Low Bank**			
Station	**BS (+)**	**HI**	**FS (-)**	**Elevation**	**FS (-)**	**Elevation**	**FS (-)**	**Elevation**	**FS (-)**	**Elevation**	**FS (-)**	**Elevation**

Colorado Stream Quantification Tool
Longitudinal Profile Form

Survey:			Thalweg		Water Surface		Bankfull		Top of Low Bank			
Station	BS (+)	HI	FS (-)	Elevation	FS (-)	Elevation	FS (-)	Elevation	FS (-)	Elevation	FS (-)	Elevation

Colorado Stream Quantification Tool
Cross Section Form

Date:	Rod Team:
Stream Name:	Instrument Team:
Reach I.D.	Notes Team:
Team Number:	

Key Codes:

Head of Riffle	R	Bankfull	BKF	Benchmark	TBM
Head of Run	N	Top of Bank	TOB	Turning Point	TP
Head of Pool	P	Edge of Channel	EC	Backsight	BS
Head of Glide	G	Inner Berm	IB	Foresight	FS
Thalweg	TW			Height of Instrument	HI

Cross Section Field Form

Station	BS (+)	HI	FS (-)	Elevation	Notes

Date:
Investigators:

Colorado Stream Quantification Tool
Rapid Survey Form

Reach ID:

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

A.	Representative Sub-Reach Length		20*Bankfull Width	

B. Bank Height & Riffle Data: Record for each riffle in the Sub-Reach

	R1	R2	R3	R4	R5	R6	R7	R8
Begin Station								
End Station								
Low Bank Height (ft)								
BKF Max Depth (ft)								
BKF Mean Depth (ft)								
BKF Width (ft)								
Flood Prone Width (ft)								
Riffle Length (ft) *Including Run*								
Bank Height Ratio (BHR) Low Bank H / BKF Max D								
BHR * Riffle Length (ft)								
Entrenchment Ratio (ER)								
ER * Riffle Length (ft)								
WDR BKF Width/BKF Mean Depth								

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

Shading Key
Field Value
Calculation

II. Pool Data (Bed Form Diversity)

A. Pool Data: Record for each pool within the Sub-Reach

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

B. | **Average Pool Depth Ratio** | |
|---|---|

C. | **Median Pool Spacing Ratio** | |
|---|---|

III. Slope

	Begin	End	Difference	Slope (ft/ft)
Station along tape (ft)				
Stadia Rod Reading (ft)				

IV. Notes

Date:
Investigators:

Colorado Stream Quantification Tool
Lateral Migration Form

Reach ID:
Valley Type:
Bed Material:

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

Date:

Investigators:

Colorado Stream Quantification Tool

Lateral Migration Form

Summary Table

BEHI/NBS Ranking	Enter bank Length from all rows on p.1 with same ranking									Length (Feet)	Percent of Total
Ex/Ex											
Ex/VH											
Ex/H											
Ex/M											
Ex/L											
Ex/VL											
VH/Ex											
Vh/VH											
VH/H											
VH/M											
VH/L											
VH/VL											
H/Ex											
H/VH											
H/H											
H/M											
H/L											
H/VL											
M/Ex											
M/VH											
M/H											
M/M											
M/L											
M/VL											
L/Ex											
L/VH											
L/H											
L/M											
L/L											
L/VL											
									Total Length:		
									Eroding Length:		

Date:
Investigators:

Colorado Stream Quantification Tool
Riparian Vegetation Form

Sub-Reach Name: ____________________

Sub-Reach Length: ________ # Plots/side: _____ Random Start # (1-20 ft): _____ Plot Spacing: _______

Primary Cover Type (H, S, F, M, U) _____	Plot ____ L / R
Geomorphic Position: (IM, OM, S) _____	Station ______

Absolute Cover (AC) by Species - use scientifc names of plants.		
Tree Plot (1, 32 x32 ft plot)	AC (%)	Native Status (N/I)
1.		
2		
3		
Tree Subtotal		
Shrub Plot (1, 16 x16 ft plot)		
1.		
2.		
3.		
4.		
Shrub Subtotal		
Woody Vegetation Cover (Total)		
Native Woody Veg Total		

Herb Plots (2, 3x3 ft* plots) or (1, 16 x16 ft plot)	Herb Plot 1 AC (%)	Herb Plot 2 AC (%)	Avg Herb* AC (%)	Native Status (N/I)
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				
Herb Veg. Cover (Total)				
Native Herb. Veg Total				

Total Vegetation Cover ____
Total Native Cover ____
Percent Native Cover ____

Bareground/litter/gravel			
Embedded rock			

Notes:

Primary Cover Type (H, S, F, M, U) _____	Plot ____ L / R
Geomorphic Position: (IM, OM, S) _____	Station ______

Absolute Cover (AC) by Species - use scientifc names of plants.		
Tree Plot (1, 32 x32 ft plot)	AC (%)	Native Status (N/I)
1.		
2		
3		
Tree Subtotal		
Shrub Plot (1, 16 x16 ft plot)		
1.		
2.		
3.		
4.		
Shrub Subtotal		
Woody Vegetation Cover (Total)		
Native Woody Veg Total		

Herb Plots (2, 3x3 ft* plots) or (1, 16 x16 ft plot)	Herb Plot 1 AC (%)	Herb Plot 2 AC (%)	Avg Herb* AC (%)	Native Status (N/I)
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				
Herb Veg. Cover (Total)				
Native Herb. Veg Total				

Total Vegetation Cover ____
Total Native Cover ____
Percent Native Cover ____

Bareground/litter/gravel			
Embedded rock			

Notes:

Date:
Investigators:

Colorado Stream Quantification Tool
Riparian Width Form

Sub-Reach Name:
Sub-Reach Length: # Plots/side: Random Start # (1-20 ft): Plot Spacing:

From aerial imagery:	Expected (Ft):		Observed (ft):	
Station ID:	Expected (L Bank):	Expected (R Bank):	Expected (Ft):	
Channel Width:	Observed (L Bank):	Observed (R Bank):	Observed (Ft):	
Check Observed Indicators:			Riparian Width %:	
☐ Valley Edge	☐ Slope break/Terrace	Notes:		
☐ Change in Sediment	☐ Other:			
☐ Evidence of Flooding				
☐ Change in Vegetation				

From aerial imagery:	Expected (Ft):		Observed (ft):	
Station ID:	Expected (L Bank):	Expected (R Bank):	Expected (Ft):	
Channel Width:	Observed (L Bank):	Observed (R Bank):	Observed (Ft):	
Check Observed Indicators:			Riparian Width %:	
☐ Valley Edge	☐ Slope break/Terrace	Notes:		
☐ Change in Sediment	☐ Other:			
☐ Evidence of Flooding				
☐ Change in Vegetation				

From aerial imagery:	Expected (Ft):		Observed (ft):	
Station ID:	Expected (L Bank):	Expected (R Bank):	Expected (Ft):	
Channel Width:	Observed (L Bank):	Observed (R Bank):	Observed (Ft):	
Check Observed Indicators:			Riparian Width %:	
☐ Valley Edge	☐ Slope break/Terrace	Notes:		
☐ Change in Sediment	☐ Other:			
☐ Evidence of Flooding				
☐ Change in Vegetation				

From aerial imagery:	Expected (Ft):		Observed (ft):	
Station ID:	Expected (L Bank):	Expected (R Bank):	Expected (Ft):	
Channel Width:	Observed (L Bank):	Observed (R Bank):	Observed (Ft):	
Check Observed Indicators:			Riparian Width %:	
☐ Valley Edge	☐ Slope break/Terrace	Notes:		
☐ Change in Sediment	☐ Other:			
☐ Evidence of Flooding				
☐ Change in Vegetation				

Average Riparian Width O/E:

Shading Key
Desktop Value
Field Value
Calculation

Date:
Investigators:

Colorado Stream Quantification Tool
Physicochemical and Biology Form

Stream Name:
Sub-reach Name:

Time begin:	
Time end:	
Describe location of sampling within reach:	

ALSO IDENTIFY DATA COLLECTION LOCATIONS ON SUB-REACH SKETCH ON PROJECT REACH FORM

Benthic macroinvertebrates: □ **Yes** □ **No**

Sample taken per habitat type:
□ Riffle Habitat □ Multi-Habitat

Gear used:
□ Kicknet □ Hess □ Other: _________

Duplicate Samples: □ Yes □ No
Total samples: _______________

Preservative used:
□ 95% ethyl alcohol □ Other: _________

Periphyton (Chlorophyll-a): □ **Yes** □ **No**

Five transects sampled: □ Yes □ No
Three rocks from ea. transect? □ Yes □ No

Initial volume of composite: ________ ml (500 ml target)
Chlorophyll-a ml filtered: ________

Type of Plant Growth:

	% Cover	Amount	Color	Condition
Microalgae				
Macroalgae				
Mosses				
Macrophytes				
Bare Substrate				
Total	***100%***			

Substrate Present Rank: Rock_____ Sediment_____ Wood_____

Cover: Estimate the % of wetted substrate area colonized by each of the categories listed and the percent area not colonized by any plants.

Amount: Record the relative amount of plant growth in each category as being LIGHT, MODERATE or HEAVY. Light growth barely covers the substrate surface and is not immediately evident. Heavy growth extends almost to the water surface or beyond. Moderate is intermediate between light and heavy growth.

Color: The colors of aquatic plants are clues to their identity and to the health of aquatic ecosystems. Record the predominant color of the plants in each of the categories present.

Condition: Aquatic plants go through seasonal cycles of growth, maturity, and decay. GROWING plants show new growth and bright colors. MATURE plants are larger but have more subdued colors because of age, epiphytes and sediment deposits. DECAYING plants display a loss of both pigmentation and physical integrity.

Rank: Rank the types of substrates that are available for colonization by plants (1 = substrate accounting for the most area, etc)

Fish Data Collection: □ **Yes** □ **No**

First sampling event? □ Yes □ No
Repeat visit? □ Yes □ No Date/time of previous event:
Reference site sampled? □ Yes □ No
Reference Site Location: Latitude: Longitude:
First ref. sampling event? □ Yes □ No Date/time of reference collection:
Repeat visit to ref. site? □ Yes □ No Date/time of previous event:

PEBBLE COUNT DATA SHEET

SITE OR PROJECT:	
REACH/LOCATION:	
DATE COLLECTED:	
FIELD COLLECTION BY:	
DATA ENTERED BY:	

			PARTICLE CLASS			Reach Summary	
MATERIAL	PARTICLE	SIZE (mm)	Riffle	Pool	Total	Class %	% Cum
	Silt / Clay	< .063					
	Very Fine	.063 - .125					
	Fine	.125 - .25					
	Medium	.25 - .50					
	Coarse	.50 - 1.0					
	Very Coarse	1.0 - 2.0					
	Very Fine	2.0 - 2.8					
	Very Fine	2.8 - 4.0					
	Fine	4.0 - 5.6					
	Fine	5.6 - 8.0					
	Medium	8.0 - 11.0					
	Medium	11.0 - 16.0					
	Coarse	16 - 22.6					
	Coarse	22.6 - 32					
	Very Coarse	32 - 45					
	Very Coarse	45 - 64					
	Small	64 - 90					
	Small	90 - 128					
	Large	128 - 180					
	Large	180 - 256					
	Small	256 - 362					
	Small	362 - 512					
	Medium	512 - 1024					
	Large-Very Large	1024 - 2048					
	Bedrock	> 2048					

Totals

Date:
Investigators:

Colorado Stream Quantification Tool
Sensor Log

Stream Name:
Sub-reach Name:

Temperature Sensors Deployed? ☐ **Yes** ☐ **No**

Date Deployed:	
Date Retreived:	

Was air temperature sensor also deployed? ☐ Yes ☐ No

Frequency of data: ☐ 30 min ☐ Other: _______

Describe sensor location within reach:

Dissolved Oxygen Logger Deployed? ☐ **Yes** ☐ **No**

Date Deployed:	
Date Retreived:	

Frequency of data: ☐ Daily ☐ Other: _______
Timing of data: ☐ 1-3pm ☐ Other: _______

Describe sensor location within reach:

Stream Gage Deployed? ☐ **Yes** ☐ **No**

Date Deployed:	
Date Retreived:	

Type of Gage: ☐ Pressure Transducer ☐ Stage only ☐ Other: _______________
Frequency of data (if applicable): _______

Describe gage location within reach:

Other Sensor Deployed? Sensor Type:

Date Deployed:	
Date Retreived:	

Frequency of data (if applicable): _______

Describe location within reach:

ALSO IDENTIFY ALL SENSOR LOCATIONS ON SUB-REACH SKETCH ON PROJECT REACH FORM

APPENDIX C:

Fish Species Assemblages within Major River Basins in Colorado

Family	Species Code	Common Name	Genus Species	Arkansas	Colorado	Republican	Rio Grande	South Platte	North Platte	Gunnison	Cimarron	Yampa	Dolores	Green	San Juan	White
CATOSTOMIDAE	BMB	BIGMOUTH BUFFALO	*Ictiobus cyprinellus*	A	A	A	A	I	A	A	A	A	A	A	A	A
CATOSTOMIDAE	BHS	BLUEHEAD SUCKER	*Catostomus discobolus*	A	N	A	A	A	A	N	A	N	N	N	N	N
CATOSTOMIDAE	FMS	FLANNELMOUTH SUCKER	*Catostomus latipinnis*	I	N	I	A	A	A	N	A	N	N	N	N	N
CATOSTOMIDAE	LGS	LONGNOSE SUCKER	*Catostomus catostomus*	I	I	I	I	N	N	I	A	I	I	I	I	I
CATOSTOMIDAE	MOS	MOUNTAIN SUCKER	*Catostomus platyrhynchus*	A	N	A	A	A	U	U	A	N	U	A	A	N
CATOSTOMIDAE	QUI	QUILLBACK	*Carpiodes cyprinus*	A	A	A	A	X	A	A	A	A	A	A	A	A
CATOSTOMIDAE	RBS	RAZORBACK SUCKER	*Xyrauchen texanus*	I	N	I	A	A	A	N	A	N	N	N	A	N
CATOSTOMIDAE	RGS	RIO GRANDE SUCKER	*Catostomus plebeius*	I	A	I	N	A	A	A	A	A	A	A	A	A
CATOSTOMIDAE	RCS	RIVER CARPSUCKER	*Carpiodes carpio*	N	A	N	A	N	A	A	A	A	A	A	A	A
CATOSTOMIDAE	NRH	SHORTHEAD REDHORSE	*Moxostoma macrolepidotum*	A	A	A	A	N	A	A	A	A	A	A	A	A
CATOSTOMIDAE	WHS	WHITE SUCKER	*Catostomus commersonii*	N	U	N	U	N	N	U	N	U	U	U	U	U
CENTRARCHIDAE	BCR	BLACK CRAPPIE	*Pomoxis nigromaculatus*	I	I	I	A	I	A	I	I	I	I	I	I	I
CENTRARCHIDAE	BGL	BLUEGILL	*Lepomis macrochirus*	I	I	I	I	I	A	I	N	I	I	I	I	I
CENTRARCHIDAE	SNF	GREEN SUNFISH	*Lepomis cyanellus*	N	I	I	N	N	A	I	N	I	I	I	N	I
CENTRARCHIDAE	LMB	LARGEMOUTH BASS	*Micropterus salmoides*	I	I	I	I	I	A	I	I	I	I	I	I	I
CENTRARCHIDAE	OSF	ORANGESPOTTED SUNFISH	*Lepomis humilis*	N	I	N	A	N	A	I	A	I	I	I	A	I
CENTRARCHIDAE	PKS	PUMPKINSEED	*Lepomis gibbosus*	I	U	U	A	I	A	A	A	U	U	A	U	A
CENTRARCHIDAE	RSF	REDEAR SUNFISH	*Lepomis microlophus*	I	A	I	A	I	A	A	A	A	A	A	A	A
CENTRARCHIDAE	SPE	SACRAMENTO PERCH	*Archoplites interruptus*	A	A	I	A	I	A	A	A	A	A	A	A	A
CENTRARCHIDAE	SMB	SMALLMOUTH BASS	*Micropterus dolomieui*	I	I	I	I	I	A	I	I	I	I	I	I	I
CENTRARCHIDAE	SPB	SPOTTED BASS	*Micropterus punctulatus*	I	A	I	A	A	A	A	A	A	A	A	A	A
CENTRARCHIDAE	WCR	WHITE CRAPPIE	*Pomoxis annularis*	I	A	I	A	I	A	A	I	A	A	A	A	A
CLUPEIDAE	GSD	GIZZARD SHAD	*Dorosoma cepedianum*	N	U	N	F	N	A	U	N	U	U	U	U	U
COTTIDAE	MTS	MOTTLED SCULPIN	*Cottus bairdii*	I	N	I	A	I	A	N	A	N	N	N	A	N
COTTIDAE	PAS	PAIUTE SCULPIN	*Cottus beldingii*	A	N	I	A	I	I	N	A	N	N	N	A	N
CYPRINIDAE	BMS	BIGMOUTH SHINER	*Notropis dorsalis*	I	A	A	A	N	U	A	A	A	A	A	A	A
CYPRINIDAE	BYT	BONYTAIL (CHUB)	*Gila elegans*	I	N	I	A	A	A	N	A	N	N	N	N	N
CYPRINIDAE	BMW	BRASSY MINNOW	*Hybognathus hankinsoni*	I	I	N	A	N	I	I	A	I	I	I	A	I
CYPRINIDAE	STR	CENTRAL STONEROLLER	*Campostoma anomalum*	N	A	N	A	N	A	A	N	A	A	A	A	A
CYPRINIDAE	CPM	COLORADO PIKEMINNOW	*Ptychocheilus lucius*	I	N	I	A	A	A	N	A	N	X	N	N	N
CYPRINIDAE	CPP	COMMON CARP	*Cyprinus carpio*	I	I	I	I	I	A	I	I	I	I	I	I	I
CYPRINIDAE	CSH	COMMON SHINER	*Notropis cornutus*	I	A	I	A	N	A	A	A	A	A	A	A	A
CYPRINIDAE	CRC	CREEK CHUB	*Semotilus atromaculatus*	I	I	N	A	N	N	I	A	I	I	I	A	I
CYPRINIDAE	EMS	EMERALD SHINER	*Notropis atherinoides*	A	A	I	A	I	A	A	A	A	A	A	A	A
CYPRINIDAE	FMW	FATHEAD MINNOW	*Pimephales promelas*	N	U	N	N	N	N	U	N	U	I	U	U	U
CYPRINIDAE	FHC	FLATHEAD CHUB	*Platygobio gracilis*	N	A	A	N	I	A	A	A	A	A	A	A	A
CYPRINIDAE	GSH	GOLDEN SHINER	*Notemigonus crysoleucas*	I	I	I	A	I	A	I	A	I	I	I	A	I
CYPRINIDAE	GDF	GOLDFISH	*Carassius auratus*	I	I	I	A	I	A	I	A	I	I	I	A	I
CYPRINIDAE	HBC	HUMPBACK CHUB	*Gila cypha*	I	N	I	A	A	A	N	A	N	N	N	N	N
CYPRINIDAE	HGC	HYBRID GRASS CARP (TRIPLOID)	*Ctenopharyngodon*	I	I	I	I	I	A	I	I	I	I	I	I	I
CYPRINIDAE	LAC	LAKE CHUB	*Couesius plumbeus*	I	A	I	A	N	A	A	A	A	A	A	A	A
CYPRINIDAE	LND	LONGNOSE DACE	*Rhinichthys cataractae*	N	I	N	N	N	N	I	A	A	A	A	A	A
CYPRINIDAE	NRD	NORTHERN REDBELLY DACE	*Phoxinus eos*	I	A	I	A	N	A	A	A	A	A	A	A	A
CYPRINIDAE	PMW	PLAINS MINNOW	*Hybognathus placitus*	N	A	N	A	N	A	A	A	A	A	A	A	A
CYPRINIDAE	RDS	RED SHINER	*Cyprinella lutrensis*	N	I	N	N	N	A	I	I	I	I	I	N	I
CYPRINIDAE	RSS	REDSIDE SHINER	*Richardsonius balteatus*	I	I	I	A	I	A	I	A	I	I	I	A	I
CYPRINIDAE	RCH	RIO GRANDE CHUB	*Gila pandora*	I	A	A	N	A	A	I	A	A	A	A	I	A
CYPRINIDAE	RTC	ROUNDTAIL CHUB	*Gila robusta*	I	N	I	A	I	A	N	A	N	N	N	N	N
CYPRINIDAE	RUD	RUDD	*Scardinius*	I	A	I	A	I	A	A	I	A	A	A	A	A
CYPRINIDAE	SAH	SAND SHINER	*Notropis stramineus*	N	I	N	A	N	I	I	N	I	I	I	I	I
CYPRINIDAE	SMC	SMALLMOUTH BUFFALO	*ICTIOBUS BUBALUS*	A	A	A	A	I	A	A	A	A	A	A	A	A
CYPRINIDAE	SRD	SOUTHERN REDBELLY DACE	*Phoxinus erythrogaster*	N	A	I	A	A	A	A	A	A	A	A	A	A
CYPRINIDAE	SPD	SPECKLED DACE	*Rhinichthys osculus*	I	N	I	A	I	I	N	A	N	N	N	N	N
CYPRINIDAE	SSH	SPOTTAIL SHINER	*Notropis hudsonius*	A	A	A	A	I	A	A	A	U	A	A	U	A
CYPRINIDAE	SMM	SUCKERMOUTH MINNOW	*Phenacobius mirabilis*	N	A	N	A	N	I	A	A	A	A	A	A	A
CYPRINIDAE	TEN	TENCH	*Tinca tinca*	U	A	A	U	U	A	A	A	A	A	A	A	A

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Family	Species Code	Common Name	Genus Species	Arkansas	Colorado	Republican	Rio Grande	South Platte	North Platte	Gunnison	Cimarron	Yampa	Dolores	Green	San Juan	White
CYPRINIDAE	WHA	WHITE AMUR (DIPLOID GRASS CARP)	*Ctenopharyngodon idella*	I	I	I	I	I	I	I	I	I	I	I	I	I
ESOCIDAE	NPK	NORTHERN PIKE	*Esox lucius*	U	U	I	I	I	A	U	A	U	U	U	U	U
ESOCIDAE	TGM	TIGER MUSKIE (NORTHERN X MUSKIE HYBRID)	*Esox lucius x masquinongy*	I	I	I	I	I	I	I	I	I	I	I	I	I
FUNDULIDAE	PKF	NORTHERN PLAINS KILLIFISH	*Fundulus kansae*	N	I	N	A	N	A	I	N	I	I	I	A	I
FUNDULIDAE	PTM	PLAINS TOPMINNOW	*Fundulus sciadicus*	A	A	N	U	N	A	A	A	A	A	A	U	U
GASTEROSTEIDAE	BST	BROOK STICKLEBACK	*Culaea inconstans*	I	I	I	I	N	I	I	A	I	I	I	I	I
ICTALURIDAE	BBH	BLACK BULLHEAD	*Ameiurus melas*	N	I	N	N	N	A	I	I	I	I	I	I	I
ICTALURIDAE	BCF	BLUE CATFISH	*Ictalurus furcatus*	I	A	I	A	I	A	A	A	A	A	A	A	A
ICTALURIDAE	BRH	BROWN BULLHEAD	*Ameiurus nebulosus*	A	A	I	A	I	A	A	A	A	A	A	A	A
ICTALURIDAE	CCF	CHANNEL CATFISH	*Ictalurus punctatus*	N	I	I	I	N	A	I	I	I	I	I	I	I
ICTALURIDAE	FLC	FLATHEAD CATFISH	*Pylodictis olivaris*	I	A	I	A	I	A	A	A	A	A	A	A	A
ICTALURIDAE	STP	STONECAT	*Noturus flavus*	I	A	N	A	N	A	A	A	A	A	A	A	A
ICTALURIDAE	YBH	YELLOW BULLHEAD	*Ameiurus natalis*	U	U	N	A	U	A	U	A	A	A	A	U	U
MORONIDAE	SXW	PALMETTO BASS (WIPER)	*Morone saxatilis x chrysops*	I	A	I	A	I	A	A	I	A	A	A	A	A
MORONIDAE	SBS	STRIPED BASS	*Morone saxatilis*	I	A	I	A	I	A	A	I	A	A	A	A	A
MORONIDAE	SHB	SUNSHINE BASS	*Morone chrysops(f) x m. saxatilis(m)*	I	A	A	A	I	A	A	A	A	A	A	A	A
MORONIDAE	WBA	WHITE BASS	*Morone chrysops*	I	A	I	A	I	A	A	I	A	A	A	A	A
OSMERIDAE	SMT	RAINBOW SMELT	*Osmerus mordax*	I	I	I	A	I	A	I	A	I	I	I	A	I
PERCIDAE	ARD	ARKANSAS DARTER	*Etheostoma cragini*	N	A	I	A	A	A	A	I	A	A	A	A	A
PERCIDAE	LPH	BIGSCALE LOGPERCH	*PERCINA MACROLEPIDA*	A	A	A	A	I	A	A	A	A	A	A	A	A
PERCIDAE	IOD	IOWA DARTER	*Etheostoma exile*	A	A	U	A	N	U	A	A	U	A	A	U	A
PERCIDAE	JOD	JOHNNY DARTER	*Etheostoma nigrum*	I	A	I	A	N	N	A	A	A	A	A	A	A
PERCIDAE	ORD	ORANGETHROAT DARTER	*Etheostoma spectabile*	A	A	N	A	A	A	A	A	A	A	A	A	A
PERCIDAE	SGR	SAUGER	*Sander canadense*	I	A	A	A	N	A	A	A	A	A	A	A	A
PERCIDAE	SAG	SAUGEYE (WALLEYE X SAUGER HYBRID)	*Sander vitreum x canadense*	I	A	I	A	I	A	A	I	A	A	A	A	A
PERCIDAE	WAL	WALLEYE	*Sander vitreum vitreum*	I	I	I	I	I	I	I	A	I	I	I	I	A
PERCIDAE	YPE	YELLOW PERCH	*Perca flavescens*	I	I	I	I	I	A	I	A	I	I	I	I	I
POECILIIDAE	MSQ	WESTERN MOSQUITOFISH	*Gambusia affinis*	I	I	I	I	I	A	I	A	I	I	I	I	I
SALMONIDAE	ARC	ARCTIC CHAR	*Salvelinus alpinus*	A	I	I	A	A	A	A	A	A	A	A	A	A
SALMONIDAE	GRA	ARCTIC GRAYLING	*Thymallus arcticus*	I	I	I	A	I	I	I	A	I	I	I	A	I
SALMONIDAE	ATL	ATLANTIC SALMON	*Salmo salar*								A					
SALMONIDAE	BRK	BROOK TROUT	*Salvelinus fontinalis*	I	I	I	I	I	I	I	A	I	I	I	I	I
SALMONIDAE	LOC	BROWN TROUT	*Salmo trutta*	I	I	A	I	I	I	I	I	I	I	I	I	I
SALMONIDAE	CHI	CHINOOK SALMON	*Oncorhynchus tshawytscha*	A	A	I	A	A	A	A	A	A	A	A	A	A
SALMONIDAE	COH	COHO (SILVER) SALMON	*Oncorhynchus kisutch*	A	A	I	A	A	A	A	A	A	A	A	A	A
SALMONIDAE	CRN	COLORADO RIVER CUTTHROAT	*Oncorhynchus clarkii pleuriticus*	I	N	I	I	I	I	N	A	N	N	N	I	N
SALMONIDAE	GOL	GOLDEN TROUT	*Oncorhynchus aguabonita*	A	I	I	A	I	I	I	A	I	I	I	A	I
SALMONIDAE	BAC	GREENBACK CUTTHROAT, BEAR CREEK	*Oncorhynchus clarkii stomias*	I	A	A	A	N	A	A	A	A	A	A	A	A
SALMONIDAE	KOK	KOKANEE (SOCKEYE) SALMON	*Oncorhynchus nerka*	I	I	I	I	I	I	I	A	I	I	I	I	I
SALMONIDAE	MAC	LAKE TROUT (MACKINAW)	*Salvelinus namaycush*	I	I	I	A	I	I	I	A	I	I	I	A	I
SALMONIDAE	LWF	LAKE WHITEFISH	*Coregonus clupeaformis*	A	A	I	A	A	A	A	A	A	A	A	A	A
SALMONIDAE	MWF	MOUNTAIN WHITEFISH	*Prosopium williamsoni*	A	N	I	A	I	A	I	A	N	A	N	A	N
SALMONIDAE	RBT	RAINBOW TROUT	*Oncorhynchus mykiss*	I	I	I	I	I	I	I	I	I	I	I	I	I
SALMONIDAE	RGN	RIO GRANDE CUTTHROAT	*Oncorhynchus clarkii virginalis*	I	A	I	N	A	A	A	A	A	A	A	N	A
SALMONIDAE	SRN	SNAKE RIVER CUTTHROAT	*Oncorhynchus clarkii behnkei*	I	I	I	I	I	I	I	A	I	I	I	I	I
SALMONIDAE	SPL	SPLAKE (BROOK X LAKE HYBRID)	*Salvelinus fontinalis x namaycush*	I	I	I	I	I	I	I	A	I	I	I	I	I
SALMONIDAE	LXB	TIGER TROUT	*Salmo trutta x salvelinus fontinalis*	I	I	I	I	I	A	I	A	I	A	A	I	I
SALMONIDAE	YSN	YELLOWSTONE CUTTHROAT	*Oncorhynchus clarkii bouvieri*	I	I	I	I	I	I	I	A	I	I	I	I	I
SCIAENIDAE	DRM	FRESHWATER DRUM	*Aplodinotus grunniens*	I	A	U	A	U	A	A	A	A	A	A	A	A

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