Scientific Support for the Wisconsin Stream Quantification Tool (Beta Version)

US Army Corps of Engineers®
St. Paul District

WISCONSIN DEPT. OF NATURAL RESOURCES

StreamMechanics

ECOSYSTEM PLANNING & RESTORATION

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United States Environmental Protection Agency, Region 5

United States Army Corps of Engineers, St. Paul District

Wisconsin Department of Natural Resources

Contractors:

Ecosystem Planning and Restoration

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Version

Version	**Date finalized**	**Description**
Beta Version	May 19, 2023	Interim Draft

Acronyms

BEHI – Bank Erosion Hazard Index
BHR – Bank Height Ratio
BMP – Best Management Practice
CFP – Concentrated Flow Point
CFPI – Concentrated Flow Point Index
CFR – Code of Federal Regulations
CN – (Runoff) Curve Numbers
CWA § 404 – Clean Water Act Section 404
d50 – Median Particle Size
DBH – Diameter at Breast Height
DPI – Diatom Phosphorus Index
EPA – United States Environmental Protection Agency
ER – Entrenchment Ratio
FF – Functional Feet
fIBI – Fish Index of Biotic Integrity
HBI – Hilsenhoff Biotic Index
HSG – Hydrologic Soil Group
IBI – Index of Biotic Integrity
LWD – Large Woody Debris
LWDI – Large Woody Debris Index
mIBI – Macroinvertebrate Index of Biotic Integrity
NBS – Near Bank Stress
NLCD – National Land Cover Database
NRCS – Natural Resource Conservation Service
NRSA – EPA National Rivers and Streams Assessment
O/E – Ratio of Observed/Expected
RHA § 10 – Section 10 of the Rivers and Harbors Act
SFPF – Stream Function Pyramid Framework
SQT – Stream Quantification Tool
USACE – United States Army Corps of Engineers
W/D – Width/Depth Ratio
WDNR – Wisconsin Department of Natural Resources
WDRS – Width Depth Ratio State
WISQT – Wisconsin Stream Quantification Tool
WISQT SC – Wisconsin Stream Quantification Tool Steering Committee
WISQT TC – Wisconsin Stream Quantification Tool Technical Committee

Glossary of Terms

Absolute cover – Total vegetative areal cover (by a species, group of species or sum of all species present).

Areal cover – Areal cover is the degree to which above ground portions of plants (not limited to those rooted in a sample plot) cover the ground surface.

Alluvial valley – Valley formed by the deposition of sediment from fluvial processes. See also definitions for confined alluvial valley and unconfined alluvial valley.

Armoring – 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.

Bankfull – Bankfull is a discharge that forms, maintains, and shapes the dimensions of the channel as it exists under the current climatic regime. The bankfull stage or elevation represents the break point between channel formation and floodplain processes (Wolman and Leopold 1957).

Catchment – Land area draining to a common outlet (see also Watershed).

Colluvial valley – Valley formed by the deposition of sediment from hillslope erosion processes. Colluvial valleys are bowl-shaped and typically confined by terraces or hillslopes. Colluvium is material that originates on the hillslopes and moves down slope through mass wasting processes to the valley bottom. These valleys are confined and support straighter, step-pool type channels (e.g., A, B, Bc, F). These valley types typically have a valley width ratio less than 7.0 and a meander width ratio (MWR) ratio less than 3.

Concentrated Flow Point (CFP) – An ephemeral, erosional feature, such as a swale, gully, or other constructed channel or drainage feature that alters or concentrates runoff directly into a stream. Examples include ditches, storm drains, and drain tiles. Additionally, CFPs include channels that have formed where a pipe or other drainage feature discharges to open ground that has subsequently eroded to form a channelized feature. Natural ephemeral channels, spring outlets, outlets from properly functioning best management practices, and natural streams impacted by channelization or other man-made activities are not considered CFPs.

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 33 CFR 332.2).

Condition score – A score from 0.00 to 1.00 that represents the condition or quality of a metric based on the departure from a reference condition. The metric index values are averaged to characterize the condition for each parameter, functional category, and overall project reach.

ECS - Existing Condition Score

PCS - Proposed Condition Score

<u>Confined alluvial valleys</u> – Valley formed by the deposition of sediment from fluvial processes, typically confined by terraces or hillslopes that support transitional stream types between step-pool and meandering, or where meanders often intercept hillslopes (e.g., C, Bc). These valley types typically have a valley width ratio less than 7.0 and a meander width ratio (MWR) between 2 and 4.

<u>Credit</u> – 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 33 CFR 332.2).

<u>Debit</u> – 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 33 CFR 332.2).

<u>Debit Calculator workbook</u> – A Microsoft-Excel workbook used to evaluate change in condition at impact sites.

<u>Effective riparian area</u> – The area adjacent to and contiguous with the stream channel that supports the dynamic equilibrium of the stream. It is typically a corridor associated with a stream reach where, under natural conditions, the valley bottom is influenced by fluvial processes under the current climatic regime; riparian vegetation characteristic of the region and plants known to be adapted to shallow water tables and fluvial disturbance are present; and the valley bottom is flooded at the stage of the 100-year recurrence interval flow (Merritt et al. 2017).

<u>Effective vegetated riparian area</u> – The portion of the effective riparian area that currently supports riparian vegetation and is free from utility-related, urban, or other soil disturbing land uses.

<u>Field value</u> – A field or desktop measurement or calculation from an existing assessment method that is input into the SQT for a specific metric. Units vary based on the assessment method used.

<u>Functional capacity</u> – The degree to which an area of aquatic resource performs a specific function (see 33 CFR 332.2). In the WISQT, index scores for functional capacity are presented in “functioning”, “functioning-at-risk” or “not-functioning” ranges.

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

<u>Functional category</u> – The organizational levels of the stream quantification tool, adopted from the Stream Functions Pyramid Framework (Harman et al., 2012): Hydrology, Hydraulics, Geomorphology, Physicochemical, and Biology. Each category is defined by functional statement(s).

<u>Functional feet (FF)</u> – 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.

<u>Functional lift</u> – The difference in the condition score or functional feet before and after restoration, which results in improved function.

Functional loss – The difference in the condition score or functional feet before and after a permitted impact, which results in a loss of function.

Functional Loss worksheet – This is a worksheet in the Debit Calculator workbook and is used to calculate the functional loss due to proposed impacts.

Function-based Parameter – A measure which characterizes a condition at a point in time, or a process (expressed as a rate) that describes and supports the functional statement for a given functional category (Harman et al., 2012).

Geomorphic pools – Geomorphic pools are associated with large planform features and generally remain intact over time and across a range of flow conditions. In meandering streams, geomorphic pools are located in the meander bend. These pools are also called lateral-scour pools. In step-pool streams, geomorphic pools are found immediately downstream from cascades or steps.

Index values – Dimensionless values between 0.00 and 1.00 that express the functional capacity and the relative condition of a metric field value compared with reference condition. Index values convert the different units used in the assessment methods to one scale. These values are derived from reference curves for each metric.

Impact Severity Tiers – The Functional Loss 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.

Large Woody Debris – Dead wood, standing or fallen, over 3.28 feet (1m) in length and at least 3.94 inches (10 cm) in diameter at the largest end. The wood must be within the bankfull channel or spanning the bankfull channel.

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 (Harman et al., 2012) (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).

Minnesota Stream Quantification Tool (MNSQT) – The MNSQT workbooks, user manual and scientific support documents (MNSQT SC 2020a; MNSQT SC 2020b).

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 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 activities.

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. Reference aquatic resources represent the full range of functional capacity characterized by SQT condition scores.

Reference condition – The relative functional capacity of reference standard resources, characterizing the range of natural variability under undisturbed to least disturbed condition and representing the subset of reference aquatic resources that exhibit the highest level of function. In the SQT, this condition is considered functioning, culturally unaltered, or pristine for the metric being assessed (see Reference standard).

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 in a project reach.

Reference standard – The subset of reference aquatic resources that are least disturbed and exhibit the highest level of function (see Reference condition).

Relative cover – The proportional cover by vegetation type; the total across all types should not exceed 100%.

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 et al. 1994).

Restoration Potential – 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).

Riffle – Riffles are shallow, steep-gradient channel segments typically located between pools. Riffles are the river's natural grade control feature (Knighton 1998) and are sometimes referred to as fast-water channel units (Hawkins et al. 1993, Bisson et al. 2017). For purposes of the SQT, in meandering streams, riffles broadly represent the section between lateral-scour pools known as a crossover, regardless of bed material size. Therefore, the term riffle is also used in the crossover section of a sand bed channel. Riffles are measured from head of riffle to head of pool; thus, runs are considered riffles and glides are considered pools.

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

Significant pool – Significant pools are pools not classified as geomorphic pools. They are often associated with wood, boulders, convergence, and backwater in the main channel. Significant pools must be deeper than the riffle, have a concave shaped bed surface and a width that is at least one-third the width of the channel. The pool may also have a flatter water surface slope than the riffle; however, this is not always the case, e.g., a pool downstream of a log in a steep-gradient channel.

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 (reference 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 rehabilitation, re-establishment, and enhancement.

Stream type – Stream type reflects the Rosgen stream type classification system and the basic fluvial landscapes where they typically occur (Rosgen 1996; NRCS 2007). Four stream types are applied in the WISQT, and each of these stream type characterizations provides information on the project reach to inform the restoration potential determination, project goals and objectives, reach-specific performance standards and/or reference curve selection. The following stream types are used in this document:

Existing Stream Type – The stream type before impact or restoration activity. It is determined using existing condition data.

Design Stream Type – The stream type that will be constructed as part of a project design (i.e., the as-built stream type). It is determined from the design process and other factors as described in the User Manual.

Proposed Stream Type – The stream type that is expected to form (evolve to) by the end of the monitoring period (i.e., the restoration target stream type at project closeout). It is informed by factors described in the User Manual and should be consistent with the estimated conditions identified in the proposed condition assessment.

Reference Stream Type – The stream type that would naturally occur given the valley morphology and absent from anthropogenic influences. The WISQT relies on the reference stream type to stratify reference curves for the entrenchment ratio, pool spacing ratio, and percent riffle metrics.

Stream/wetland complex – A stream channel or channels with adjacent riverine wetlands located within the floodplain or riparian geomorphic setting, where overbank flow from the channel(s) is the primary wetland water source (Brinson et al. 1995). Stream types may be single-thread or anastomosed. Common stream types for stream/wetland complexes include Rosgen E, Cc-, and DA.

Threshold values – Criteria used to develop the reference curves for each metric. These criteria differentiate between three condition categories: functioning, functioning-at-risk, and not-functioning and relate to the Performance Standards as defined previously.

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 or a meander width ratio (MWR) greater than 4.0 (Rosgen 2014).

Watershed – Land area draining to a common outlet (see also Catchment).

Wisconsin Stream Quantification Tool (WISQT) – The WISQT is a spreadsheet-based tool used to evaluate change in condition. The WISQT consists of two workbooks, the WISQT workbook and the Debit Calculator workbook (see WISQT workbook and Debit Calculator workbook).

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

Wisconsin Stream Quantification Tool Technical Committee (WISQT TC) – The group that provided technical direction on the metrics and reference curves included in the WISQT.

WISQT workbook – The Microsoft-Excel workbook file used to evaluate change in condition before and after restoration or impact activities to determine functional lift or loss, respectively. The WISQT workbook can also be used to determine restoration potential, develop monitoring criteria and assist in other aspects of project planning. Also referred to as the SQT workbook.

Chapter 1 Background and Introduction

The purpose of this document is to provide the scientific underpinnings of the Wisconsin Stream Quantification Tool (WISQT) and Debit Calculator and the rationale for the conversion of measured stream condition into dimensionless index scores. The WISQT is an application of the Stream Functions Pyramid Framework (SFPF), outlined in *A Function-Based Framework for Stream Assessment and Restoration Projects* (Harman et al. 2012). Harman et al. (2012) presents the SFPF and provides supporting references and rationale for the organizational framework and its components. This document expands on the concepts presented in the SFPF and the WISQT User Manual (User Manual; WISQT SC 2023). The WISQT is one of several Stream Quantification Tools (SQTs) that have been developed for use in specific states, including North Carolina (Harman and Jones 2017), Tennessee (TDEC 2018), Wyoming (USACE 2018a), Georgia (USACE 2018b), Colorado (USACE 2020a), Minnesota (MNSQT SC 2020a), Michigan (MI EGLE 2020), South Carolina (South Carolina Steering Committee 2021) and Alaska (Alaska Stream Quantification Tool Steering Committee 2021a).

This document is based on the scientific support document from Wyoming (WSTT 2018) and science support documents for other states where similar metrics and/or reference curves are applied (USACE 2020b; Alaska Stream Quantification Tool Steering Committee 2021b; MNSQT SC 2020b). This document has been modified for Wisconsin with input from the Wisconsin Stream Quantification Tool Steering Committee (WISQT SC) and Technical Committee (WISQT TC) to reflect the regionalization of the tool for use in Wisconsin streams. Some chapters in this document are reproduced with little or no modification from the science support documents referenced above.

Information on how to use the WISQT or collect data for use in the WISQT is not included in this document but can be found in the User Manual.

Section 1.1 provides a summary of the SFPF terminology, including function-based parameters and metrics.

Section 1.2 provides background on the WISQT, including key considerations for applying the SQT.

Section 1.3 provides a description of reference curve development and describes how key concepts of reference standard and functional capacity are used in the tool.

Section 1.4 gives an overview of how the WISQT calculates the overall reach condition scores.

Section 1.5 discusses the selection of functional feet as the primary unit for communicating functional lift and loss within the tool, and its use in informing debits and credits.

Section 1.6 provides the general criteria used to select function-based parameters and metrics from the SFPF and new metrics included in the WISQT.

Section 1.7 provides a general summary of the datasets used to develop reference curves and the tool's data gaps and limitations.

Section 1.8 provides information on the process for revising reference curves and metrics.

After Chapter 1, the remainder of the document is organized by function-based parameter. Each parameter description includes a summary of why it was included, reasons for selecting the metrics, and in some cases, why other metrics were not selected. Then, a description of metrics used to quantify the parameter is provided. Each metric section provides the rationale for developing reference curves and any stratifications, followed by data gaps and limitations.

1.1. Background on the Stream Functions Pyramid Framework (SFPF)

In 2006, the Ecosystem Management and Restoration Research Program of the United States Army Corps of Engineers (USACE) noted that specific functions for stream and riparian corridors had yet to be defined in a manner that was generally agreed upon and could be used as a basis for management and policy decisions (Fischenich 2006). To address this need, an international committee of scientists, engineers, and practitioners defined 15 key stream and riparian zone functions aggregated into five categories: system dynamics, hydrologic balance, sediment processes and character, biological support, and chemical processes and pathways (see Table 1 in Fischenich 2006). The committee noted that restoration of hydrodynamic processes, sediment transport processes, stream stability, and riparian buffers could lead to improvements in dependent functions that typically require time to establish, such as diverse biological communities, nutrient processes, diverse habitats, and improved water and soil quality. The SFPF builds on the work completed by Fischenich (2006) by organizing stream functions into a hierarchical structure to create a conceptual model for restoration practitioners to use in communication and the development of function-based assessments.

The SFPF organizes stream and riparian functions into five functional categories: hydrology, hydraulics, geomorphology, physicochemical, and biology (Figure 1-1). This organization recognizes that foundational functions, like watershed hydrology and sediment transport processes, generally support higher-level functions like aquatic animal life histories, and that all functions are influenced by local geology and climate. Cause and effect can flow from top to bottom as well, e.g., beavers (biology) can affect hydrology, and riparian communities can influence hydraulics and geomorphology through wood inputs, rooting depths, and floodplain roughness. However, the primary thought process for this framework is this: what supporting processes are needed to restore a particular function? With this perspective, the beaver example would change to: what functions are needed to support a healthy beaver population?

Within each of the five functional categories, the SFPF outlines parameters and methods to quantify the degree to which a stream ecosystem is functioning (Figure 1-2). In this framework, function-based parameters describe and support the functional statements of each functional category, and the measurement methods (metrics) are specific tools, equations, measured values, and/or assessment methods that are used to quantify the function-based parameter. The SFPF presents two types of function-based parameters and metrics: structural indicators, which describe a condition at a point in time, and functions expressed as a rate that tie directly to a stream process (e.g., bank erosion rates). Each metric is compared against reference curves that represent departure from, or achievement of, reference standard. The selection of function-based parameters used in the WISQT and their relationship to reference standards are discussed in more detail in the following sections.

Figure 1-1: Stream Functions Pyramid (Image from Harman et al. 2012).

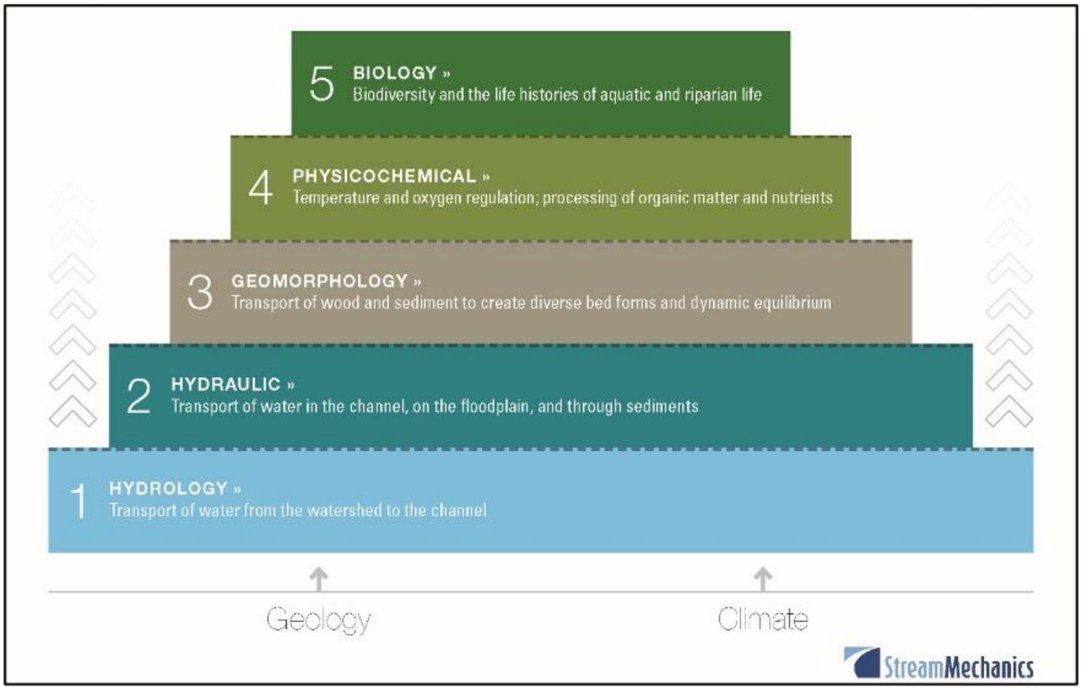
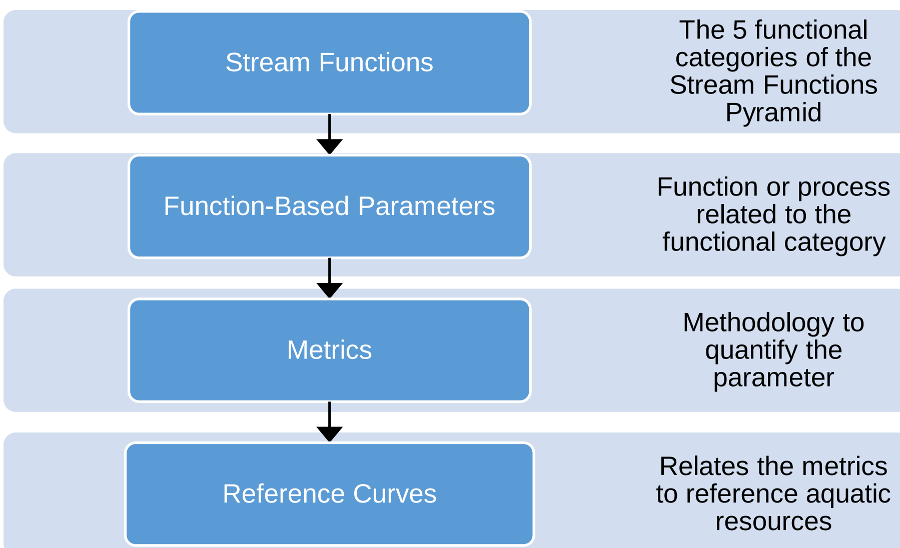


Figure 1-2: Stream Functions Pyramid Framework (Note: terms have been modified from Harmon et al. 2012 to reflect WISQT application).



1.2. BACKGROUND ON THE WISQT

The SFPF has informed the development of SQTs, which are tools that consolidate components of the SFPF into an Excel workbook to quantify stream ecosystem functions at a specific project reach. SQTs have been primarily developed for use in the Clean Water Act Section 404 regulatory program (CWA § 404) to support the function-based approaches set forth in the 2008 Compensatory Mitigation Rule (33 CFR 332.3). In 2021, the National Committee on Stream Assessment outlined the need for function-based assessment tools to characterize stream condition/function, improve understanding of the impacts of proposed actions on aquatic resources and/or inform the development of function/condition-based compensatory mitigation tools (David et al. 2021). David et al. (2021) identifies important attributes of stream assessment methods, including having objective, measurable, and repeatable methods that are scalable, responsive to regionally relevant projects at regulatory timescales, and able to appropriately assess the condition of the range of stream resources within the region. These factors are also important considerations in the SQT regionalization process.

The WISQT includes a sub-set of function-based parameters and metrics listed in Harman et al. (2012), along with new parameters and metrics identified as part of the WISQT development and regionalization process which are relevant to the stream systems and projects occurring within the state of Wisconsin. All the metrics selected for the WISQT are structural or compositional attributes that indicate condition at a given point-in-time. Metrics serve as surrogates for stream functions (33 CFR 332.2) and relate to the function-based parameters selected for a given functional category (see Chapter 16 for the full list of metrics and associated data sources). For example, bed form diversity is a partial surrogate for sediment transport processes, which is a geomorphology function. Bed form diversity is NOT a surrogate for macroinvertebrate functions because macroinvertebrates are in a different functional category (biology).

Assessment data are input into the SQT, where field values for each metric are translated into index values via a set of reference curves, thus converting a variety of units into a standardized unitless score. Reference curves have been derived for each metric and relate site-specific data to degrees of departure from regional reference condition; reference curves are stratified, as needed, to appropriately assess condition across a range of regional stream resources. Index values range from 0.00 to 1.00 and relate to the functional capacity descriptions described in Section 1.3 below.

Though the WISQT and this scientific support document have been developed for use in the CWA § 404 and RHA § 10 regulatory programs, the WISQT can also be applied to restoration projects outside of the regulatory context. There are numerous applications for the WISQT beyond CWA § 404 and RHA § 10, including as a stream assessment tool in water quality monitoring programs, for grant projects (e.g., NPS) to evaluate project goals and successes, and for other stream restoration projects aimed at improving stream function to support physical and biological functions, particularly within coastal watersheds of the Great Lakes Basin. The WISQT specifically addresses Focus Area 4 of the Great Lakes Restoration Initiative (GLRI) to "[p]rotect and restore communities of native aquatic and terrestrial species important to the Great Lakes", including identifying opportunities for restoring habitat connectivity, and to implement sound "on the ground habitat restoration and protection." Additionally, the WDNR Office of Great Waters may benefit from quantifying functional lift as a part of their habitat and aquatic connectivity priorities. Ideally, the SQT will be useful to many Wisconsin state and local agencies, with broader utility extending to the US Forest Service, non-profit organizations like Trout Unlimited, tribes, and other entities, including those in other Great Lakes states.

KEY CONSIDERATIONS

The following concepts are critical in understanding the applicability and limitations of this tool:

- The parameters and metrics in the tool were selected due to their sensitivity in responding to reach-scale changes associated with the types of activities commonly encountered in the CWA § 404 or RHA § 10 programs and commonly used in stream restoration. These parameters do not comprehensively characterize all structural measures or processes that occur within a stream.

- The WISQT is designed to assess the same parameters 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 WISQT as a change, or delta, tool for this reason – it is intended to detect change at a site over time. Unless the same parameters and metrics are used across all sites, it would be inappropriate to compare scores.
- The WISQT 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 restoration potential (see User Manual).
- The WISQT is not a design tool. 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 WISQT measures the physical, chemical, and biological responses or outcomes related to a project design at a reach scale.
- Not all parameters and metrics in the tool will be applicable to stream/wetland complexes, especially those with multiple channels. Practitioners working in these resource types should consult with agencies to determine the most applicable parameters to be used (see User Manual).

1.3. Development of Reference Curves

The WISQT calculates the change in condition at a project site following an impact or restoration activity and allows the user to draw reach-scale conclusions on changes in functional capacity pre- and post-project. These changes in functional capacity are referred to in the WISQT as functional loss and lift and can be used to inform debits and credits as defined in the 2008 Mitigation Rule (33 CFR 332.3). Functional lift or loss is the difference in condition or functional feet within a project reach before and after restoration or a permitted impact.

Reference curves are used in the WISQT to convert metric field values into a dimensionless index score. This process converts point-in-time condition measurements to functional capacity and standardizes all metrics to an ecologically relevant scale. For example, metric assessments vary widely in their output units (e.g., feet, meters, dimensionless, and more), and all are converted into a common index scale. Reference curves are developed to assign index values that reflect a range of condition and relate field values for each metric to functional capacity, i.e., functioning, functioning-at-risk, and not-functioning condition (Table 1-1). Describing the functional characteristics, attributes, and condition of ecosystems is a traditional approach to describing functional capacity (Proper Functioning Condition per Prichard et al. 2003).

Reference curves were developed by first partitioning the index value range (0.00-1.00) into three categories (Table 1-1) which characterize the degree to which the measured condition differs from a reference condition (Hawkins et al. 2010). Other assessment methods have taken similar approaches to scale, or score, functional capacity to reference systems (e.g., Johnson et al. 2013, Nadeau et al. 2018). Thresholds were defined for each metric to demarcate the index values for not-functioning/functioning-at-risk (0.30) and functioning-at-risk/functioning (0.70) categories. These thresholds and their corresponding field values for each metric were determined by evaluating existing datasets, literature sources, or relying on thresholds developed in other assessments or studies. For purposes of mitigation, these threshold values can also provide a quantitative, objective approach to monitoring and can be used to inform performance standards.

To account for natural variability among stream systems, reference curves for specific metrics may be stratified by differences in stream type, valley type, temperature class, reference community type, or similar. Stratification varies by metric and is described in the individual metric sections of this document.

Calculating Change in Condition

It is important to remember that this tool is intended to compare pre- and post-project conditions at a site. As such, the difference between existing and future site conditions is the most important element.

Reference curves are used in the SQT to convert point-in-time condition measurements (called field values) to functional capacity and standardize all metrics to an ecologically relevant scale (index values).

SQT regionalization, including metric selection and reference curve development, relies on the expertise of the WISQT Steering Committee (WISQT SC) and Technical Committee (WISQT TC) members. David et al. (2021) notes the benefits of developing multidisciplinary teams which include members with expertise in relevant stream processes, as well as those with regulatory expertise and applied permitting and restoration experience. The WISQT TC is generally organized around functional category and includes members with expertise in these areas who can provide their knowledge and experience on stream processes, methodologies, regional datasets, regional stream resources and application within Wisconsin. In the regionalization process, the WISQT TC considers the potential metrics available to inform functional parameters, relevant datasets, and the need for stratification; they also propose threshold values and reference curves for each metric. These recommendations are then reviewed and approved by the WISQT SC.

To develop reference curves, field values are identified for each metric that serve as thresholds between the categories of functional capacity outlined in Table 1-1. Three approaches were taken to identify these threshold values:

1. Where possible, thresholds are derived from field values already identified in the state of Wisconsin's technical publications and/or peer-reviewed literature (e.g., based on water quality standards or existing indices).
2. Where published values were not available, threshold values are developed using data from national and regional resource surveys and other available datasets. In evaluating reference datasets, the WISQT SC and TC considered the degree of departure from reference condition to identify threshold values. For example, the interquartile range of reference standard sites within a dataset may be used to identify the 0.70 and 1.00 field values for developing a reference curve. This is similar to other approaches that identify benchmarks or index values (e.g., BLM 2017; Nadeau et al. 2018). When using existing datasets, the WISQT SC and TC rely on the definitions of reference standard and condition provided by the authors.

3. Where existing data or literature are limited, the expertise of members of the WISQT SC and TC is relied on to identify threshold values. In some instances, the decision may be made to not identify thresholds between all categories and instead extrapolate index values from a best fit line from available data or literature values.

Following the identification of threshold values, linear relationships are fit to the threshold values. These continuous curves allow index scores to account for incremental changes in field values, which is important for determining a change in the pre- and post-project condition. If a non-linear fit is used, the rationale for selecting an alternative fit is provided in the specific metric section below. Reference curves and threshold values are determined for each metric individually. Therefore, a reach may achieve a functioning index value for one metric, e.g., large woody debris index (LWDI), and not others. Metric index values are then combined to provide a reach score (Section 1.4).

Table 1-1: Functional capacity definitions used to define threshold values and develop reference curves for the WISQT.

Functional Capacity	Definition	Index Score Range
Functioning	A functioning value 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. The reference standard concept aligns with the definition of reference condition for biological integrity (Stoddard et al. 2006). A score of 1.00 represents an un-altered or pristine condition (native or natural condition). A range of index values (0.70-1.00) accounts for the natural variability from undisturbed to least disturbed condition.	0.70 to 1.00
Functioning-at-risk	A functioning-at-risk value means that the metric is quantifying or describing one aspect of a function-based parameter in a way that may support aquatic ecosystem structure and function but does not reflect reference condition. Often, this indicates an adjustment or response to changes in the reach or the catchment towards lower or higher function. This range represents an intermediate area, where a resource is neither achieving reference condition nor is significantly degraded or impaired.	0.30 to 0.69
Not-functioning	A not-functioning value 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. An index value less than 0.30 represents an impaired or severely altered condition relative to reference standard, and an index value of 0.00 represents a condition that provides no functional capacity for that metric.	0.00 to 0.29

1.4. CALCULATING REACH-SCALE CONDITION

The architecture and scoring of SQTs are simple, to allow for flexibility in selecting function-based parameters and metrics, and to allow for additions or exchanges of parameters with future advances in stream science. This approach differs from assessment approaches that rely on rigorous statistical analyses for metric selection, calibration, and scoring (Stoddard et al. 2008). There are obvious limitations to this simpler approach. However, a benefit is the flexible architecture: metrics and parameters can be added to or subtracted from the tool based on new scientific understandings or site-specific considerations without requiring substantial reanalysis of the weighting in the tool. For example, for a specific site or analysis, the same weighting and metrics would be used for each monitoring event to preserve the rigor of the comparison, but additional metrics could be applied at another site based on a different set of site objectives. Because the focus of the tool is on the difference between before and after conditions, flexibility was prioritized over a rigorous approach to weighting (given that scoring will be handled the same for before and after conditions).

Index values are generated for each metric and then combined to provide parameter and functional category scores, as described below:

- Metric index values are averaged to calculate a parameter score. Only the metrics assessed at a given project reach are used to calculate these scores (refer to the User Manual for guidance on parameter and metric selection).
- Parameter scores are averaged to calculate a functional category score.
- Functional category scores are weighted and then summed to calculate a reach condition score.

The functional category weighting is fixed, regardless of the number of metrics, parameters or functional categories assessed; each functional category (e.g., hydrology) provides 20% of the functional feet value. The maximum condition and functional feet value that can be achieved is affected by the number of functional categories assessed. For example, only 60% of the potential functional feet value will be realized at a site if only reach hydrology, hydraulics, and geomorphology parameters are assessed and monitored. Meanwhile, monitoring one or more metrics in all five functional categories would result in achieving 100% of the potential functional feet value. The weighting incentivizes restoration practitioners to attempt to improve and monitor physicochemical and biology parameters even if they may not reach full restoration potential.

Because parameter and metric selection can vary based on site-specific considerations, the proportional weighting of each metric will vary from site to site as the number of metrics or parameters measured varies (Table 1-2). If only the basic suite of metrics identified in Section 2.3 of the User Manual are evaluated, each of those metrics will contribute more to each functional category score when compared with application of all metrics or parameters within a functional category. For example: if a user evaluates lateral migration, large woody debris, bed form diversity, and riparian vegetation in the geomorphology category, each parameter will contribute 5% to the overall potential score; whereas, if bed material is also evaluated, each parameter would contribute 4% to the overall potential score.

Table 1-2: Implicit parameter and metric weighting that results from averaging for perennial streams.

Functional Category	Category Weight	Function-based parameters (no.)	Parameter weight*	Metrics (no.)	Metric weight*
Hydrology	20%	2	10-20%	3	6.7-10%
Hydraulics	20%	2	10%	3	6.7%
Geomorphology	20%	5	4-5%	15	1.6-2.2%
Physicochemical	20%	3	6.7-20%	4	6.7-20%
Biology	20%	2	10-20%	3	6.7-20%

**Calculated based on the parameters and metrics that would be applied in combination per parameter selection. Note: higher percentage is if only basic suite of parameter/metrics are applied.*

INTERPRETING THE CONDITION SCORE

When all five functional categories are assessed, the overall condition score can be interpreted as a percent of pristine condition for the parameters assessed. For example, if the overall condition score is 0.60, the reach is considered functioning at 60% of pristine for the parameters that were assessed. There could still be unknowns in condition if optional parameters are not assessed. If less than five categories are assessed, these same conclusions cannot be drawn about the overall condition score.

The overall condition score reflects the stream type, flow regime, and landscape setting that is characterized in the input and stratification table. For example, an overall condition score could represent a perennial, third order (Strahler 1957) stream, or it could represent an ephemeral, first order headwater stream. To improve communication about the overall score, the number of categories assessed, flow regime and channel size indicators are included in the functional change summary table. Flow regime is denoted by a P, I, or E to represent perennial, intermittent, or ephemeral, and the Strahler stream order method is used to denote stream size. A 1, 2, 3 etc. is added to the change in Functional Feet Score (∆FFS) to show the stream order. Using the example above, the perennial, third order stream will have P3 next to the ∆FFS. The first order ephemeral channel will have E1 next to the ∆FFS.

1.5. CALCULATING FUNCTIONAL FEET

In the CWA § 404 regulatory program, determinations need to be made as to whether a compensatory mitigation project offsets the impacts associated with a permitted activity. These determinations are made through the calculation of credits (compensatory mitigation) and debits (impacts), and rely on a common currency, or unit of measure, to consistently compare across projects. Harman et al. (2021) define a unit of measure as "*feet, area, or other physical dimension used alone, or applied to assessment output scores to provide a common unit for comparison with other projects (debit and credit calculations)*." Many programs continue to rely on stream length or area measurements alone as the unit of measure (ELI et al. 2016, Harman et al. 2021). Other units of measure include valley length and valley area. These physical dimensions are applied either alone or in combination with output scores from function or condition-based stream or stream/floodplain assessments (Harman et al. 2021).

For the WISQT, stream length was selected as the physical dimension to include in the unit of measure. Stream length communicates the scale of a project. For example, a small project such as a culvert removal, may yield a substantial difference between the proposed and existing condition score but the reach is very short, and thus would generate a smaller amount of credit. A very long project with moderate condition improvement would generate more credit because of its scale. The use of stream length follows that of other USACE Districts with established compensatory stream mitigation programs, which rely on stream length in combination with other factors to create a debit or credit. Stream length can be effectively applied in single-thread stream systems, although it is more limited in multi-thread stream types where other approaches may be better suited (Harman et al. 2021).

Other alternatives to the stream length-based approach have been considered for use in SQTs, including stream and valley area-based units of measure and valley length. Area-based measures (e.g., PADEP 2014) may better account for the size differences between small and large streams, including a greater amount of aquatic habitat in a larger stream. However, channel area does not perform consistently across different stream types (Harman et al. 2021). Valley length or area approaches have merit, as they characterize the stream and floodplain corridor in a more holistic way. However, a major challenge with this approach is in accounting for the net loss or gain in stream length, an important consideration in the regulatory program. Similarly, this approach can be challenging if the active valley width is difficult to define, for example, in wide alluvial valleys (Harman et al. 2021). The USACE currently accounts for permitted impacts in linear feet or aquatic resource area (e.g., Nationwide Permit impact thresholds, data entry into OMBIL Regulatory Module [ORM] database) and only regulates activities within aquatic resource boundaries (e.g., within a delineated wetland or the ordinary high-water mark of streams); it is unclear how a valley-based approach would align with current impact accounting practices.

In the WISQT, stream length is multiplied by a condition score to generate a functional feet score (FFS). The difference between proposed and existing functional feet scores, referred to as the change in functional feet (∆FF), is the amount of functional lift or loss within a project reach and is the unit of measure that serves as the basis for calculating debits and credits. Because it incorporates both length and quantitative measures of stream condition that characterize the stream and floodplain/riparian corridor, ∆FF better integrates changes in condition into crediting and debiting approaches. Combining ecological assessment with length or areal measure (e.g., stream or valley length/area) provides more scientific credibility in the calculation of debits and credits than a length or areal measure alone (Harman et al. 2021). Thus, the functional feet unit serves as the bridge between the condition assessment and application within a debit/credit policy framework for program implementation because it provides an integrated unit of measure that can be compared across sites better than condition scores or length/areal measures alone. This product of quality and length is a common currency for debit and credit calculations (ELI et al. 2016).

Currently, the functional feet approach is used to generate debits and credits in all existing SQTs, though other units of measure (e.g., area) could be incorporated into the SQT instead of length. Future versions of the WISQT may accommodate alternate or modified approaches, as discussed above, but more consideration on how these approaches could be implemented on the debit and credit side is needed before this selection is made.

1.6. Function-Based Parameters in the WISQT

The WISQT considers a suite of functional indicators that are sensitive to anthropogenic modification of reach-scale processes, i.e., the types of activities (both impact and mitigation projects) that are common in the CWA § 404 dredge and fill permitting program. The tool also considers related ecosystem functions that could similarly be affected by these activities, including changes to water quantity, water quality, and biological communities. The WISQT incorporates many of the functions and parameters outlined in Fischenich (2006) and Harman et al. (2012). The User Manual identifies a basic set of parameters and metrics included that should be evaluated for all projects. Recognizing that not all compensatory mitigation projects will have the same objectives or components, the WISQT allows for flexibility in selecting additional parameters and metrics for specific projects. ELI et al. (2016) noted that regulatory protocols should allow for function-based goals and objectives that are project specific, clearly stated, and feasible so that reference standards and monitoring can be targeted for that specific project. Parameters included in the WISQT could assist in setting performance standards for projects with goals to restore habitat, restore targeted fish communities, improve water quality, or implement other project-specific objectives.

The complete set of function-based parameters and metrics used in the WISQT is presented in table format in Chapter 16. The rationale for including parameters and metrics is briefly summarized in Table 1-3 and detailed throughout this document. This table also provides rationale for excluding parameters and metrics that were included in the original SFPF (Harman et al. 2012). The overarching criteria used to select parameters and metrics included the following:

- Ability to link the parameters to the functional statement in the SFPF and ability to link the metrics to restoration or impact activities: The metric that informs the functional capacity of the parameter should be responsive to restoration and impact activities.
- Parameters and metrics should be reach-based: Changes in metrics should occur at a reach scale where restoration and impact activities occur. Note: stressors and perturbations that occur at a catchment scale may affect both existing and proposed condition scores and are considered in the catchment assessment and determination of restoration potential (see User Manual for details).
- Preference is given to parameters and metrics that can be measured in the field over modeling approaches that cannot be field verified through monitoring.
- Ability to develop reference curves representative of Wisconsin conditions for each metric: Information needs to be available to characterize the reference aquatic resources and relate this range of conditions to a reference standard.
- Flexibility in the level of effort for data collection and analysis: the level of analysis and documentation for evaluating applications under CWA § 404 should be commensurate with the scale and scope of a project (see USACE Regulatory Guidance Letter 93-02).
- Applicable and meaningful in Wisconsin: Wisconsin includes a range of ecoregions influenced by a long and varied glacial history. The state contains 24 major river basins that drain to the Gulf of Mexico, Lake Superior, or Lake Michigan (Figure 1-3). Each

basin contains unique geology, land use, vegetation, and climate that influence stream characteristics.

Table 1-3: Summary of parameters considered for the WISQT.

Functional Category	Parameter	Included (Yes/No)	Rationale
Hydrology	Catchment Hydrology	Yes	See Chapter 2.
	Channel Forming Discharge	No	Metrics are better suited for the design phase of a project rather than to show functional lift and loss. Hard to develop reference curves given the significant lag time for many of these parameters. Primary use in design is to size the channel; the effects of channel size shows up in other parameters, like Floodplain Connectivity.
	Precipitation/ Runoff Relationship		
	Flood Frequency		
	Flow Duration		
	Reach Runoff **	Yes	See Chapter 2.
Hydraulics	Flow Dynamics	Yes	See Chapter 4.
	Groundwater/ Surface Water Exchange	No	Difficult to assess and develop reference curves. Better suited for research projects.
	Floodplain Connectivity	Yes	See Chapter 3.
Geomorphology	Channel Evolution	No	Considered when determining restoration potential and selecting stream types.
	Sediment Transport Competency and Capacity*	No	Not recommended by function-based framework for showing functional lift/loss. Recommended as part of the design process.
	Large Woody Debris (LWD)	Yes	See Chapter 5.
	Lateral Migration	Yes	See Chapter 6.
	Bed Material Characterization	Yes	See Chapter 9.
	Bed Form Diversity	Yes	See Chapter 8.
	Planform	No	Sinuosity is already captured in scoring with the use of functional feet (i.e., increasing or decreasing stream length results in a relative increase or decrease in functional feet). Plan form improvements are also captured in pool spacing between geomorphic pools in meandering systems. Note: Use of sinuosity as a metric was problematic in earlier SQTs due to measurement variability on a reach-scale, particularly when determining valley length in confined reaches or with design changes to the floodplain.
	Riparian Vegetation	Yes	See Chapter 7.

Functional Category	Parameter	Included (Yes/No)	Rationale
Physicochemical	Organic Carbon	No	Difficult to assess and develop reference curves.
	Water Quality (Dissolved Oxygen, pH and Conductivity)	No	Dissolved Oxygen is related to temperature and was not prioritized for inclusion in this SQT. Conductivity and pH are good indicators of overall stream health, but they are typically not affected by reach-scale stream restoration activities. Thus, these metrics were not prioritized for inclusion in the WISQT.
	Water Quality (Temperature and Organic Pollution)	Yes	See Chapters 10 and 12.
	Nutrients	Yes	See Chapter 11.
	Macrophyte Communities	No	Uncommon in stream mitigation monitoring.
	Microbial Communities	No	Uncommon in stream mitigation monitoring.
Biology	Landscape Connectivity	No	Requires assessments beyond the project reach; scale of connectivity is typically species specific.
	Macroinvertebrate Communities	Yes	See Chapter 13.
	Fish Communities	Yes	See Chapter 14.
** The function-based framework refers to Harman et al. (2012) which provides more information about these parameters and why they are recommended for the design phase and not for characterizing lift or loss. ** These parameters were not included in Harman et al. (2012) but were added later to this or other SQT's.*			

Figure 1-3: Major river basins in Wisconsin[1].

1.7. DATA SOURCES, DATA GAPS, AND LIMITATIONS

DATA SOURCES:

As described in Section 1.3, due to the lack of Wisconsin data at the time of development, the reference curves included in the WISQT sometimes relied on data from national and regional resource surveys and other available datasets, particularly for hydraulic and geomorphology metrics. As additional hydraulic and geomorphic data are made available from Wisconsin streams, the reference curves can be further evaluated and updated as needed (Section 1.8).

Potential data sources were evaluated using the five assessment factors outlined by the Science Policy Council in A Summary of General Assessment Factors for Evaluating the Quality of Scientific and Technical Information, including applicability and utility; evaluation and review; soundness; clarity and completeness; and uncertainty and variability (EPA 2003). Datasets that are either compiled into one dataset from smaller datasets or are used to inform more than one metric are introduced below. Datasets used to inform singular metrics are introduced in the corresponding chapter. The list of metrics in Chapter 16 summarizes the data used to develop each metric.

[1] https://dnr.wisconsin.gov/topic/Watersheds/basins

Reference Datasets:

- Jennings and Zink (2017; TN): This dataset, referred to as “Jennings & Zink (TN)” throughout this document, represents the best-available reference sites from across Tennessee and was used as an aid in developing reference curves for metrics that describe floodplain connectivity (ER) and bed form diversity (pool spacing ratio and pool depth ratio). Jennings & Zink (TN) is a data collection effort contracted by Tennessee Department of Environment and Conservation (TDEC) for developing regional curves and collecting hydraulic and geomorphic data to plan and evaluate design ranges for channel morphology in stream restoration projects. Cross-section data were collected statewide from 114 reference sites in the following Omernik level III ecoregions: Blue Ridge (ecoregion 66); Ridge and Valley (ecoregion 67); Southwestern Appalachians and Central Appalachians (ecoregions 68/69); Interior Plateau (ecoregion 71); and the Southeastern plains and Mississippi Valley Loess Plains (ecoregions 65/74). In addition, large woody debris was collected from 92 references sites and bedform data were collected at 31 sites across the same ecoregions. BHR was used as a quality assurance measure: 8 of the 114 reference sites were deeply incised (BHR > 1.5) and were removed from the dataset because they were not considered to represent reference condition. Additionally, four Rosgen F streams were removed from the analysis for entrenchment ratio because these stream types are naturally entrenched. Only two of the four F stream types in this dataset actually had channel pattern morphology data (one cobble bed and one sand bed). However, these data were not included in the analyses due to the small sample size.

- Lowther (2008; NC): This dataset, referred to as “Lowther (NC)” within this document, represents reference standard sites and was used to develop reference curves for metrics that describe bed form diversity: pool depth ratio and pool spacing ratio. As part of an NC State University master’s thesis, hydraulic and geomorphic data were collected from the Piedmont ecoregion of North Carolina at 19 geomorphic reference standard sites. BHR was used as a quality assurance measure to ensure reference quality. All sites were considered reference quality due to BHRs near 1.0 (Lowther 2008). One site was removed from analysis due to its unique character as an E5b stream type and small sample size. The dataset consisted of 16 C and E and two Bc stream types.

- Zink et al. (2012; NC & TN): This dataset, referred to as “Zink et al. (NC & TN)” throughout this document, represents reference standard sites and was used to develop reference curves for metrics that describe bed form diversity: pool spacing ratio and percent riffle. Geomorphic data were collected from 14 alluvial streams in the mountains of North Carolina and Tennessee from watersheds without urbanization or impacts from logging (Joyce Kilmer/Slickrock Wilderness of NC and TN). These data are thus considered reference standard. Slopes ranged between 1.4% and 10.4% and characterize and A and B stream types.

- Harman & Clinton (NC & WV): This dataset, referred to as “Harman & Clinton (NC & WV)” throughout this document, represents reference condition and was used to develop reference curves for metrics that describe bed form diversity: pool spacing ratio and percent riffle. The dataset is a composite dataset of six sites, where the NC data are compiled from an NC State University master’s thesis and the West Virginia dataset in an unpublished dataset collected by Harman.

- Michigan Department of Environment, Great Lakes, and Energy (MI EGLE): This dataset, referred to as "MI EGLE" within this document, represents reference condition and was used to develop reference curves for metrics that describe bed form diversity: pool spacing ratio, pool depth ratio, and percent riffle. Geomorphic data were collected from 16 reference sites in Michigan. One site was removed due to a very large drainage area. Of the 15 sites, four were Bc stream type and 11 were C and E stream types.
- WDNR Reference Dataset: This dataset, referred to as the "WDNR Reference Dataset" includes hundreds of streams, selected by WDNR water quality biologists as representative of the least disturbed stream sites equitably distributed across WDNR management regions. These streams represent "the best of what's left" and therefore are not necessarily pristine or culturally unaltered but were deemed appropriate for use when developing reference curves. This data set was used to inform reference curves for the Hilsenhoff Biotic Index and the Diatom Phosphorus Index.

DATA GAPS AND LIMITATIONS:

There is a large diversity of stream types in Wisconsin due to differences in landform, climate, and geology, which in turn influences the hydrogeomorphic context of streams. The WISQT SC and TC aimed to develop a tool that is broadly applicable across different hydrologic and geomorphic regimes through the stratification process and simple scoring but recognize that there will always be gaps with this approach.

Some metrics and their reference curves are not stratified and are applicable for the entire state. Others are stratified by reference stream type, valley type or thermal class with reference curves for each (see Chapter 16). In some instances, data were not available for all regions or stream types, and thus application of certain metrics may be limited. Specific data gaps and limits to applicability are addressed within each metric description. Future versions of the tool will benefit from additional data collection and analysis.

Rigorously accounting for regional variability among sites requires large datasets and statistically derived conclusions. These types of datasets were not always available for metrics included in this tool. It will be possible to revise certain reference curves as more data become available (see Section 1.8). It is important to remember, however, that this tool is intended to compare pre- and post-project conditions at a site. As such, the difference between existing and future site conditions is the most important element.

A lack of available datasets from Wisconsin led the WISQT TC to use datasets from other regions to develop reference curves for some metrics (e.g., the Large Woody Debris Index). The use of national datasets or data from other regions may be appropriate, particularly where there is comparable climate, ecoregional, or other characteristics. For example, Hey (2006) shows that geomorphic reference data from other regions is applicable if the slope, bed material, and bank roughness are comparable. National datasets or data from other regions were considered by the WISQT TC as reference curves were developed and were used where deemed appropriate and necessary. As data in Wisconsin using the methods outlined in the WISQT become available, reviewing reference curves and consideration of additional stratification is encouraged.

In general, not all metrics are applicable to, or have been tested in, ephemeral and intermittent streams or stream/wetland complexes (Table 1-4). Reference curves to assign index values have been primarily derived from data within perennial, wadeable, single-thread stream systems. While a parameter and associated metrics may be applicable to ephemeral and/or anastomosed channels, unique reference curves were not developed specifically for these systems. Where reference expectations for a particular metric may vary based on stream type or flow permanence, more focus should be placed on the difference in pre- and post-project scores rather than the absolute value. Further, modifications to sampling methods may be needed to accommodate data collection in stream/wetland complexes or non-wadable streams.

Table 1-4: Applicability of WISQT metrics across flow type and in stream/wetland complexes.

<table>
<tr><th>Applicable Parameters</th><th>Perennial</th><th>Intermittent</th><th>Ephemeral</th><th>Stream/ Wetland Complexes (Anastomosed, DA)</th><th>Stream/ Wetland Complexes (Single thread, E/Cc-)</th></tr>
<tr><td>Catchment Hydrology</td><td>x</td><td>x</td><td>x</td><td>x</td><td>x</td></tr>
<tr><td>Reach Runoff</td><td>x</td><td>x</td><td>x</td><td>x</td><td>x</td></tr>
<tr><td>Floodplain Connectivity</td><td>x</td><td>x</td><td></td><td>x[1]</td><td>x</td></tr>
<tr><td>Bankfull Dynamics</td><td>x</td><td>x</td><td></td><td></td><td>x</td></tr>
<tr><td>Large Woody Debris</td><td>x</td><td>x</td><td>x</td><td>x</td><td>x</td></tr>
<tr><td>Lateral Migration</td><td>x</td><td>x</td><td>x</td><td></td><td>x</td></tr>
<tr><td>Bed Material Characterization</td><td>x</td><td>x</td><td>x</td><td>x</td><td>x</td></tr>
<tr><td>Bed Form Diversity</td><td>x</td><td>x</td><td></td><td></td><td>x</td></tr>
<tr><td>Riparian Vegetation</td><td>x</td><td>x</td><td>x</td><td>x</td><td>x</td></tr>
<tr><td>Temperature</td><td>x</td><td rowspan="4">Where baseflows extend through sampling period</td><td></td><td>x</td><td>x</td></tr>
<tr><td>Nutrients</td><td>x</td><td></td><td>x</td><td>x</td></tr>
<tr><td>Organics</td><td>x</td><td></td><td>x</td><td>x</td></tr>
<tr><td>Macroinvertebrates</td><td>x</td><td></td><td>x</td><td>x</td></tr>
<tr><td>Fish</td><td>x</td><td></td><td></td><td>x</td><td>x</td></tr>
<tr><td colspan="6">[1] Entrenchment Ratio not applicable for stream/wetland complexes with DA stream types.</td></tr>
</table>

In beaver-influenced systems, application of the SQT should be evaluated on a case-specific basis. There are several potential geomorphic responses to beaver activity. The first is where a beaver dam slows the flow of water in the channel but does not impound water to such a degree that it inundates the adjacent floodplain. In this case, the SQT can be applied, and users will need to wade the impounded reach and evaluate bedforms as usual, even though the bedforms are flooded. The second scenario is where a beaver dam spans the full width of the floodplain, including the channel, creating a pond or series of ponds. In this case, the SQT is not easily applicable, and a wetland or lentic assessment may be more appropriate. A third scenario may be where a beaver dam is located on the floodplain or side channel, but not in the main channel (e.g., oxbows, sloughs, or small tributaries within the project area). In this case, the SQT can be used, but a wetland assessment or lentic assessment may be more appropriate in areas of beaver activity on the floodplain.

Several metrics rely on bankfull depth or width to account for differences in stream size. Inaccuracies and/or inconsistencies in determining bankfull dimensions for a site will affect the way these metrics are characterized in the tool. Therefore, guidance on bankfull identification and verification is provided in the User Manual. If accurate bankfull regional curves are developed and practitioners follow the process, the bankfull identification and verification process is accurate and repeatable. If the process is not followed, variability in identifying bankfull is much higher.

Future Work:

There are numerous upcoming projects within targeted watersheds that intend to apply the WISQT to assess and quantify functional lift, including projects in the Little Manitowoc River, the Green Bay West Shore, Lower Green Bay, Fox River, and the Peshtigo River watersheds; the Peshtigo River watershed in particular has been a priority watershed for restoration by WDNR and their partners such as Trout Unlimited. Projects include removal of fish passage barriers to reconnect trout habitat on Little Balsam Creek, as well as numerous stream crossing and habitat restoration projects that will benefit northern pike, particularly in Brown, Oconto, and Ozaukee counties. Results from these applications will inform future updates and improvements to the tool.

Work is ongoing to consider how to broaden the applicability of SQTs in ephemeral and intermittent streams, and stream/wetland complexes with multiple channels (anastomosed). SQTs are not intended to compare streams to another resource type (e.g., wetlands, impoundments). However, some agencies are investigating ways to use the SQT for dam removal projects that convert lentic systems back into lotic systems.

As additional data become available through testing, future versions of the tool will be updated.

1.8. Revisions to the WISQT and Reference Curves

Reference curves included in the WISQT and this document will be reviewed and updated, as needed. If additional data and/or literature values are provided during the public comment period or in the future, they will be evaluated using the five assessment factors outlined in *A Summary of General Assessment Factors for Evaluating the Quality of Scientific and Technical Information* (EPA 2003) and considered for inclusion in the tool.

Additionally, the WISQT architecture is flexible and can accommodate additional parameters and metrics that are accompanied by reference curves. If a user is interested in proposing additional parameters or metrics for incorporation into the tool, they should provide a written proposal for consideration.

Proposals and technical feedback may be submitted at any time to: Technical Services Branch, St. Paul District US Army Corps of Engineers, 332 Minnesota Street, Suite E1500, St. Paul, Minnesota 55101 or call (651) 290-5525; or email StPaulSQT@usace.army.mil. The proposal should include data sources and/or literature references and should follow the framework for identifying threshold values and index scores that is outlined in this document. Such proposals will be considered in future versions of the tool.

More information on the SQT and District mitigation guidance can be found at https://www.mvp.usace.army.mil/Missions/Regulatory/

Chapter 2 Catchment Hydrology and Reach Runoff Parameters

Functional Category: Hydrology

Hydrology Functional Statement: Transport of water from the watershed to the channel.

Function-based Parameters Summary:

Hydrologic processes are critical to stream health and play a role maintaining surface water storage processes, surface/subsurface water exchange, quality and quantity of sediments, necessary aquatic and riparian habitats, water and soil quality, and landscape pathways (Fischenich 2006). The functional statement for the hydrology category is the transport of water from the watershed to the channel (Harman et al. 2012). There are two parameters in the WISQT that are used to quantify the functional statement: catchment hydrology and reach runoff. Catchment hydrology focuses on the transport of water from the portion of the catchment upstream of the project reach and reach runoff focuses on the lateral (adjacent) drainage areas of the project reach.

Runoff relationships are strongly influenced by human activity and land use patterns. Changes in land cover and land use impact water quality (e.g., sediment, nutrients, or other pollutants) as well as the magnitude, duration, frequency, timing, and rate of change of runoff hydrographs entering the project reach (Beechie et al. 2012; ELI and TNC 2014). The conversion of mature, natural vegetation communities to other land uses increases runoff volumes due to reductions in canopy interception, surficial and depressional storage, soil infiltration, and evapotranspiration. These changes alter the historic conditions that created a stable stream form (NRC 2008). Precipitation that historically was infiltrated, evaporated, or transpired is converted to runoff (NRC 2008). Multiple studies have shown that increases in impervious cover are linked to declines in stream condition (Schueler et al. 2009), while agricultural practices can contribute sediment, nutrients, and other pollutants (EPA 2005; Kleinman et al. 2015).

Similar to other SQTs, the WISQT relies on a land use coefficient metric to evaluate natural versus anthropogenic land covers in the contributing watershed. Land use coefficients are developed by the Natural Resource Conservation Service (NRCS) and are based on curve numbers used to predict runoff volumes in hydrologic modeling (NRCS 1986). This metric can be applied at either the catchment scale to characterize land uses within the contributing watershed upstream of the project reach (catchment hydrology parameter) or at the reach scale to characterize the lateral drainage area (reach runoff parameter). Though many SQTs treat catchment hydrology processes as independent from an individual stream project, multiple projects may collectively influence watershed processes where disturbance is primarily associated with the riparian corridor and management, or where regulatory controls allow for consistent restoration practices.

In addition to quantifying land use changes, the WISQT includes a new metric to assess concentrated flow points, a Concentrated Flow Point Index (CFPI). Multiple SQTs include land use coefficient and concentrated flow point metrics. Concentrated flow points alter storm-flow routing, typically increasing water velocities to drain the landscape more effectively. In projects with large lateral drainage areas, restoration practices may be limited to the riparian corridor and while these practices may not result in measurable changes to land cover in the lateral drainage area, they could affect the routing of concentrated flows into the stream. Thus, this metric was developed to address changes in concentrated flows associated with a project. The land use coefficient and concentrated flow point index metrics are intended to be applied together for reach runoff.

METRICS FOR CATCHMENT HYDROLOGY:

- Land Use Coefficient

METRICS FOR REACH RUNOFF:

- Land Use Coefficient
- Concentrated Flow Points Index

2.1. LAND USE COEFFICIENT

The WISQT uses an area-weighted land use coefficient to quantify the impact of various land uses on reach runoff. This metric is calculated by delineating areas of different land uses within the upstream catchment area and lateral drainage area of a stream reach, assigning a land use coefficient to these areas, and then calculating an area-weighted coefficient. As noted, the same metric is applied to the catchment hydrology parameter and the reach runoff parameter.

Land use coefficients are based on runoff curve numbers (CN) developed by the NRCS in Urban Hydrology for Small Watersheds (NRCS 1986), commonly referred to as TR-55. CNs quantify the runoff potential due to land use and infiltration capacity of underlying soils. TR-55 presents CN values for various natural, agricultural, and urban land uses across a range of soil types and surface conditions. CN values for urban land uses trend higher than agricultural lands depending on the percent of impervious cover associated with various cover type descriptions. Therefore, as the catchment or lateral drainage area is cultivated or developed, the CN value and runoff increase.

Land use coefficient values were adapted from Hydrologic Soil Group (HSG) B curve numbers presented in the TR-55 (1986). Soil groups differ across ecoregions in WI and runoff potential increases as soils move from group A to D. To focus on land use instead of soils (because only land use change is sensitive to reach-scale restoration and impact activities), one soil group was chosen to inform land use coefficients. Generally, HSG C and D soils are found in the riparian corridor; these soils drain poorly and are associated with higher runoff potential. Meanwhile, HSG A and B generally correspond to soils outside of the riparian corridor. For this reason, HSGs A and B were targeted because the catchment and lateral drainage area for most project sites will include more total non-riparian area than riparian area. Additionally, A and B soils are generally more sensitive than C and D soils to land use change. Between HSG A and HSG B, HSG B was chosen because these soils exhibit higher runoff potential, have moderate infiltration rates when wetted, and are moderately to well drained (NRCS 2007).

Curve numbers for HSG B were then modified to accommodate a simplified list of land uses applicable to WI. For example, native prairie, which is not included in TR-55, was included and assigned a land use coefficient consistent with woods in good condition (i.e., native prairies are comparable in function to woods), which promotes restoration of appropriate habitat for a given ecological setting. When poor, fair, and good condition options were available for a given land use in TR-55, the fair value was generally chosen, except for woods, where good and poor condition CNs were used to address forested areas protected from grazing and with adequate litter as well as woods disturbed by heavy grazing, respectively. The land use list also includes open water in the land use table; but this is only applicable for impounded open water to allow for characterization of functional change associate with installation or removal of man-made impoundments. Open water that is not impounded is not included in the land use coefficient calculation. Land use coefficients are presented in Table 2-1.

Table 2-1: Land use descriptions and associated land use coefficients. Adapted from NRCS (1986).

Land Use Description (adapted from TR-55)	Land Use Coefficient
Urban Areas Land Uses	
Open Space (lawns/turf, parks, golf courses, cemeteries, etc.)	69
Impervious areas	98
Unpaved Roads (e.g., dirt/gravel)	85
Commercial, business and industrial districts	92
Residential districts by average lot size: < 1/4 acre ~ 1 acre > 2 acres	 75 68 65
Agricultural Lands/Natural Land Cover	
Open Water – refers to impounded water behind dams only (can be in agricultural or urban areas).	100
Cropland	74
Pasture, grassland, or range – continuous forage for grazing	69
Meadow – continuous grass, protected from grazing and generally mowed for hay	58
Brush – brush-weed-grass mixture with brush major element	56
Woods – grass combination (orchard or tree farm)	65
Woods – disturbed by heavy grazing	66
Woods – forested areas protected from grazing and w/adequate litter and brush covering the soil	55
Native Prairie	55

REFERENCE CURVE DEVELOPMENT:

To develop reference curves, the WISQT TC considered the functional capacity of the various land use covers and their respective curve numbers presented in Table 2-1. Threshold values were developed after considering the range of possible field values generated by an area-weighted equation and considering which land uses may represent no functional capacity, severely impaired, minimally disturbed and reference standard conditions. The following were used to define threshold values (Table 2-2):

- A field value of 55 was used to define the 1.00 index value. This field value represents a catchment or lateral drainage area entirely made up of natural land uses (woods or native prairie) in good condition. These land uses represent pristine, deeply rooted, plant communities.
- A field value of 68 was used to define the 0.70 index value. This field value represents a minimally disturbed runoff condition, such as woods in poor condition, pasture, and open space.
- A field value of 75 was used to define the 0.30 index value. This field value equates with land uses such as ¼ acre residential densities and croplands, which reflect land uses that would permit substantial runoff.

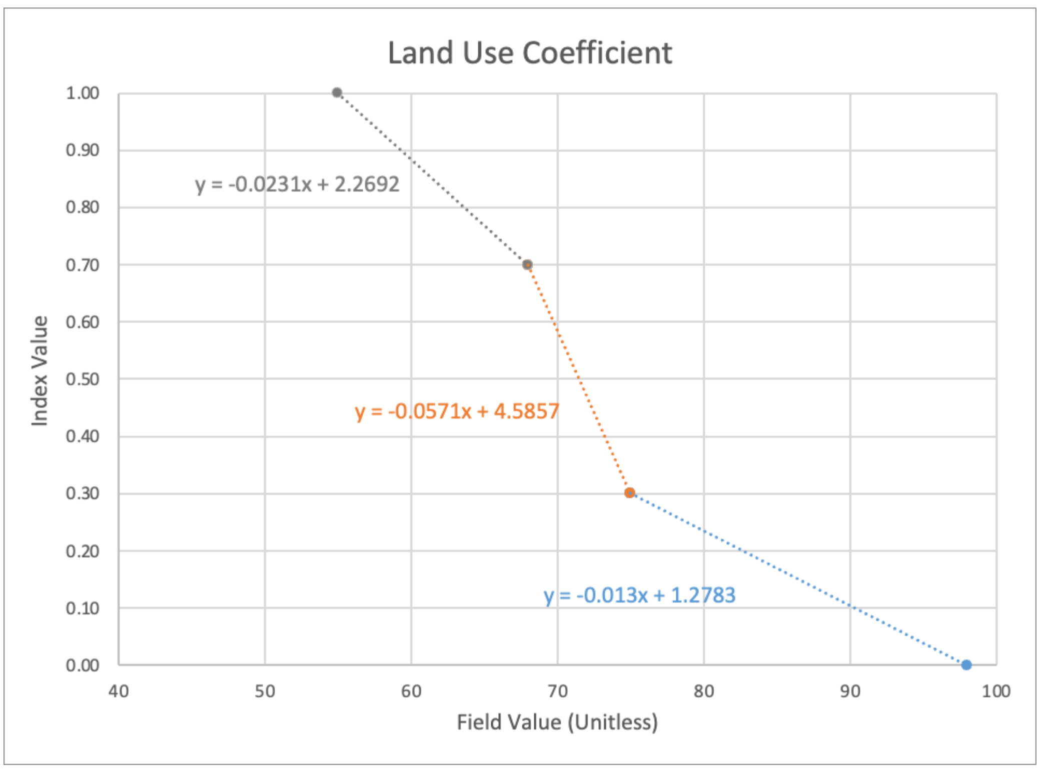
- A field value of 98 was used to define the 0.00 index value. This field value equates with an entirely impervious catchment or lateral drainage area, which would provide no infiltration and no functional capacity.

A broken-linear curve was applied for the land use coefficient metric (Figure 2-1). The slope of the resulting reference curve (i.e., how much functional change is attributed to a change per unit field value) varies and is steeper in the functioning-at-risk range of scoring. In other words, the rate of functional capacity improvement is lowest within the not-functioning range. Going from no function (0.00) to not-functioning at 0.29 does not yield much change. The transition from 0.30 to 0.70 (the functioning-at-risk range) yields the greatest per unit change in functional capacity. The rate of change (slope) decreases again within the functioning range at index values greater than 0.70; a pristine field value will score higher than a field value at the lower end of functioning, but the rate of change within functioning is not as great as moving from not-functioning to functioning.

Table 2-2: Threshold values for Land Use Coefficient.

Index Value	Field Value
1.00	≤ 55
0.70	68
0.30	75
0.00	98

Figure 2-1: Reference curve for Land Use Coefficient.



LIMITATIONS AND DATA GAPS:

The land use coefficient metric does not account for variation in infiltration capacity, impermeable layer depth, or other characteristics important to estimating runoff volumes. Additionally, because only soil group B coefficients were considered, the reference curve also does not account for the variability of natural soil types.

The size of the project area compared to the size of the catchment or lateral drainage area will influence how much index scores change in response to land use. Reaches with larger catchments or lateral drainage areas would need to acquire and revegetate more land to achieve a lift similar to projects with a smaller relative area.

Similarly, the relative catchment location (e.g., the proportion of land area within the lateral drainage area compared with the entire catchment area) could influence the relative impact of direct drainage to the channel versus in-channel delivery from upstream. The larger the contributing upstream catchment area, the less influence the lateral drainage has in maintaining stream functions. A reach located far downstream from the headwaters may be more affected by hydrologic changes occurring upstream than from land use changes in the lateral drainage area. Alternatively, improving land use condition in small streams near the headwaters may have a greater relative effect. The limitation of not accounting for project size versus lateral drainage area and of the relative catchment location could be addressed through further stratification and development of additional reference curves.

Stratification of the natural land use types, for example by soil type, ecoregion, or relative condition, would better account for differences in runoff and infiltration potential among natural land uses. For example, natural prairies function differently than broadleaf forests, but both may represent a reference condition. Also, the land use coefficient metric may be less sensitive to changes between natural land cover types and developed land uses where natural land use coefficients are similar to those in certain developed land use types.

The land use coefficient metric has received limited testing and would benefit from additional application and testing in Wisconsin. It would also benefit from sensitivity testing and comparison to other indicators of altered stream processes.

2.2. CONCENTRATED FLOW POINT INDEX

Alterations in runoff processes associated with land use changes are common, particularly due to changes in, or removal of, vegetation; increased impervious surface area; soil compaction and decreased infiltration; and interception of subsurface flows and routing to streams (Beechie et al. 2012). Changes in land use can affect the volume and velocity of water transported from adjacent areas to the stream during stormwater events. Overland flow typically erodes soils relatively slowly through sheet flow; however, anthropogenic impacts can lead to concentrated flows that erode soils quickly, transporting water and sediment into receiving stream channels (Al-Hamdan et al. 2013). New conveyances formed by concentrated flows or constructed for drainage (e.g., agricultural ditches, swales connecting parking lots to stream channels, and gutter systems that route rainwater away from structures) accelerate runoff and route it more quickly to streams. Surface and subsurface agricultural drainage systems export significant quantities of phosphorous, and the concentrations and forms of phosphorous are often similar to those in agricultural surface runoff following storm events (Kleinman et al. 2015). Concentrated flow points (CFPs) can intercept and convey surface and subsurface flows resulting from agricultural practices or cut and fill activities like roads or building sites. There is a clear relationship between concentrated flows and degradation of stream stability and aquatic life (Hammer 1972).

CFPs are defined as ephemeral, erosional features, such as swales, gullies, or other channels, built as drainage features that alter or concentrate runoff directly into the stream. Examples include farm ditches, storm drains, road ditches, and drain tiles. Additionally, CFPs include channels that have formed where a pipe or other drainage feature discharges to open ground that has then subsequently eroded to form a channelized feature. Natural ephemeral channels, outlets from properly functioning stormwater best management practices (BMPs), and natural streams impacted by channelization or other man-made activities are not considered CFPs. Any natural stream channels flowing into a project reach, even if they are impaired or degraded, would be considered a tributary and an individual SQT assessment would be performed.

Earlier SQTs characterized concentrated flows by counting the number of concentrated flow points entering a project reach per 1,000 linear feet of stream. This earlier approach did not consider the type or size of the concentrated flow points, only the quantity. The WISQT TC decided to convert the existing CFP metric into an index that would also capture differences in CFP feature type (e.g., vegetated channel versus pipe) and the size of the contributing drainage area. By accounting for these factors, the concentrated flow point index (CFPI) metric characterizes the relative influence of concentrated flow points that enter the project reach by weighting individual CFPs by the size of their contributing drainage area and the type of conveyance delivering water to the stream.

Stream restoration projects can reduce concentrated flow that directly enters the project reach by dispersing flow in the floodplain, increasing surface roughness, regrading to flatten slopes, removing roads, filling ditches, restoring riparian vegetation or adding other stormwater BMPs that enhance infiltration and/or reduce outfall velocity.

CONCENTRATED FLOW POINT INDEX AND REFERENCE CURVE DEVELOPMENT:

The Concentrated Flow Point Index (CFPI) metric was developed for the WISQT to capture the degradation caused by increased volume and velocity of water transported from the lateral drainage area to the project reach via concentrated flow points. The intent of this metric is to characterize the relative volume and velocity of water entering the channel through individual concentrated flow points by characterizing the size of the contributing drainage area and type of channel, respectively.

The CFPI incorporates the following variables:

- **Area of land draining to the CFP:** The WISQT TC decided that it was important to characterize the area (acres), draining to each CFP. In the index, this contributing area is divided by the total lateral drainage area to yield a weighted area value that represents the proportion of the lateral drainage area contributing to each CFP.
- **Types of CFP conveyance:** Channel type rankings were developed to address differences in velocity and the potential for infiltration of stormwater runoff entering the stream channel (WDNR 2017). The channel type rankings consider how the channel slope and construction may contribute to accelerating the transport of stormwater runoff to the project reach. Channel type rankings were developed by the WISQT TC based on

their knowledge and experience working with stormwater runoff. The rankings are on a scale of 0-1.0. A 1.0 means that the conveyance feature transports 100% of the flow with no infiltration into the ground.

- Pipe or open concrete channel = 1.0

  Pipes and open concrete channels will convey stormwater rapidly from the upstream drainage area, and thus rapidly transport sediment, nutrients, and other pollutants to the stream[2]. High velocities and no infiltration contribute to events with higher runoff peak magnitudes and reduced duration and contribute to more frequent runoff events.

- Open channels with > 4% slope or impermeable soils = 0.9

  Steep channels, or channels with impermeable soils will convey stormwater rapidly from the upstream drainage area, and thus rapidly transport sediment, nutrients, and other pollutants to the stream. High velocities and no infiltration contribute to events with higher runoff peak magnitudes and reduced duration, and cause more frequent runoff events.

- Open channels with less than 4% slope and <50% vegetation cover = 0.8

  Open channels with low vegetation cover create erosion potential for the channel itself, and will also convey stormwater, including sediment and nutrient loads, rapidly from the upstream drainage area. High velocities contribute to events with higher runoff peak magnitudes and reduced duration, and cause more frequent runoff events. Some infiltration will occur in these channels, reducing their adverse effects during smaller events.

- Open channels with less than 4% slope and 50-90% vegetation cover = 0.7

  Open channels with some vegetation cover will have some erosion potential within the channel itself, and will also convey stormwater, including sediment and nutrient loads, rapidly from the upstream drainage area. These conveyances will contribute to higher runoff peak magnitudes and reduced duration and contribute to more frequent runoff events. Roughness from vegetation and more infiltration reduces adverse effects, particularly during smaller events.

- Open channels with less than 4% slope > 90% vegetation cover = 0.6

  Open channels where a majority of the channel bed has vegetative cover will have minimal erosion potential within the channel itself, but will continue to convey stormwater, including sediment and nutrient loads, from the upstream drainage area. These conveyances will contribute to higher runoff peak magnitudes and reduced duration, and contribute to more frequent runoff events, although these effects will be attenuated, particularly during smaller events.

[2] The WISQT TC discussed drain tiles at length during the development of the CFPI. Although drain tiles have different effects on runoff patterns, they should be scored using the same channel type rankings as other concentrated flow points. In other words, if a drain tile outlet is discharging to a stream via a pipe, the channel type ranking (1.0) for pipe should be used to calculate the CFP score for that tile drain.

Vegetation will filter and trap pollutants, improve water quality, attenuate peak flows, and improve infiltration (WDNR 2017).

The CFPI is calculated by multiplying each CFP's weighted area by the channel ranking, and then summing all CFPs within the reach. The resulting field value is on a scale of 0.0-1.0, where a 0.0 field value reflects no concentrated flow points and 1.0 represents a reach where 100% of the lateral drainage area flows into the reach via piped concentrated flow points.

Threshold values are shown in Table 2-3 and were defined as follows:

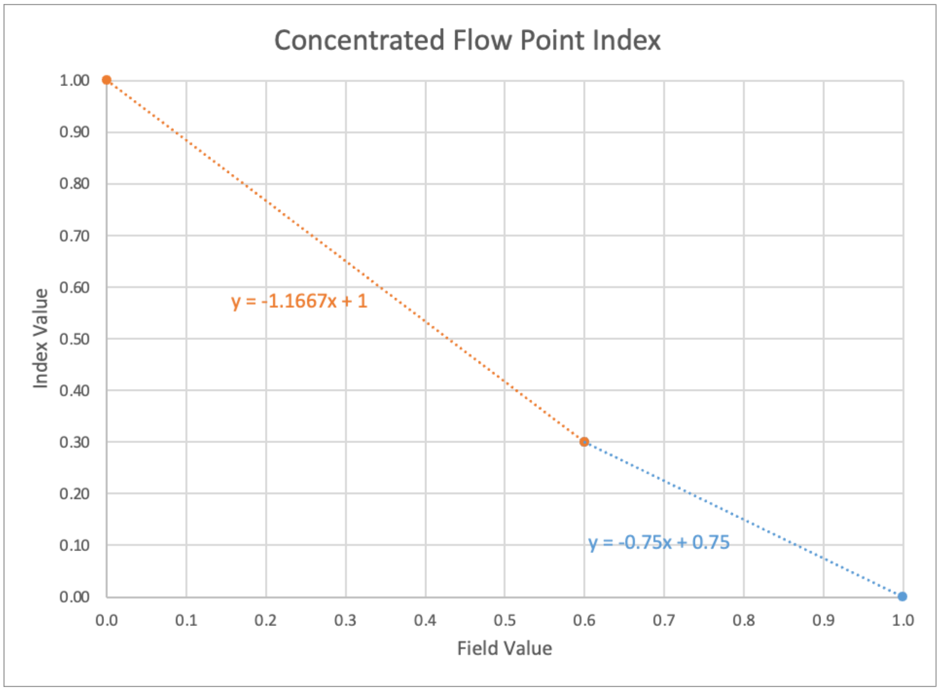
- Functioning: A field value of 0.00, meaning no CFPs are present, is used to define the 1.00 index value and represents a functional capacity that is equal to pristine or culturally unaltered.
- Not-functioning: A CFPI field value of 1.00 reflects 100% of the LDA draining via piped or concreted CFPs into the project reach and was considered to represent no functional capacity and a 0.00 index value. A field value of 0.6 was selected to differentiate the not-functioning and functioning-at-risk range of index values (0.30 index vale), as this would still reflect 100% of the LDA draining via a CFP, regardless of CFP channel ranking.

A broken-linear curve was applied for the CFPI metric (Figure 2-2).

Table 2-3: CFPI field values and their index values used to inform reference curve.

Index Value	Field Value
0.00	1.0
0.30	0.6
1.00	0.0

Figure 2-2: Reference curve for Concentrated Flow Point Index.



Limitations and Data Gaps:

Even with the inclusion of contributing area and channel type, the CFPI metric does not provide a complete characterization of CFPs. For example, the difference in infiltration and velocities across channel types will vary based on the length of the conveyance relative to the contributing area, as well as the dimensions of the conveyance itself. Flow path length and density are often considered when evaluating BMPs (e.g., WDNR 2017). These additional factors may be incorporated into the index in the future.

Although drain tiles are considered CFPs, they are an imperfect fit for this metric. Drain tiles alter the hydrology of the landscape in numerous ways (Moore 2016) and often function differently than most other CFPs, e.g., they continuously drain surface and groundwater to the channel in agricultural landscapes. This process accelerates the natural hydraulic pathways that groundwater would travel through to the channel, thus increasing hydraulic conductivity. While some infiltration occurs despite the presence of drain tiles, these CFPs transports water with nutrients and other pollutants to streams, potentially contribute to the frequency and magnitude of stream discharge, and affect the duration of higher runoff, particularly increasing runoff in baseflow periods. Additionally, subsurface drainage networks via drain tiles may not always align with surface topography, and thus, the contributing area of drain tiles may not always fall within the lateral drainage area delineated for a reach. Application of this metric in agricultural settings will provide useful data to consider how drain tiles can be better accounted for within this or other metrics.

The CFPI metric has received limited testing and would benefit from additional application and testing in Wisconsin. It would also benefit from sensitivity testing and comparison to other indicators of altered stream processes.

Chapter 3 Floodplain Connectivity Parameter

Functional Category: Hydraulics

Hydraulics Functional Statement: Transport of water in the channel, on the floodplain, and through sediments.

Function-based Parameter Summary:

Floodplain connectivity is one of the most important function-based parameters for stream restoration work (Fischenich 2006) because it is a driver for many geomorphic and ecological functions (Wohl 2004). Floodplains and bankfull benches (also called flood-prone areas) are assessed as floodplain connectivity in the SQT. The floodplain of a stream is inundated during moderate to high flows or floods and is formed by sediment deposition during overbank flooding under present climatic conditions (Leopold et al. 1994). Floodplains consist of alluvium and are associated with meandering streams in alluvial valleys. Bankfull benches are narrower than floodplains and exist in confined or colluvial valleys. Bankfull benches are flat depositional features that provide some energy dissipation for higher flows (Harman et al. 2012). Rosgen (2002) defines a flood-prone area as “the area adjacent to the stream that is inundated or saturated when the elevation of the water is at twice the maximum depth at bankfull stage.”

The functional loss associated with channelization and berm or levee construction includes displaced flooding, loss of bed form diversity, downcutting and incision, increased erosion, and loss of fish species and biomass (Darby and Thornes 1992; Hupp 1992; Kroes and Hupp 2010; Richer et al. 2015; Kondratieff and Richer 2018). Severely incised channels can also lower the local water table, draining riparian wetlands or otherwise impacting the local riparian community (Harman et al. 2012). While it is a common perception that a straight and deep channel can move floodwaters quickly downstream, they cause flood damage downstream of the channelization (Schoof 1980). Incised channels cannot store water and sediment in the floodplain during large storm or snowmelt events. When a channel is connected to its floodplain, flood flows can inundate the floodplain and spread out across the landscape allowing in-channel velocities to maintain bed forms without excessive erosion. In a comparison between an incised stream and a similar, non-incised stream, the incised stream had significantly higher turbidity, solids, total nitrogen and phosphorous and chlorophyll concentrations, and lower fish diversity and biomass than the non-incised stream (Shields et al. 2010).

The SFPF (Harman et al. 2012) describes three measurement methods for the floodplain connectivity parameter: bank height ratio (BHR), entrenchment ratio (ER), and stage-discharge relationships. BHR is a physical measure of channel incision that corresponds with the frequency that flood flows could reach the floodplain. The ER estimates the lateral extent of floodplain inundation once the flow depth reaches a stage that is two times the bankfull depth (Rosgen 1996). During regionalization, the WISQT TC discussed other approaches to characterize floodplain connectivity. For example, the use of crest gages was examined as a way to confirm floodplain connectivity. Ultimately, the WISQT TC did not include those other methods due to cost concerns and the data needs associated with those metrics. Instead, the WISQT TC decided to include the BHR and ER to characterize floodplain connectivity.

Metrics for Floodplain Connectivity:

- Bank Height Ratio
- Entrenchment Ratio

3.1. Bank Height Ratio

The bank height ratio (BHR) is a measure of channel incision and indicates whether a stream is or is not connected to an active floodplain or bankfull bench. BHR is defined as the depth from the top of the lowest bank to the thalweg divided by the depth from the bankfull elevation to the thalweg (Rosgen 1996).

In a stable high functioning stream with ideal floodplain connectivity, the low bank height should be equal to the bankfull depth; this results in a BHR equal to 1.0. Thus, any discharge greater than bankfull accesses the floodplain or bankfull bench, while the bankfull discharge is contained within the channel (Rosgen 2009). As the BHR increases, the degree of incision also increases. For example, a BHR of 2.0 means that it takes two times the bankfull stage for flows to access the floodplain, indicating the stream is highly incised and disconnected from its former floodplain.

Simon and Rinaldi (2006) found that while non-incised channels dissipate erosive energy of high flows across the floodplain, incised channels within the same region contain flows of greater magnitude and return interval (the probability that a given storm event will be equaled or exceeded in any given year). Greater BHR values are characteristic of an unstable condition, deeper and often wider channels, and higher return interval for flows leaving the channel. As greater flows with increased erosive power are confined to the channel, BHR increases as the streambed lowers or degrades. Active degradation is often signaled by head cutting (bed erosion manifested as a step or sudden grade drop that propagates headward) and BHR increases downstream. This results in even larger floods being contained in the channel, and a decrease in floodplain connectivity as the channel evolves through predictable stages (Cluer and Thorne 2013; Rosgen 2009; Schumm et al. 1984). Sullivan and Watzin (2009) found that measurements of BHR, as an indicator of floodplain connectivity, were significantly correlated to fish assemblage diversity, and as incision increased, floodplain fish species richness and fish diversity within the stream corridor decreased, while species turnover increased.

Reference Curve Development:

Thresholds are based on Rosgen (2009) narrative descriptions of channel incision and the performance standards recommended in Harman et al. (2012) that consider the degree of incision and the relative functional capacity of incised streams (Table 3-1); this is consistent with the approach taken in the MNSQT and other SQTs.

Table 3-1: Bank Height Ratio categories from Rosgen (2009) and Harman et al. (2012).

Channel Incision Descriptions (Rosgen 2009)		Performance Standards Harman et al. (2012)	
BHR	**Degree of Channel Incision**	**BHR**	**Functional Capacity**
1.0 – 1.1	Stable	1.0 – 1.2	Functioning
1.1 – 1.3	Slightly Incised		
1.3 – 1.5	Moderately Incised	1.3 – 1.5	Functioning-at-risk
1.5 – 2.0	Deeply Incised	> 1.5	Not-functioning

Stratification by stream size is built into the metric by using the bankfull depth as the denominator. Bankfull depth varies throughout the country due to differences in precipitation and runoff characteristics; however, there are predictable, documented relationships that predict bankfull dimensions for streams in the same physiographic or hydrologic region (Dunne and Leopold 1978; Blackburn-Lynch et al. 2017; Torizzo and Pitlick 2004). Because the BHR metric focuses on the ability of flood flows to access areas outside the channel and not the extent of floodplain inundation, stratification by valley type was not considered.

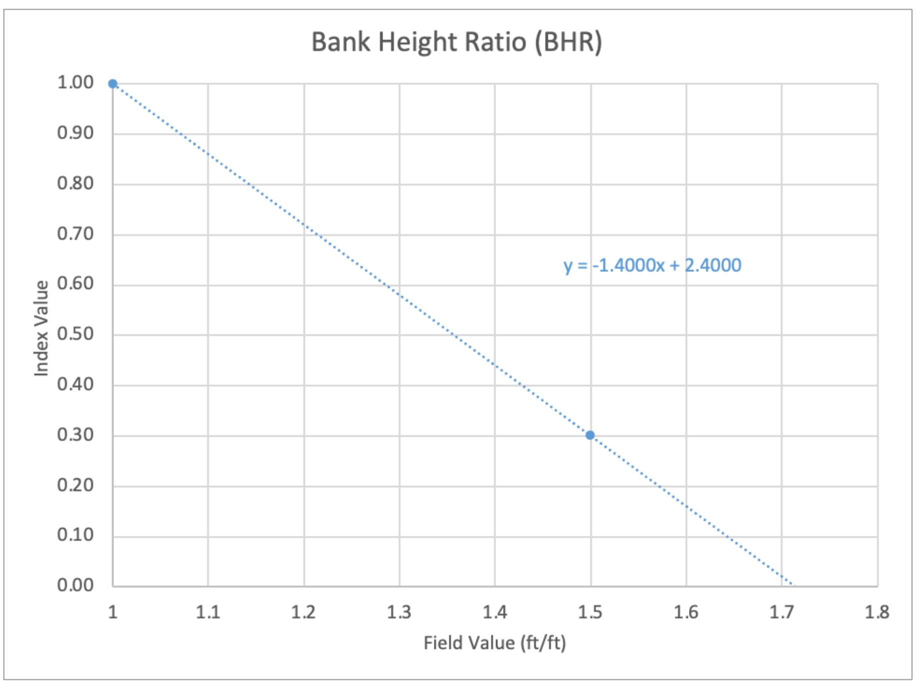
A threshold of 1.5 was used to differentiate index values within the functioning-at-risk and not-functioning ranges. BHRs greater than 1.5 were considered not-functioning, consistent with the supporting literature classifying these as deeply incised channels with a greater likelihood of vertical instability (Rosgen 2009). Deeply incised streams (e.g., BHR > 1.7) provide extremely rare floodplain connectivity. A channel that contains any significant flood event, e.g., a 10- year or 25-year recurrence interval, is likely to experience significant erosion during a large precipitation event and transport water and sediment downstream instead of dispersing them across the floodplain.

While some prior SQTs identify a threshold between functioning and functioning-at-risk, the WISQT TC decided to simplify the reference curve by removing the 0.70 threshold value. This change allows for a line fit through two points. Threshold values were plotted, and a best-fit line was derived to provide a single equation to calculate index values from field values.

Table 3-2: Threshold values for Bank Height Ratio.

Index Value	Field Value
1.00	1.0
0.30	1.5

Figure 3-1: Reference curve for Bank Height Ratio.



LIMITATIONS AND DATA GAPS:

BHR often relates to the stage (water level) and corresponding return interval at which water leaves the channel and inundates a floodplain or terrace. By contrast, in watersheds where the hydrology has been severely altered, the return interval associated with a floodplain surface may dramatically increase (or decrease). For example, the return interval may increase from 1.5 years to 5 years downstream from new impoundments that reduce the frequency (increase the return interval) of flood events. The change in the return interval and stage at which water leaves the channel converts the active floodplain to a terrace. The BHR will not detect this change initially because the floodplain appears to be intact and the stream does not appear to be incised because the depth from the streambed to the top of the bank has not changed, though eventually a smaller channel will develop within the former channel as reduced flood flows fail to scour riparian areas and transport less bed sediment. In these cases, watershed specific regional curves that related bankfull dimensions to drainage are needed to calibrate the feature.

If bankfull dimensions are not accurately determined for a site, then the bank height ratio will not accurately represent the incision processes. Information on verifying bankfull information is provided in the User Manual. The accuracy and repeatability of selecting and verifying a bankfull feature is improved when experienced practitioners follow this verification process.

3.2. ENTRENCHMENT RATIO

The entrenchment ratio (ER) is a ratio of the flood-prone area width divided by the bankfull riffle width, where the flood prone area width is the width of the floodplain at a depth that is twice the bankfull maximum riffle depth (Rosgen 2009). The ER metric is based on physical measurements (i.e., can be measured in the field at any time), and can be assessed in any stream with a bankfull indicator or regional curve. While BHR measures channel incision and whether a stream is connected to an active floodplain or bankfull bench, ER estimates the lateral extent that floodwaters can spread across a valley.

A stream is considered entrenched when flooding is horizontally confined, i.e., the flood prone width is the same or similar to the bankfull width. Large ERs are found in alluvial valleys where flood events spread laterally. ER naturally varies by valley shape and is therefore used as a primary metric in differentiating stream types (Rosgen 1996). ER can also be a useful indicator of functional capacity as many anthropogenic alterations (e.g., levees, berms, and channelization) constrict the natural extent of floodplains and thereby decrease floodplain connectivity.

ER characterizes the vertical containment of the river by evaluating the ratio of the flood-prone width to the bankfull width measured at a riffle cross-section (Rosgen, 1996) and is described in depth by Rosgen (2014). The flood-prone width is the cross-section width at a riffle feature perpendicular to the valley at an elevation of two times the bankfull max depth at that riffle.

REFERENCE CURVE DEVELOPMENT:

Reference curves for ER were adopted without revision from the MNSQT (MNSQT SC 2020b) for use in the WISQT. This section is reproduced with minor edits from the *Scientific Support for the Minnesota Stream Quantification Tool* (MNSQT SC 2020b).

ER is a primary metric in determining the Rosgen stream type: entrenched stream types (A, G and F streams) have ER values less than 1.4 ±0.2; slightly entrenched stream types (E and C stream types) have ER values greater than 2.2 ±0.2; and streams with ER values in between 1.4 ±0.2 and 2.2 ±0.2 are considered moderately entrenched (B stream types; Rosgen 1996). The values used to delineate between stream types were empirically based on data collected by Rosgen. The flood prone width (the ER numerator) was based on the elevation at a depth of two times bankfull max depth. The cross-section width approximated by two times bankfull max depth came from modeling a bankfull discharge and 50-year return interval flood through typical cross sections representing various stream types. The ratio of the depth of the 50-year flood to the bankfull depth ranged from 1.3 to 2.7 for all stream types except the DA channels. Less confined streams like E channels have lower ratios (the larger the horizontal area floodwaters can occupy, the lower the difference in stage between a small flood and a large one). A “typical” ratio of 2.0 was selected to calculate the elevation of the flood prone width for all stream types, as a generalized comparison of confinement (Rosgen 1996).

Harman et al. (2012) translated the adjective descriptions of entrenchment used by Rosgen (1996) into functioning, functioning-at-risk, and not-functioning categories as shown in Table 3-3 after considering the differences among stream types. The reference standards were based on the stream type delineations listed above and the ±0.2 that “allows for the continuum of channel form” (Rosgen 1996).

Table 3-3: Entrenchment Ratio reference standards from Harman et al. (2012).

ER for C and E Stream Types	ER for B and Bc Stream Types	Functional Capacity
> 2.2	> 1.4	Functioning
2.0 – 2.2	1.2 – 1.4	Functioning-at-risk
< 2.0	< 1.2	Not-functioning

The MNSQT SC evaluated the criteria proposed by Harman et al. (2012) as well as the Jennings & Zink (2017; TN), WY, and Donatich et al. (2020; NC) reference datasets. Reference curves were then developed from this compiled dataset.

The WY dataset was compiled from two reference datasets collected by the Wyoming Game and Fish Department and the US Forest Service (USFS). The dataset consists of 61 sites composed of 22 B, 27 C, 9 E and 3 F Rosgen stream types. BHR was used as a quality assurance measure to ensure reference quality: 2 of the 61 reference sites were deeply incised (BHR > 1.5) and were removed from the dataset because they were not considered to represent reference standard condition. Additionally, the three F streams were removed from the dataset due to the small sample size, because F stream types are an atypical target for restoration, and because they are naturally incised which makes the ER metric less applicable. In summary, of the 61 WY sites, two sites were identified as degraded (BHR > 1.5) and three sites were classified as F channels and were thus, removed from the analysis.

The Jennings & Zink (TN) dataset consists of 110 sites that report ER. One site classified as an F channel and nine were classified as reference-degraded (BHR > 1.5) and were removed from the analysis. Also, seven sites were reported with an ER > 10.0, without an exact number. Thus, a conservative value of 10.01 was used for analyses.

Donatich et al. (2020) implemented the NC SQT v3 protocol in the Piedmont ecoregion of North Carolina at 18 geomorphic reference sites, 1 biological reference site, 9 restored sites, and 6 degraded sites. The restored and degraded sites were not considered in developing reference curves for the WISQT. BHR was used as a quality assurance measure to ensure reference quality: 6 of the 18 geomorphic reference sites were deeply incised (BHR > 1.5) and removed from the dataset because they were not considered to represent reference standard condition. This reference dataset subset included one Bc stream type and 11 C and E stream types.

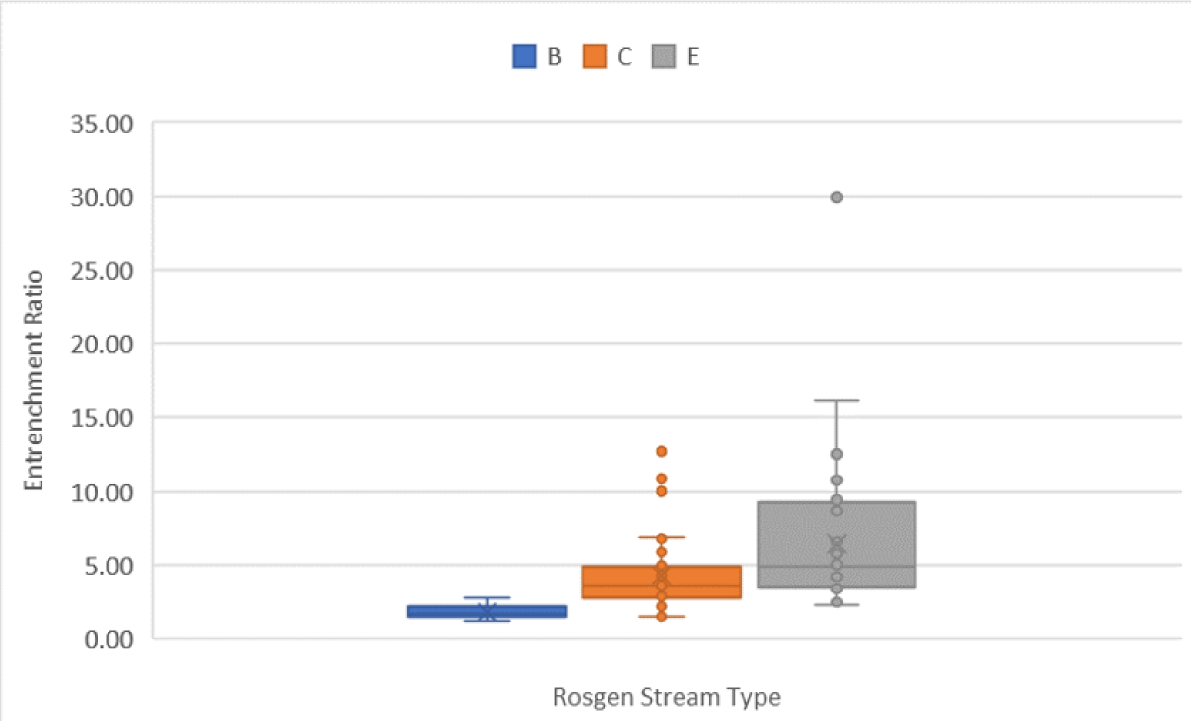
The statistics for ER stratified by stream type are provided in Table 3-4 and Figure 3-2[3].

Table 3-4: Statistics for ER from the reference standard sites within the WY, Jennings & Zink (TN), and Donatich et al. (NC) reference datasets.

	Rosgen Stream Type		
Statistic	**B**	**C**	**E**
Number of Sites (n)	44	73	48
Average	1.8	4.3	6.4
Standard Deviation	0.4	2.4	4.7
Minimum	1.2	1.5	2.3
25th Percentile	1.5	2.8	3.5
Median	1.8	3.6	4.9
75th Percentile	2.2	4.8	8.9
Maximum	2.8	12.7	29.9

[3] This is distinct from the BHR analyses where the datasets were presented separately. Datasets were combined due to the stratification of ER.

Figure 3-2: Box plots for ER from the WY, Jennings & Zink (TN), and Donatich et al. (NC) reference datasets, stratified by Rosgen stream type.



Stratification by stream size is not needed for the ER metric since bankfull width is the denominator of the ratio. Scaling by bankfull width accounts for the differences in stream size that may otherwise be relevant in determining flood prone width.

Stratification was needed to account for the natural variability in flood prone width, and therefore entrenchment ratios, across stream and valley types. Stream type was used to stratify the reference curves, and stream types were grouped into relevant valley types. Stream types in confined valleys naturally have low entrenchment ratios and include the following stream types: A, B, Ba, and Bc. Stream types in wider, alluvial valleys include C and E stream types. Only one A stream type, located in Tennessee, was included in the datasets (Jennings & Zink 2017); however, A streams are likely represented by confined-valley stream types as they naturally occur in confined valleys.

The reference standards presented by Harman et al. (2012) (Table 3-3) were evaluated using the WY, Jennings & Zink (TN), and Donatich et al. (NC) reference datasets (Table 3-4) to develop the threshold values summarized below and presented in Table 3-5.

For B stream types (Figure 3-3):

- Functioning: Field values of 1.4 and 2.2 were set at 0.70 and 1.00 index values, respectively. The ER values of 1.4 and 2.2 are used to delineate B stream types (Rosgen 2009). Additionally, the ER value of 2.2 is the 75th percentile value for B stream types from the reference data in Table 3-4.

- Functioning-at-risk: The regression lines were extrapolated from the functioning and not-functioning thresholds because the datasets did not provide explicit field values for this condition category.
- Not-functioning: A field value of 1.0 was set at 0.00. An ER value of 1.0 is the minimum value for this ratio and physically means that the flood prone width is equal to the bankfull width. In other words, if the ER is 1.0 there is not a floodplain or floodplain bench; there is no floodprone area.

For C stream types (Figure 3-4):

- Functioning: Field values of 2.2 and 5.0 were set at 0.70 and 1.00 index values, respectively. The ER value of 2.2 is the value used to delineate between Rosgen stream types for C streams (Rosgen 2009). The ER value of 5.0 is the 75th percentile value for C stream types from the reference data in Table 3-4, rounded to the nearest whole number.
- Functioning-at-risk: A threshold value between the functioning-at-risk and not-functioning category was not assigned because the reference datasets did not provide explicit field values for this condition category.
- Not-functioning: A field value of 1.0 was set at 0.00. An ER value of 1.0 is the minimum value for this ratio and physically means that the flood prone width is equal to the bankfull width. In other words, if the ER is 1.0 there is not a floodplain or floodplain bench; there is no floodprone area.

For E stream types (Figure 3-5):

- Functioning: Field values of 2.2 and 9.0 were set at 0.70 and 1.00 index values, respectively. The ER value of 2.2, is the value used to delineate between Rosgen stream types for E streams (Rosgen 2009). The ER value of 9.0 is the 75th percentile value for E stream types from the reference data in Table 3-4, rounded to the nearest whole number.
- Functioning-at-risk: A threshold value between the functioning-at-risk and not-functioning category was not assigned because the reference datasets did not provide explicit field values for this condition category.
- Not-functioning: A field value of 1.0 was set at 0.00. An ER value of 1.0 is the minimum value for this ratio and physically means that the flood prone width is equal to the bankfull width. In other words, if the ER is 1.0 there is not a floodplain or floodplain bench; there is no floodprone area.

Table 3-5: Threshold values for Entrenchment Ratio.

Index Value	Rosgen Stream Type		
	B	C	E
1.00	≥ 2.2	≥ 5.0	≥ 9.0
0.70	1.4	2.2	2.2
0.0	≤ 1.0	≤ 1.0	≤ 1.0

Figure 3-3: Entrenchment Ratio reference curve for B stream types.

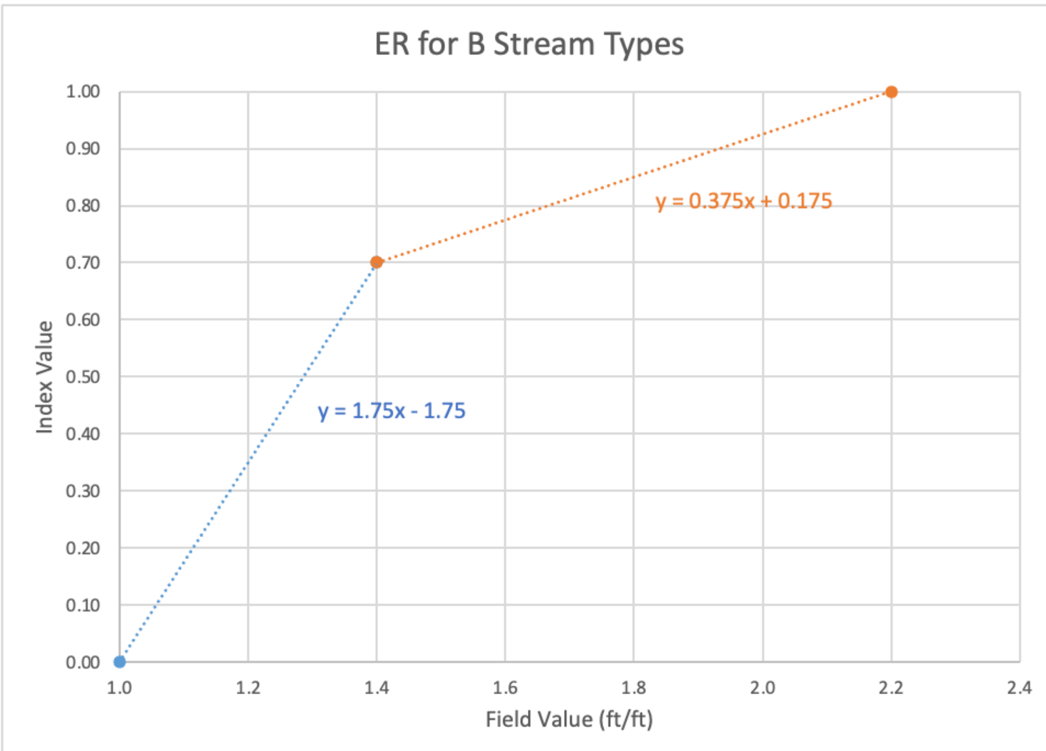


Figure 3-4: Entrenchment Ratio reference curve for C stream types.

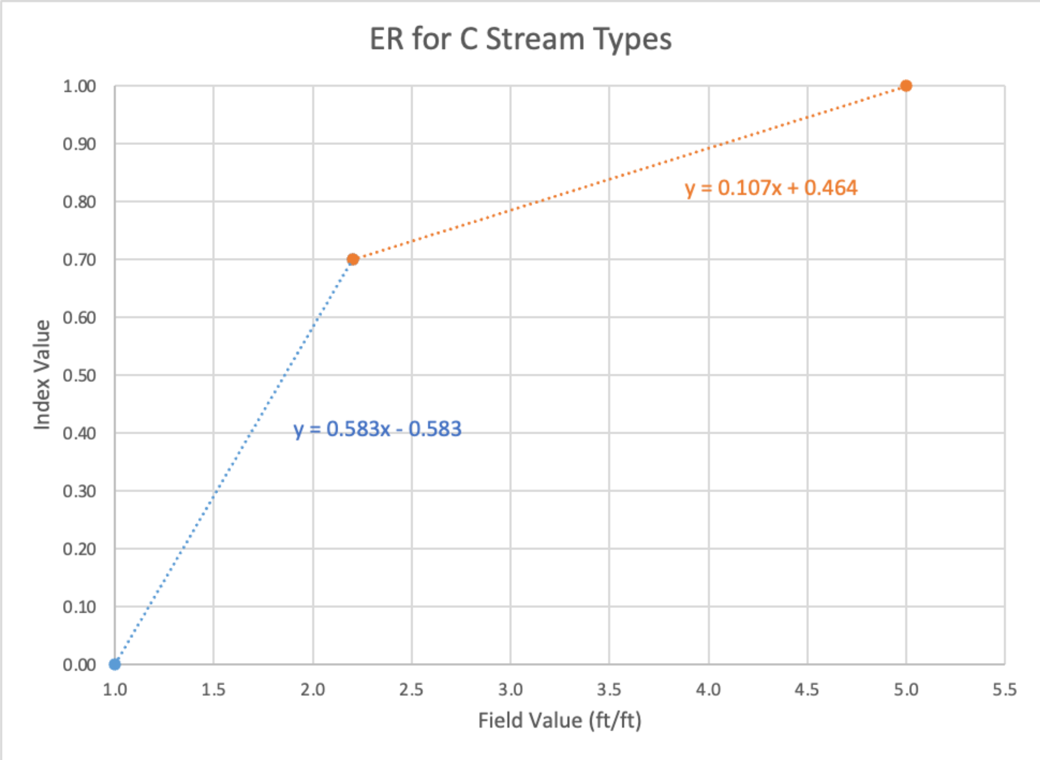
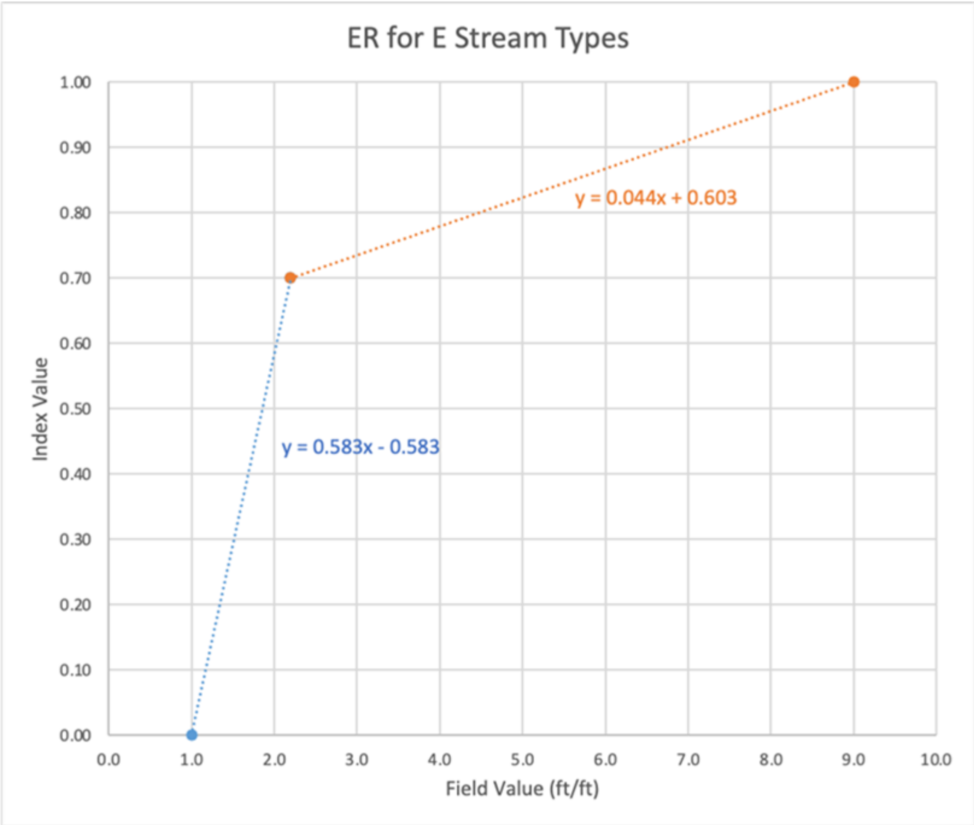


Figure 3-5: Entrenchment Ratio reference curve for E stream types.



LIMITATIONS AND DATA GAPS:

Data for developing the pristine, culturally unaltered index value of 1.00 came from data outside of WI. Local data collection is encouraged to validate the 1.0 field value.

The datasets used to develop reference curves were largely composed of B, C, and E stream types. One A stream type was included in the combined reference datasets. However, because A and B streams are both located in confined valley types, they were grouped together. Reference curves were not developed for naturally occurring F and G stream types. If the stream is a naturally occurring F or G stream type, e.g., located in a canyon or gorge setting, a reference curve must be developed for this stream type before this metric is evaluated. Additionally, the ER metric is not typically used in multi-thread channels like braided (D) and anastomosed (DA) stream types since the width of the channels is often the same as the valley width (Rosgen 2009).

Selection of the appropriate reference stream type is important for consistently applying the ER metric. Guidance is provided in the User Manual to assist practitioners in identifying the reference stream type. For example, F and G channels that represent degraded streams should be compared against the reference stream type, as informed by channel evolution processes (Cluer and Thorne 2013; Rosgen 2014).

If bankfull dimensions are not accurately determined for a site, then the ER will not accurately represent entrenchment processes. Information on verifying bankfull is provided in Appendix A of the User Manual (WISQT SC 2023).

Chapter 4 Bankfull Dynamics Parameter

FUNCTIONAL CATEGORY: Hydraulics

HYDRAULICS FUNCTIONAL STATEMENT: Transport of water in the channel, on the floodplain, and through sediments.

FUNCTION-BASED PARAMETER SUMMARY:

Bankfull dynamics is included in the WISQT to capture the benefits and impacts that changing channel dimensions has on higher level functions. This parameter, referred to as flow dynamics in Harman et al. (2012), initially included three metrics: velocity, shear stress, and stream power, with all three assessed for a bankfull discharge. These metrics have never been applied in an SQT, but variations of the parameter and metrics have been used in Alaska and Colorado. The Alaskan Interior SQT uses flow dynamics as a hydraulics parameter, with a bankfull width/depth ratio state metric. The Colorado SQT uses flow dynamics as a parameter; however, the metrics are used to assess baseflow rather than bankfull flow.

Bankfull dynamics refers to the interaction of flowing water with the streambed and banks and can be quantified by a wide range of metrics. Bankfull dynamics influence channel geometry and characterize the stream's ability to transport sediment sourced from upstream, the streambed, and streambanks (Harman et al. 2012). Channel adjustment (e.g., aggradation and degradation) is a response to changes in flow dynamics. Channel geometry adjustments and resulting changes in stream type are detailed in Rosgen's Channel Succession Scenarios (Rosgen 2006) and other channel evolution models (Cluer and Thorne 2013).

Width/Depth Ratio State (WDRS) was selected as the WISQT metric to characterize channel adjustments. Other SQTs have included a metric called aggradation ratio under the bed form diversity parameter to capture the extensive deposition associated with aggradation. However, the WDRS is included as a hydraulic metric, as it informs how water and sediment are transported within the channel and serves as an indicator for changes in bankfull dynamics that supports geomorphic sediment transport processes.

METRIC FOR BANKFULL DYNAMICS:

- Width/Depth Ratio State (WDRS)

4.1. WIDTH/DEPTH RATIO STATE (WDRS)

SUMMARY:

The Width/Depth Ratio State (WDRS) described by Rosgen (2014) assesses the departure of width/depth ratios (W/D) from a reference standard caused by downcutting, streambank erosion, excessive deposition, or direct mechanical impacts. The W/D is the bankfull riffle width divided by the mean depth (Rosgen 2014). A small W/D indicates a narrow and deep channel while a larger W/D indicates a wide and shallow channel. Mean depth is the riffle bankfull cross-sectional area divided by the riffle bankfull width.

The WDRS method assesses increases and decreases in W/D to quantify departure from reference. Relative to reference, increasing W/D represent aggradation risk and decreasing W/Ds represent degradation risk. The field value is calculated as a percent of a reference W/D where the reference W/D is selected by the user. The reference W/D can come from the representative riffle cross-section, a riffle cross-section at a reference reach, or through the design process.

Reference Curve Development:

The channel stability descriptions for the WDRS from Rosgen (2014) are provided in Table 4-1. Values greater than 1.0 indicate aggradation potential. The stable range is 1.0 to 1.2, meaning that observed W/Ds are 100% to 120% of the reference W/D. As the ratio increases, the risk of aggradation increases. When the value exceeds 140% of the reference W/D, the channel is likely to be unstable due to aggradation.

As shown in Table 4-1, WDRS values less than 1.0 can indicate degradation potential, but there is a caveat. The stable range is 0.8 to 1.0, meaning that the observed W/Ds are 80% to 100% of reference W/Ds. As the ratio decreases, the risk of degradation increases if the bank height ratio increases. Conversely, a decrease in WDRS values could indicate progress toward greater stability (a Rosgen C stream evolving into a Rosgen E stream as vegetation establishes and bank stability increases; Rosgen 2014). The degradation potential is only assessed when the stream is also incised, as indicated by the bank height ratio (BHR; Rosgen 2014). Therefore, the rising limb of the reference curve (observed W/Ds that are less than 100% of the reference W/D) will score a 1.00 unless the BHR field value is greater than 1.2. Rosgen (2014, page 3-37) states that "the decrease category is rated as high risk only when accompanied by a BHR that is greater than 1.0." A BHR value of 1.2 was used to be consistent with the functioning range of scoring for the BHR metric (refer to Section 3.1).

Table 4-1: Width/Depth Ratio State categories (Rosgen 2014).

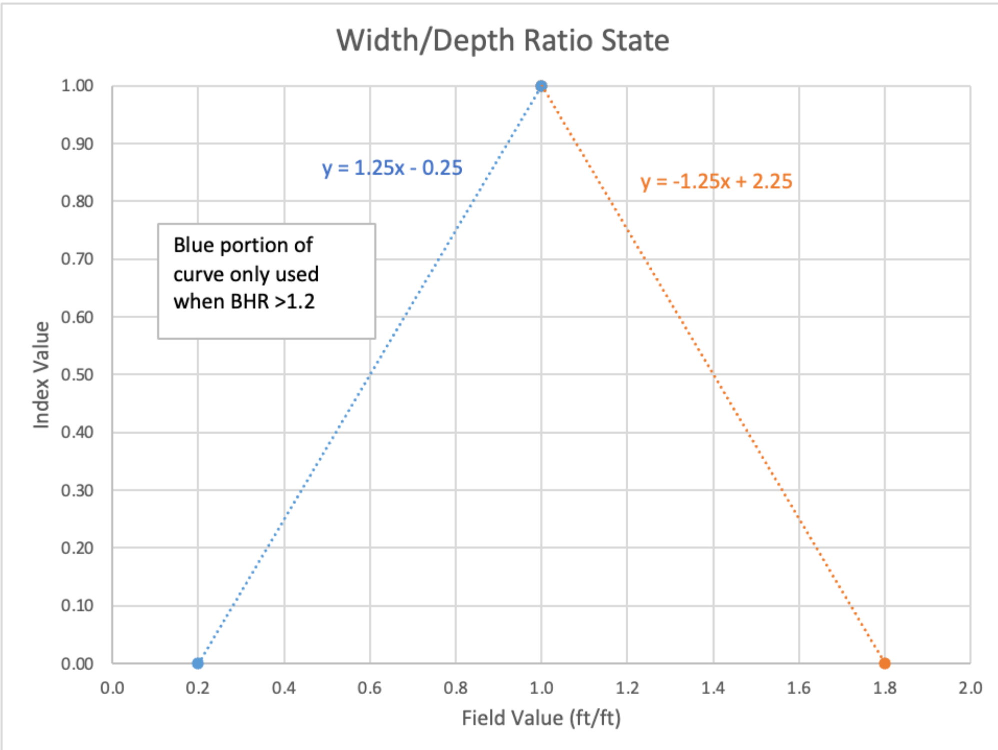
Width/Depth Ratio State		Stability Rating
Degradation Potential	Aggradation Potential	
0.8 – 1.0	1.0 – 1.2	Stable
0.6 – 0.8	1.2 – 1.4	Moderately Stable
0.4 – 0.6	1.4 – 1.6	Unstable
0.2 – 0.4	1.6 – 1.8	Highly Unstable

Thresholds for WDRS were developed by defining the maximum and minimum scores for the functioning and not-functioning categories, where the maximum score corresponds to the highly unstable 1.8 and the minimum score corresponds to the highly unstable 0.2 delineations in Table 4-1. The 0.00 index value was informed by these thresholds, where 0.2 corresponds to 20% of reference W/D and 1.8 corresponds to 180% of reference W/D. The index value of 1.00 was set to a metric field value of 1.0 which means the observed W/D is 100% of the reference W/D. Threshold values for the reference curve are presented in Table 4-2 and the reference curve is depicted in Figure 4-1.

Table 4-2: Threshold values for Width/Depth Ratio State.

Index Value	Field Value
1.00	1.0
0.00	≤ 0.2; ≥ 1.8

Figure 4-1: Reference curve for Width/Depth Ratio State.



LIMITATIONS AND DATA GAPS:

The WDRS uses a reference W/D as the denominator. The user can select the onsite reference cross section, a reference reach, or the design process for the reference W/D. This gives the user a lot of freedom in selecting the reference value, which is a potential source of bias and/or variability in the field values. Over time, it would be best to develop a more standardized method for selecting the reference value. For now, it will be important for the users to provide review agencies with information documenting how values were selected, and for review agencies to consider the appropriateness of proposed reference W/D values on a case-by-case basis.

If bankfull dimensions are not accurately determined for a site, then the WDRS will not accurately represent the hydraulics in the reach. Information on verifying bankfull information is provided in the User Manual.

Chapter 5 Large Woody Debris Parameter

FUNCTIONAL CATEGORY: Geomorphology

GEOMORPHOLOGY FUNCTIONAL STATEMENT: Transport of wood and sediment to create diverse bed forms and dynamic equilibrium.

FUNCTION-BASED PARAMETER SUMMARY:

Inputs of large wood, commonly referred to as large woody debris (LWD), provide an important structural component to many streams and floodplains. LWD can take the form of dead, fallen logs, limbs, whole trees, or groups of these components (also known as debris dams and jams) that are transported or stored in the channel, floodplain, and flood prone area (U.S. Bureau of Reclamation [USBR] and U.S. Engineer Research and Development Center [ERDC] 2016). LWD influences reach-scale sediment transport and hydraulic processes by: 1) creating sediment and organic matter storage areas; 2) increasing substrate diversity and habitat for benthic macroinvertebrates and cover for fish; 3) creating depth variability where large pieces span the channel and produce pools; 4) sometimes increasing local bank erosion and increasing sediment supply; and 5) providing boundary roughness and flow resistance (Wohl 2000).

The LWD parameter is applicable where the upstream watershed or adjacent land area has historically supported (or has the potential to support) trees large enough and close enough to recruit LWD into the stream channel. Many riparian areas and wetlands in Wisconsin are naturally characterized by a woody canopy. Extensive lowland hardwood forests occur within the floodplains of larger rivers in southern portions of the state, particularly the Driftless Area (WDNR 2015). Forested wetlands and riparian areas dominated by conifers, hardwoods or a mix of tree species occur on alluvial soils in floodplains throughout glaciated parts of Wisconsin. Many of these areas have been heavily influenced by changes in land use, fire regimes, timber harvest and historic log drives, and the encroachment of non-native and invasive species. However, because of the historical prevalence of wooded communities throughout Wisconsin, this parameter is applicable at project sites throughout Wisconsin where trees/wood would represent a natural component of the riparian corridor.

There are numerous metrics available to assess large woody debris. Methods include individual piece and jam counts within the channel and floodplain, along with characterization of wood size, type, location, and volume (Wohl et al. 2010). The LWD Index (Davis et al. 2001) characterizes geomorphic quality of LWD in a single index value for a 328-foot (100-meter) sampling reach. Complex approaches like these provide information about how the presence and configuration of wood affects reach-scale functions. Simple approaches, such as piece counts, provide less detailed information on the composition and structure of wood in the channel but serve as indicators of the influence of wood within the channel. We opted to include both piece count and LWDI options for assessing LWD.

METRICS FOR LWD (SELECT 1):

- Large Woody Debris Index (LWDI)
- LWD Frequency (# of pieces per 100 m)

5.1. Large Woody Debris Index (LWDI)

Summary:

Many riparian areas and wetlands in Wisconsin are naturally characterized by a woody canopy and vegetation community. The large woody debris index (LWDI) metric is a semi-quantitative measure of the quantity and influence of large woody debris within the active channel, up to and including the top of banks, per 328 feet (100 meters) of channel length (Davis et al. 2001; Harman et al. 2017). A piece must be at least 10 cm in diameter at one end (Wohl 2000; Davis et al. 2001) and over 1 meter in length (Davis et al. 2001) to be considered LWD. The index does not include LWD beyond the top of bank on the floodplain or terrace.

The index was developed by Davis et al. (2001) and evaluates LWD based on its ability to retain organic matter, provide fish habitat, and affect channel/substrate stability. The LWDI weights this ability for each piece or debris dam by characterizing 1) size (diameter, and the relation of length and width to bankfull dimensions); 2) location in relation to the active channel or during high flows; 3) type (bridge, ramp, submersed, buried); 4) structure (plain to sticky for organic matter retention); 5) stability during high flows; and 6) orientation relative to stream bank. Higher scores indicate greater functional influence on instream processes. Debris dams, which are defined as three or more pieces of LWD that are touching, are weighted by a magnitude of 5 when scored due to their greater influence on instream processes.

Reference Curve Development:

The reference curve for the LWDI metric was adopted without revisions from the MiSQT Version 1.0 for use in the WISQT.

Existing LWDI data are not available in Wisconsin to inform a reference curve. The WISQT TC considered applying reference curves from existing SQTs, including reference curves informed by data from Wyoming (WSTT 2018; USACE 2020b), the southeastern U.S. (South Carolina Steering Committee 2021; TDEC 2018) or Michigan (MI EGLE 2020). Following consultation with state fisheries and forestry experts and an analysis of National Rivers and Streams Assessment (NRSA) data comparing large wood in Wisconsin streams to streams in Colorado, Wyoming and Michigan, the WISQT TC concluded that the Michigan reference dataset was most similar to conditions found in Wisconsin.

The Michigan dataset includes 5 reference standard sites and 11 managed sites located in north-central Michigan. Managed sites mean that large wood is often cut, moved within the channel, or removed from the channel to provide canoe access. Because of the small size of the dataset, both reference and managed sites were used to inform threshold values:

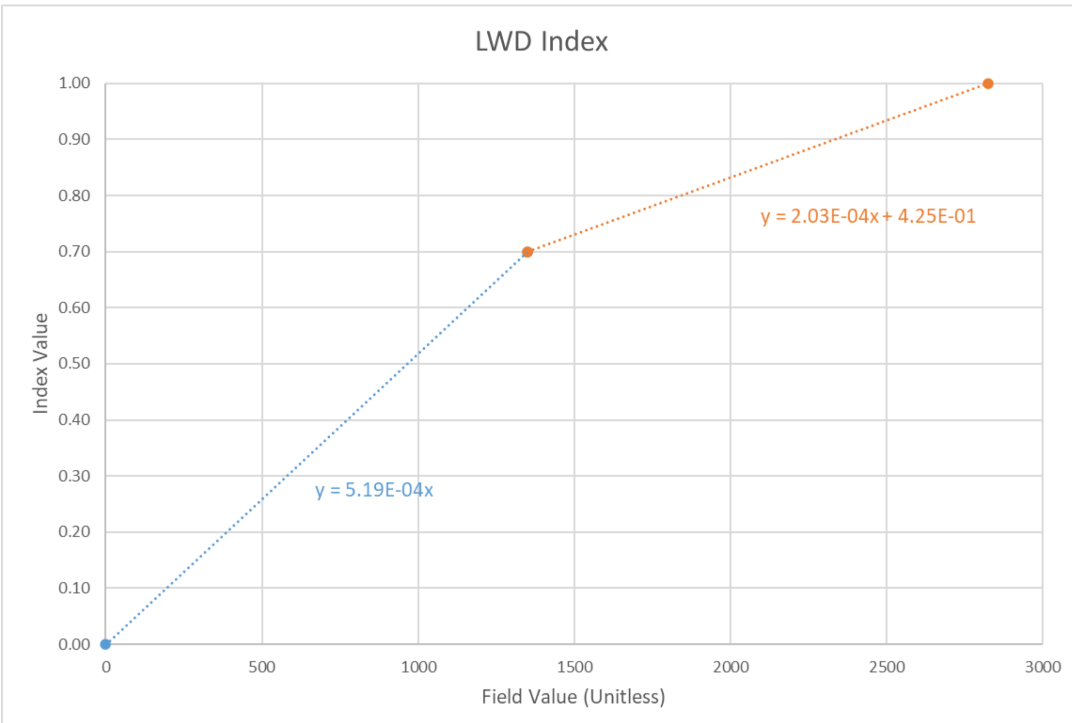
- The 75th percentile value from reference sites was used to define the 1.00 index value.
- The 25th percentile value from reference sites was used to define the 0.70 index value.
- The 0.00 index value equates to a LWDI value of 0 since the absence of large wood equals no functional capacity for this metric.

Threshold values are presented in Table 5-1 and the reference curve is plotted in Figure 5-1. Data from the managed sites were compared to the reference curve results. The 75th percentile value from the managed sites (n=11) was 1,263 meaning that most managed sites would fall within the functioning-at-risk range of index scores or lower, which is consistent with the expectations in the field, i.e., that managed sites would not represent a fully functioning condition.

Table 5-1: Threshold values for Large Woody Debris Index.

Index Value	Field Value
1.00	≥ 2,825
0.70	1,350
0.00	0

Figure 5-1: Reference curve for Large Woody Debris Index.



LIMITATIONS AND DATA GAPS:

Data collection in reference quality streams is needed to confirm the applicability of this reference curve in Wisconsin. The reference curve was developed from a relatively small dataset in Michigan and should be tested and verified in Wisconsin. Further refinement and stratification of reference curves are encouraged as data are collected in Wisconsin. Future stratification could consider the role of ecoregion, drainage area, valley type, forest age, canopy type, and other variables (Wohl 2011; Wohl and Beckman 2014).

5.2. LWD FREQUENCY (# PIECES/100M)

SUMMARY:

The LWD Frequency metric is a count of the LWD pieces in a 100-meter (328-ft) section of the reach, where each piece is counted separately (including within debris dams). A piece must be at least 10 cm in diameter at one end (Wohl 2000; Davis et al. 2001) and over 1 meter in length (Davis et al. 2001) to be considered LWD. The count does not include LWD beyond the top of bank on the floodplain or terrace. This method is a straight-forward, rapid assessment of LWD presence, and is an indicator of its overall structural influence of LWD within the stream.

REFERENCE CURVE DEVELOPMENT:

The reference curves for the LWD frequency metric were developed using the same reference dataset from Michigan that was used to inform the LWDI reference curve, which includes 5 reference standard sites and 11 managed sites.

Data collection in MI focused on the LWDI, which counts individual pieces and dams, but not the number of pieces within each dam. However, because a dam must contain three pieces of LWD to qualify as a dam in the LWDI, the total number of pieces was estimated by assuming all dams contained three pieces of LWD. These estimated piece counts are likely lower than the actual number of pieces that would be collected with the LWD Frequency metric given that there are likely many dams that contain more than three pieces of LWD. If reassessed using the protocols presented in the User Manual, it is likely these sites would yield higher scores than presented here.

Thresholds were developed as follows:

- The threshold for the 1.00 index value was informed by the 75th percentile value from reference standard sites (n=5).
- Unlike the LWDI, the threshold for the 0.70 index value was informed by the 75th percentile of the managed sites rather than the reference standard data set. This decision was made to account for the differences in how the LWDI and LWD Frequency metrics calculate scores for dams. The managed sites provide a more accurate piece count than the reference standard dataset because they contained fewer dams, and therefore there would be less error or underestimation of pieces within these sites.
- The index value of 0.00 equates to the absence of LWD in the reach (field value = 0). No large wood in the reach equates to no function for this metric.

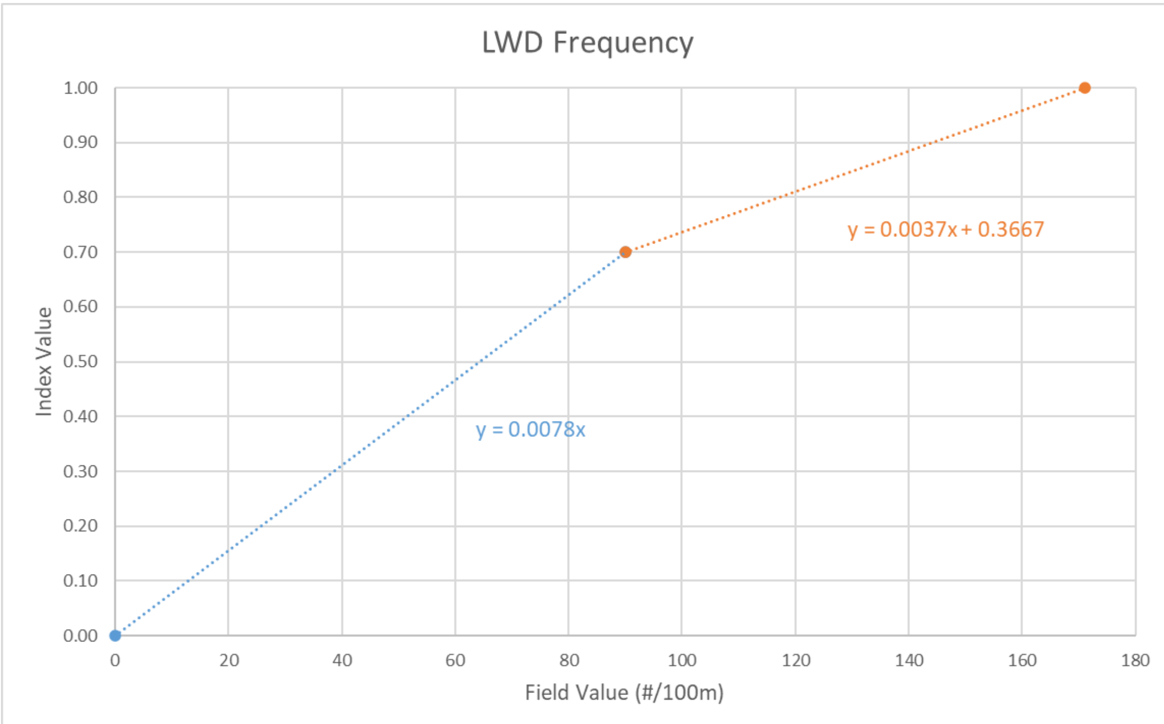
The slope of the reference curve was compared with the LWDI reference curve to determine whether similar index values would be generated when applying either of the two metrics. Because the LWD Frequency metric is provided as a rapid alternative to the LWDI metric, it is important that reference curves yield comparable results. Index values were calculated for all sites within the MI dataset (n=16) for LWDI and LWD Frequency and compared in a regression analysis, which showed a strong correlation between index scores using each method (r^2=0.80).

Threshold values are presented in Table 5-2 and the reference curve is plotted in Figure 5-2.

Table 5-2: Threshold values for Large Woody Debris Frequency.

Index Value	Field Value
1.00	≥ 171
0.70	90
0.00	0

Figure 5-2: Reference curve for Large Woody Debris Frequency.



LIMITATIONS AND DATA GAPS:

The reference curve for the LWD Frequency metric was informed by reference data from Michigan and thus data collection and analysis in Wisconsin is needed. Further refinement and stratification of reference curves are encouraged as data is collected in Wisconsin. Future stratification could consider the role of ecoregion, drainage area, valley type, forest age, canopy type, and other variables influencing contribution of LWD to the stream (Wohl 2011; Wohl and Beckman 2014).

Chapter 6 Lateral Migration Parameter

FUNCTIONAL CATEGORY: Geomorphology

GEOMORPHOLOGY FUNCTIONAL STATEMENT: Transport of wood and sediment to create diverse bed forms and dynamic equilibrium.

FUNCTION-BASED PARAMETER SUMMARY:

Lateral migration is the movement of a stream across its floodplain and is largely driven by processes influencing bank erosion and deposition. Natural processes of lateral migration vary by landscape. A channel in dynamic equilibrium maintains its cross-sectional area while moving across the landscape; that is, lateral erosion and deposition are approximately equal. Alternately, systems naturally in disequilibrium, like braided streams in glacial valleys, steep ephemeral channels, and alluvial fans may naturally experience higher rates of bank erosion as they alternate between aggrading, incising or avulsing states due to natural patterns in sediment supply and hydrologic processes (Roni and Beechie 2013).

This parameter is included in the geomorphology functional category because it provides information about sediment supply/transport and dynamic equilibrium processes. Harman et al. (2012) provides a detailed review of bank migration and lateral stability processes, and stream types that are susceptible to lateral migration versus those where migration is naturally constrained.

There are multiple approaches that can be used to measure or estimate lateral migration processes and condition. Some of these approaches include:

- Aerial imagery interpretation of bank retreat, measurements of belt width divided by bankfull width (meander width ratio), and visual assessment of bank cover and stability by photointerpretation of land use and cover types (Rosgen 1996; NRCS 2007).
- Semi-quantitative measures of bank cover and stability measured over the entire reach length (BLM 2017; WDEQ 2018; Binns 1982).
- Bank Erosion Potential Index (WDNR 2010).
- The Bank Erosion Hazard Index/Near-Bank Stress approach (BEHI/NBS, Rosgen 2014).
- Measurements of bank erosion using surveyed cross sections, bank profiles, or bank pins (Rosgen 2014).
- A modeling program, such as the Bank Stability and Toe Erosion Model, which is an intensive approach if data are not available for model calibration, and a moderately intensive approach if data are available (Simon et al. 2009).
- Measures of the extent of bank erosion and/or armoring within a reach (NRCS 2007).

The WISQT TC decided to include the Dominant Bank Erosion Hazard Index/Near-Bank Stress (dominant BEHI/NBS), percent streambank erosion, and percent streambank armoring metrics in the WISQT. These metrics are measures of channel condition that serve as indicators of altered processes, but do not characterize lateral migration rates or sediment processes themselves. The dominant BEHI/NBS metric identifies the dominant BEHI/NBS category rating within the representative sub-reach, thus providing an indication of erosion magnitude. The percent streambank erosion metric relies on the BEHI/NBS ratings from the BEHI/NBS assessment to identify the extent of actively eroding banks within the representative sub-reach. The dominant BEHI/NBS and percent streambank erosion metrics should be applied together, as they serve as indicators for the magnitude and extent of erosion within the project reach, respectively.

The Bank Erosion Hazard Index (BEHI) and Near Bank Stress (NBS) are two bank erosion assessment tools from the Bank Assessment for Non-point source Consequences of Sediment (BANCS) model (Rosgen 2009). While BEHI/NBS ratings have yielded mixed results when used to predict erosion rates (McMillan et al. 2017), the dominant BEHI/NBS rating is an indicator of the severity of bank erosion and the potential for accelerated bank erosion due to geotechnical and hydraulic forces. The State of Wisconsin has a similar method, the Bank Erosion Potential Index (BEPI), which is a rapid, quantitative and qualitative assessment of erosion adapted from BEHI/NBS (WDNR 2010). The BEPI was considered for inclusion in the WISQT, either in addition to or as a replacement for BEHI/NBS, but due to differences in data collection methods the WISQT TC decided to retain the BEHI/NBS. Dominant BEHI/NBS was included in the WISQT for the following reasons:

- It is rapid to moderate in terms of time required to collect data depending on the way it is implemented. Rosgen (2014) outlines several data collection approaches to measure BEHI and NBS depending on study objectives and site conditions.
- By integrating two ratings, the method assesses both geotechnical (BEHI) and hydraulic (NBS) forces, which is unique among rapid methods. This is important because vertical banks devoid of vegetation may visually appear to be eroding, but if the hydraulic forces acting against the bank are very low, and bank materials are cohesive and non-stratified, there may be little to no bank erosion potential.
- It is a method used by practitioners of natural channel design, which is a common approach used in compensatory stream mitigation programs (ELI et al. 2016).

Bank armoring includes any rigid human-made stabilization practice that permanently prevents lateral migration processes (see Glossary of Terms). Recognizing the adverse consequences of armoring treatments in streams, the WISQT includes a basic bank armoring metric in the lateral migration parameter. In many systems armoring treatments can be considered an adverse impact or form of functional loss, and the other metrics described above do not adequately capture the functional loss associated with hard armoring practices.

The armoring metric is only used if armoring techniques are present or proposed in the project reach. This decision was made to avoid diluting the score when armoring is not part of the system. For example, if armoring was given a 0.00 score on a site with excessive erosion, it would artificially improve the lateral migration score because it would be averaged with the other two metrics. By omitting armoring, the lateral migration score will reflect the bank erosion condition.

METRICS FOR LATERAL MIGRATION:

- Dominant BEHI/NBS
- Percent Streambank Erosion (%)
- Percent Streambank Armoring (%)

6.1. Dominant BEHI/NBS

Summary:

The Bank Erosion Hazard Index (BEHI) and Near Bank Stress (NBS) are two bank erosion estimation tools from the Bank Assessment for Non-point source Consequences of Sediment (BANCS) model (Rosgen 2009). BEHI and NBS ratings are determined based on collecting field measurements and visual observations. The BEHI assessment includes the evaluation of streambank height, bankfull height, depth and density of roots, vegetation cover, and bank angle. From the streambank assessment, a categorical BEHI risk rating is assigned, from very low to extreme. Methods with differing levels of rigor can be employed to measure NBS (Rosgen 2006). All methods determine channel flow characteristics against the study bank to assign a NBS risk rating, which also ranges from very low to extreme.

This metric requires assessment of the outside of all meander bends and any banks that are actively eroding. The dominant BEHI/NBS is the rating that occurs most frequently based on assessed bank length. For example, a dominant BEHI/NBS rating of High/High means that most of the assessed length (e.g., outside meander bends) has this rating. The score characterizes the magnitude of erosion potential within the representative sub-reach.

Reference Curve Development:

Reference curves for this metric have been adopted without modification from the MNSQT for consistency (MNSQT SC 2020b), and this section is reproduced with minor revision for application in Wisconsin.

The BEHI/NBS metric relies on categorical data, so numerical reference curves, like those developed for other metrics, were not developed. Instead, this metric relies on the characterization of BEHI/NBS combination ratings assigned to one of four stability categories (Table 6-1, Rosgen 2008).

Table 6-1: Dominant BEHI/NBS stability ratings provided in Rosgen (2008).

Stable	Moderately Unstable	Unstable	Highly Unstable
VL/VL, VL/L, VL/M, VL/H, VL/VH, VL/Ex, L/VL, L/L, L/M, L/H, L/VH, M/VL	M/L, M/M, M/H, L/Ex, H/VL, H/L*	M/VH, M/Ex, H/M, H/H*, VH/VL, Ex/VL, Ex/L	H/Ex, Ex/M, Ex/H, Ex/VH, VH/VH, Ex/Ex
*Key: (VL) is very low, (L) is low, (M) is moderate, (H) is high, (VH) is very high, etc. * The table above differs slightly form the source reference.*			

Rosgen's stability ratings were related to functional capacity as follows: stable represents functioning, moderately unstable represents functioning-at-risk, and unstable and highly unstable represent not-functioning. Specific index values were assigned based on the relationships between Rosgen's stability ratings and functional capacity (Table 6-2) using the following rationale:

- The ratings within the stable category were considered to represent a functioning condition (1.00). Stable in this context indicates that functioning streams migrate laterally at appropriate rates and maintain their cross-sectional area and sustain functioning riparian vegetation while their position on the landscape may change.

- The ratings within the moderately unstable category were considered to represent a functioning-at-risk range of conditions (0.30-0.69).
- The ratings within the Unstable and Highly Unstable categories were considered to represent a not-functioning condition (0.00-0.29).

Within these index ranges, the ratings were assigned an index value based on the severity of the instability, with more unstable ratings receiving lower scores.

Table 6-2: Index Values for Dominant BEHI/NBS.

Index Value	Field Value
0.00	H/VH, H/Ex, VH/VH, VH/Ex, Ex/M, Ex/H, Ex/VH, Ex/Ex
0.10	M/Ex
0.20	M/VH, H/M, H/H, VH/M, VH/H
0.30	M/H, Ex/L, Ex/VL
0.40	H/L, VH/L
0.50	H/VL, VH/VL, M/M
0.60	L/Ex, M/L
1.00	VL/VL, VL/L, VL/M, VL/H, VL/VH, VL/Ex, L/VL, L/L, L/M, L/H, L/VH, M/VL
Key: (VL) is very low, (L) is low, (M) is moderate, (H) is high, (VH) is very high, (Ex) is extreme	

LIMITATIONS AND DATA GAPS:

This metric is applicable where the reference standard is a stable channel. For systems with naturally high rates of bank erosion (e.g., braided streams in glacial valleys), this metric is not applicable and should not be assessed.

If bankfull dimensions are not accurately determined for a site, then the BEHI will not accurately represent erosion processes. Information on verifying bankfull stage is provided in the User Manual.

6.2. PERCENT STREAMBANK EROSION

SUMMARY:

This metric estimates the percent of the streambank within a reach that is actively eroding, according to the BEHI/NBS rating data from the representative reach. The percent eroding streambank metric provides a measure of the extent of bank erosion, whereas the dominant BEHI/NBS rating provides the magnitude of active bank erosion. BEHI/NBS ratings that represent actively eroding banks are listed in Table 6-3. These ratings were originally categorized by the WSTT (2018); all stable and some moderately stable ratings were categorized as non-eroding.

The field value is calculated by adding the length of BEHI/NBS ratings that represent actively eroding banks from the left and right banks and dividing it by the total bank length (e.g., reach length times two). Note that riffle sections that are not eroding and depositional areas like point bars are not evaluated in the BEHI/NBS assessment, but these sections are included when calculating the total bank length (denominator) for this metric.

Table 6-3: BEHI/NBS stability ratings for actively eroding and non-eroding banks.

Non-eroding Banks	Actively Eroding Banks
BEHI ratings of VL, L, M/VL, M/L	M/M, M/H, M/VH, M/Ex, BEHI ratings of H, VH, or Ex
Key: (VL) is very low, (L) is low, (M) is moderate, (H) is high, (VH) is very high, (Ex) is extreme	

REFERENCE CURVE DEVELOPMENT:

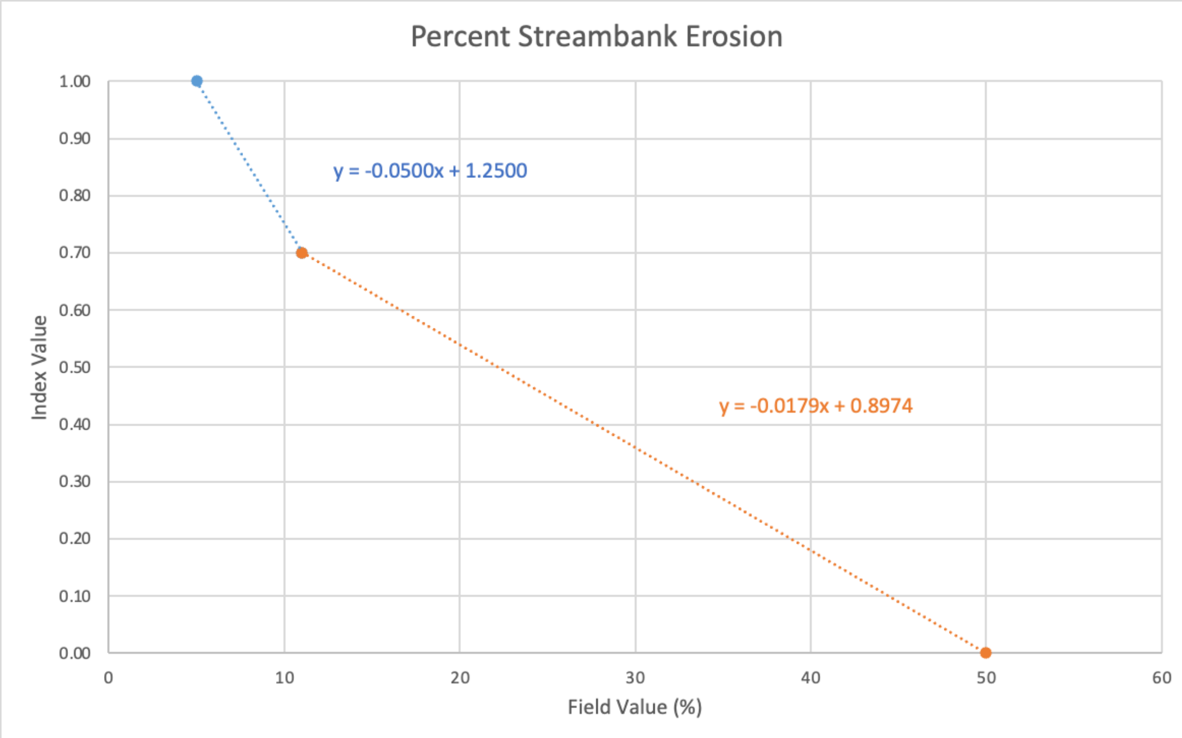
Given that lateral migration is a natural process, all rivers are expected to have some amount of eroding streambanks. Existing SQTs have generally defined the functioning range of index values using field values between 5-10% streambank erosion within a reach, and the WISQT TC decided to carry these threshold values forward in the WISQT. This range was originally informed by the Habitat Quality Index for trout streams (Binns 1982) which relates length of eroding bank with potential to support trout, notably that 0-9% eroding banks are completely adequate to support trout. The 0.00 index value was adopted from the SC SQT (South Carolina Steering Committee 2021), which relied on data from the Piedmont region of North Carolina (Donatich 2020). The 75th percentile value of the degraded sites (n=6) from this dataset was used in the SC SQT to define the 0.00 threshold value. The WISQT TC decided to adopt this threshold value, as it was informed by data from degraded sites. This decision is supported in the literature (Binns 1982), as greater than 50% streambank erosion provides very limited potential to support trout.

Threshold values are identified in Table 6-4, and reference curves are illustrated in Figure 6-1.

Table 6-4: Threshold values for Percent Streambank Erosion.

Index Value	Field Value (%)
1.00	≤ 5
0.70	11
0.00	≥ 50

Figure 6-1: Reference curve for Percent Streambank Erosion.



LIMITATIONS AND DATA GAPS:

This metric is applicable where the reference standard is a stable channel. For systems with naturally high rates of bank erosion, this reference curve is not applicable, and the metric should not be assessed.

Since the reference curve is not based on Wisconsin data, further refinement and stratification should occur in the future as data becomes available.

6.3. PERCENT STREAMBANK ARMORING

SUMMARY:

Bank armoring is a common technique to stabilize banks and/or prevent lateral migration. It is defined as any rigid human-made stabilization practice that permanently prevents lateral migration processes and typically involves the establishment of hard structures (e.g., riprap, gabion baskets, concrete or other engineered materials that prevent streams from meandering) along the bank edge. More natural approaches to reducing bank erosion, like toe-wood and/or other non-hard bioengineering techniques, are not considered armoring for purposes of the WISQT.

Literature shows that bank armoring can have positive and negative effects on aquatic functions (Fischenich 2003; Henderson 1986; Reid and Church 2015). Beneficial effects of armoring are often localized and may include the creation of fish habitat (pool and cover formation) and the reduction in excessive bank erosion and sediment supply. Negative effects of armoring often extend beyond the armored reach and include loss of fish habitat, loss of biological diversity, loss of streambank vegetation and riparian habitat, and impacts to floodplain development and channel evolution by preventing natural rates of lateral migration (Fischenich 2003; Henderson 1986). Bank armoring can also lead to accelerated bank erosion and changes in sediment dynamics in adjacent reaches. Studies documenting the effects of reach-scale streambank armoring on geomorphology, biology, and the ecosystem at large are preliminary and call for more research (Stein et al. 2013; Reid and Church 2015).

Other metrics within the lateral migration parameter do not adequately capture the functional losses associated with hard armoring practices, so the WISQT TC included a bank armoring metric in the lateral migration parameter. Importantly, the armoring metric should only be used if armoring techniques are present or proposed in the project reach. If banks are not unnaturally armored in the project reach, a field value should not be entered.

The percent of streambank that is armored is calculated as the total length of armored bank within the entire project reach divided by two times the project reach length. Note that this differs from other metrics for lateral migration, which are measured in a representative sub-reach.

Reference Curve Development:

The reference curve for this metric has been adopted without modification from the MNSQT (MNSQT SC 2020b). Threshold values are identified in Table 6-5 and the reference curve is illustrated in Figure 6-2. The discussion from Section 5.3 of the MNSQT Science Support Document (2020b) is reproduced here for reference:

No studies explicitly evaluated the relationship between the extent of armoring to functional impairment by stream length. Therefore, best professional judgment was used to set threshold values:

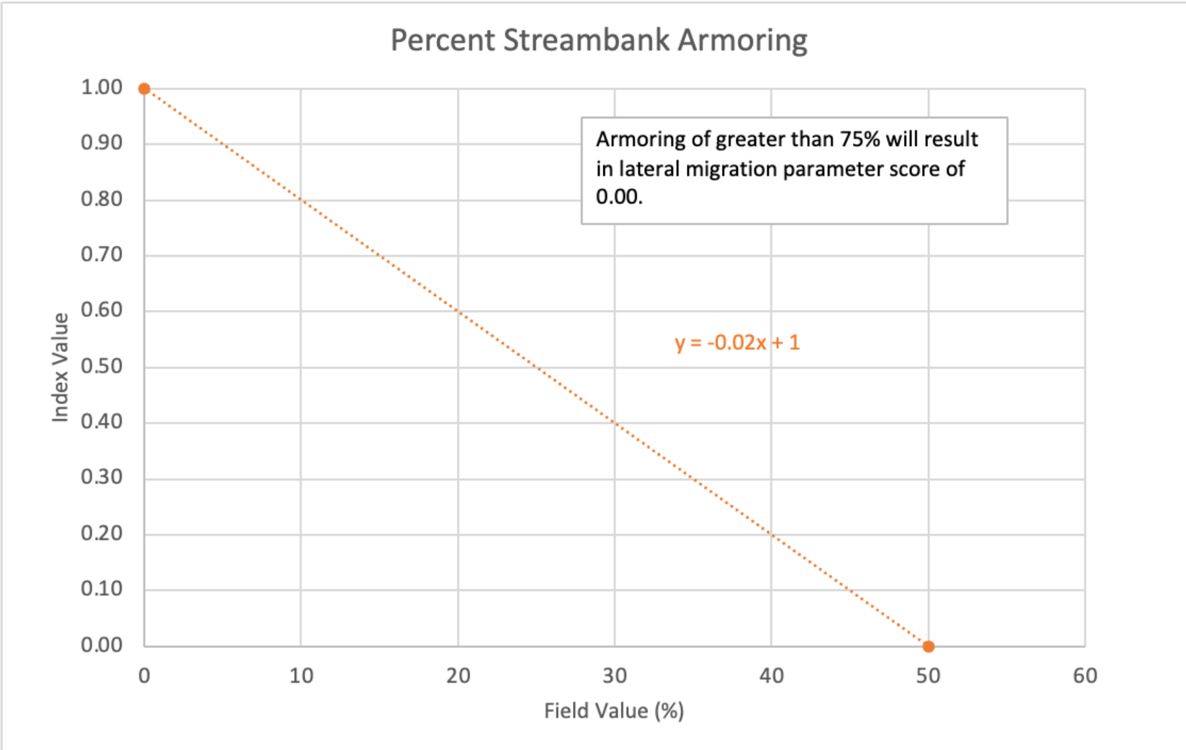
- *Functioning: Because hard armoring would be absent in reference standard sites, a field value of no armoring (0%) was assigned an index value of 1.00.*
- *Not-functioning: Fifty percent (50%) armored was assigned an index score of 0.00 and a linear relationship was established between the two points. Setting the minimum index value at 50% armored stream length seemed reasonable, as it means that half of the project reach is armored on both sides of the channel or one side is armored throughout the reach. At this level of armoring, the reach could be considered channelized and functional loss of channel migration processes could be severe.*

Based on best professional judgement, if more than 75% of the reach is armored, it is recommended that the other metrics in the lateral migration parameter not be measured. At this magnitude, the armoring is so pervasive that lateral migration processes would likely have no functional value.

Table 6-5: Threshold values for Percent Streambank Armoring.

Index Value	Field Value (%)
1.00	0
0.00	≥ 50

Figure 6-2: Reference curve for Percent Streambank Armoring.



LIMITATIONS AND DATA GAPS:

Although most of the literature and available studies document a negative relationship between bank armoring and multiple stream functions, no information could be found relating the extent of armored stream banks to the magnitude of functional loss. The reference curves for this metric will benefit from validation and testing.

Chapter 7 Riparian Vegetation Parameter

Functional Category: Geomorphology

Geomorphology Functional Statement: Transport of wood and sediment to create diverse bed forms and dynamic equilibrium.

Function-based Parameter Summary:

Riparian areas are zones of direct interaction between aquatic and terrestrial ecosystems characterized by distinct biological, geomorphic, and hydrologic processes (Gregory et al. 1991). Riparian plant communities play a critical role in supporting channel stability, as well as physicochemical and biological processes, and that is why this parameter is included in geomorphology (Harman et al. 2012). Riparian vegetation supports numerous instream and floodplain functions, including cover and shading; temperature moderation; channel stability; filtration of excess nutrients, sediments, and pollutants; source areas for carbon, nutrients, and wood recruitment; floodplain roughness; terrestrial habitat and wildlife movement corridors; and plant diversity, species richness, and functional integrity. Some of these riparian functions are structural, such as stream shading or floodplain roughness, while other functions are influenced by the composition of riparian plant communities.

Wisconsin's vegetation communities are diverse, and their historical distribution and abundance was largely shaped by glaciers, climate, fire, and wind (WDNR 2015). Vegetation communities include grasslands, oak openings and oak savannahs, oak and pine barrens, northern forests, southern forests, and wetlands, with variation in community patterns across 16 distinct ecological landscapes. Riparian areas in Wisconsin are highly variable given the variety of stream types and the ecological, geological, and climatic gradients across the state. This variation not only influences the plant assemblages of natural riparian areas of streams, but also the types of anthropogenic impacts that have changed these natural plant assemblages over time. Human activities, such as fire suppression, timber extraction, agriculture and other land use changes have led to substantial changes in vegetation distribution and abundance, and, along with the introduction of non-native species, has altered the structure and composition of riparian communities.

All existing SQTs include metrics that quantify riparian extent and structure, while some also include composition metrics. The WISQT TC selected four metrics to characterize riparian vegetation extent and structure. Consideration was given to including a species composition metric, particularly given that removal of non-native woody vegetation (e.g., hawthorn, honeysuckle, autumn olive, Russian olive, etc.) is a common riparian restoration practice in Wisconsin. At this point, the WISQT SC decided to not include a composition metric for two primary reasons. First, species composition is addressed in wetland credit policies, and there was concern that including a species composition metric in the WISQT could result in overlapping credits at sites proposing both wetland and stream mitigation. Second, the WISQT SC was interested in maintaining consistency with the MNSQT. The metrics selected are consistent with the MNSQT (MNSQT SC 2020b), which provides consistency within the St. Paul District, though the methods for establishing vegetation plots differ slightly.

In some SQTs, riparian extent is characterized using fixed buffer widths, while other states use comparisons of observed to expected riparian areas. Fixed buffer width methods can be limited as they do not account for the natural variability in riparian zone widths. For example, in confined valleys, riparian areas are naturally narrow, and may not extend as far as a fixed buffer width. Alternatively, in broad, alluvial systems, a fixed buffer width may only characterize a small fraction of the floodplain or riparian corridor. The MNSQT SC (2020b) developed the effective vegetated riparian area metric, which accounts for some of the natural variability in riparian extent by using the bankfull width in combination with a meander width ratio for different stream valley types (alluvial, confined alluvial, colluvial) (Harman et. al 2012).

Canopy cover, herbaceous cover, and woody stem basal area metrics quantify the structure of the riparian community. These metrics include data collected from two strata: herbaceous and woody < 1m and woody vegetation > 1m.

Where woody vegetation is determined to be the reference vegetation cover type within the riparian area, all four metrics should be assessed together. If woody vegetation is not the reference vegetation cover type, only the other three metrics should be assessed. Additional or alternative metrics for riparian vegetation may be considered in future versions pending further research and implementation.

METRICS FOR RIPARIAN VEGETATION:

- Effective Vegetated Riparian Area
- Canopy Cover
- Herbaceous Cover
- Woody Stem Basal Area

7.1. EFFECTIVE VEGETATED RIPARIAN AREA

SUMMARY:

The effective riparian area is the area adjacent to and contiguous with the stream channel that supports the dynamic equilibrium of the stream. The effective *vegetated* riparian area metric is the proportion of the effective riparian area that consists of natural vegetation. Areas that have anthropogenic features (roads, buildings, utility lines, etc.); or agricultural vegetation that is harvested, removed, or otherwise managed (crops, sod, tree farms, etc.); or low relative areal vegetation cover (≤ 50%) are not considered vegetated for this metric. Identifying the effective riparian area is important, as functioning riparian areas influence (and are influenced by) many instream and floodplain processes (Fischer and Fischenich 2000; Mayer et al. 2005).

The effective riparian area is initially estimated by multiplying the bankfull width of the stream by the meander width ratio for the stream valley type and then adding an additional width. The added width, like the meander width ratio, varies according to stream valley type with alluvial streams having the highest width and colluvial the lowest. This estimate is then adjusted to align with hydrologic, floodplain and topographic indicators following desktop review and field verification. The effective vegetated riparian area is then calculated by determining the percent of the established effective riparian area that is naturally vegetated (free of anthropogenic features).

Other SQTs, including Colorado, Alaska, and Wyoming, primarily rely on desktop and field-based observations to determine the expected riparian extent using geomorphic, topographic, and hydrologic attributes and only rely on the meander width ratio approach in the absence of field indicators. In the development of the WISQT, the WISQT TC decided that a combination of meander width ratio, desktop, and field methods to establish the effective riparian area would be appropriate given the lack of reference data for identifying field indicators and the potential for inconsistencies among tool users.

REFERENCE CURVE DEVELOPMENT:

The reference curve for the effective vegetated riparian area metric was adopted without revision from the riparian extent metric reference curves in the Colorado SQT (CSQT) Version 1.0 (USACE 2020b) for use in the WISQT.

The following is an excerpt from the CSQT v1.0 Science Support Document (USACE 2020b) describing the reference curve development:

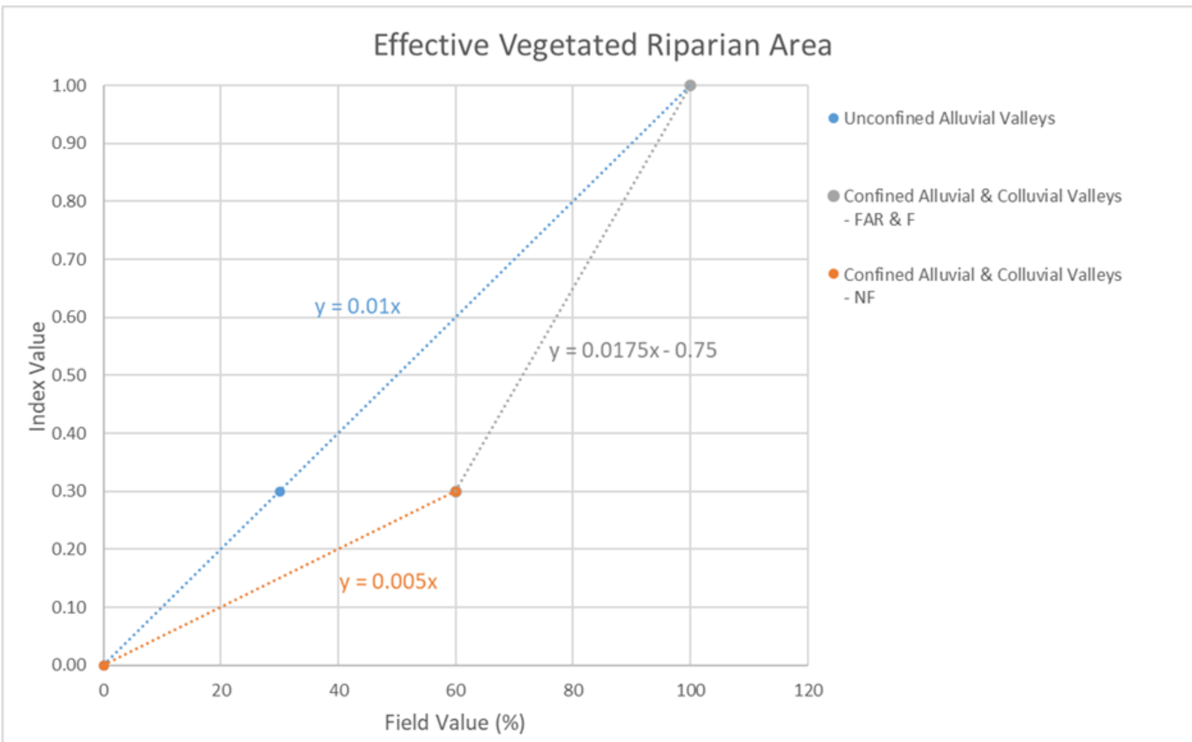
> *Limited data and peer reviewed literature are available to inform thresholds and reference curves, as much of the existing literature is related to fixed-width buffers. Thus, reference curves were developed primarily using best professional judgement. The reference curves and thresholds are intended to encourage and incentivize restoration activities that restore riparian and floodplain connectivity or remove stressors and human land uses from the riparian zone.*
>
> *Stratification of reference curves took into consideration how hydrologic and geomorphic processes drive riparian zone development. Merritt et al. (2017) recommends stratifying riparian areas by valley type using a Hydrogeomorphic Valley Classification framework, which identifies nine valley types, but also acknowledges that other simpler classification approaches (e.g., Rosgen 1996) may also be useful to place a stream segment within its watershed context. For this metric, we stratified based on valley type, recognizing the differences in hillslope and valley bottom processes that influence riparian extent in confined and unconfined valleys.*
>
> *Once stratified into valley types, consideration was given as to how the influence of potential stressors in the floodplain or adjacent stream area and changes to the hydrologic regime would affect the degree to which riparian zones function, and in turn, support instream functions. For example, whether the extent of riparian zone modification may substantially affect the recruitment of wood and organic matter, nutrient and carbon cycling, flood retention, buffering from sediment and pollutant influxes, and habitat availability (Fischer and Fischenich 2000; Sweeney and Newbold 2014). In confined and colluvial valleys, where streams and riparian zones are constrained by hillslope processes, riparian width is naturally narrower, and consequently, stressors within that area could be disproportionately higher. A reduction in riparian width of 30% would likely reflect a substantially altered, or not-functioning condition, with little remaining flood prone area and a reduced capacity to recruit wood and organic matter and buffer the stream from sediment or pollutant influxes. This magnitude of riparian area loss may no longer support instream and floodplain functions. In unconfined valleys, where riparian areas are naturally broader, a greater proportion of the riparian area may be affected (e.g., 60%) before a similar loss in functionality might occur.*

Threshold values are presented in Table 7-1, and reference curves in Figure 7-1.

Table 7-1: Threshold values for Effective Vegetated Riparian Area.

Index Value	Field Value (%)	
	Unconfined Alluvial Valleys	Confined Alluvial and Colluvial Valleys
1.00	100	100
0.30	30	60
0.00	0	0

Figure 7-1: Reference curves for Effective Vegetated Riparian Area.



LIMITATIONS AND DATA GAPS:

Effective vegetated riparian area is a new metric that has only been available in Minnesota since 2020, and reference curves developed for the CSQT version 1.0 (USACE 2020b) were developed using the Colorado Technical Committee's collective expertise. Additionally, the CSQT v1.0 methods to delineate riparian extent rely primarily on geomorphic, topographic, and hydrologic indicators of the effective riparian area; the meander width ratio approach is only applied in altered systems where these indicators are no longer present. Importantly, the meander width ratio method is only an approximation of effective riparian area and may under or overestimate riparian extent within a project reach. Additional data are needed to test the use and applicability of this metric and its reference curves.

This metric would benefit from additional validation, review, and refinement as the tool is applied. For instance, to better account for Wisconsin's natural variability in riparian extent beyond the valley stratification applied here, this metric may benefit from additional stratification or the inclusion of field-based indicators in determining effective riparian area. Accurately estimating the expected, or effective, riparian area is integral to proper application of this metric, and additional testing is needed to evaluate the accuracy and applicability of the current approach.

7.2. Canopy Cover

Summary:

Many riparian areas and wetlands in Wisconsin are naturally characterized by a woody canopy, which provides important functions such as roughness and structure within the floodplain, as well as shading and organic matter inputs to the stream. Extensive lowland hardwood forests occur within the floodplains of larger rivers in southern portions of the state, particularly the Driftless Area (WDNR 2015). Forested wetlands and riparian areas dominated by conifers, hardwoods, or a mix of tree species occur on alluvial soils in floodplains throughout glaciated parts of Wisconsin. Many of these areas have been heavily influenced by changes in land use, fire regimes, timber harvest and historic log drives, and the encroachment of non-native and invasive species. Impacts from logging or development can result in a reduction in canopy coverage within the riparian area and the surrounding watershed, which can lead to increased runoff and erosion, resulting in sloughing, blow down and other processes that decrease riparian canopy cover.

Woody and forested communities are also interspersed with naturally herbaceous or grassland communities that provide valuable habitat functions and support rare species. These communities, including herbaceous wetland communities like southern sedge meadows and wet mesic prairies, are dominated by grammanoids and forbs, and maintain naturally low woody canopy cover. In these systems, natural patterns of fire suppressed woody vegetation, agriculture, and development have led to further fire suppression and subsequent woody vegetation encroachment. Herbaceous vegetation in the riparian area of many natural grassland stream reaches have been replaced with shallow-rooted woody species that are less effective at stabilizing soils and maintaining natural stream geomorphology and lateral migration patterns.

Because of the influence woody vegetation has on the vegetation structure of riparian areas, a canopy cover metric is important to include in the WISQT. The canopy cover metric is based on a visual plot-based vegetation assessment. The field value for this metric reflects the absolute cover of woody strata (> 1m). Methods are outlined in the User Manual.

Reference Curve Development:

Because of the natural variation in riparian communities, reference curves were stratified based on whether the reference vegetation community includes woody vegetation as a natural component. The WISQT TC considered including a third reference curve stratification for savannah and barren systems, which have wood as a natural component but are dependent upon fire or management to maintain a low tree density and a high herbaceous vegetation density (Curtis 1959). However, the WISQT TC decided to move forward with two curves, with the understanding that the USACE would review projects within these systems on a case-by-case basis and advise practitioners on which reference curve is appropriate for that specific project.

Existing riparian vegetation datasets were not available in Wisconsin to develop reference curves. Therefore, the WISQT TC considered whether values from existing literature sources could be used to inform reference curves. For woody communities, canopy cover estimates for natural communities in the Missouri Ozark Region (Dey et al. 2017) were used to develop reference curves. This dataset was shared with WDNR Division of Forestry staff who agreed that it represents a reasonable estimate of natural cover values for woody community types commonly found in Wisconsin. In Dey et al. (2017), canopy cover is presented for three communities, savannah (38-60%; average 51%), open woodland (50-80%; average 66%), and closed woodland (74-87%; average 81%). Threshold values for the functioning range of condition were developed based on the natural canopy cover ranges for open woodland and closed woodland communities (Table 7-2). The minimum index value 0.00 equates to no canopy cover (0%), as this represents no function for this metric.

When the reference vegetation type is herbaceous, the WISQT TC used the coarse level monitoring protocols developed for assessing condition in southern sedge meadows and wet mesic prairies (O'Connor 2020). These protocols were developed using data from over 1,100 wetlands across the full spectrum of condition gradients in Wisconsin. The protocols include structural metrics related to native and non-native canopy cover (tree and shrub species > 3ft), with specific cover ranges relating to five condition tiers. According to O'Connor (2020):

> *Native trees and shrubs are a natural component of southern sedge meadows, but due to fire suppression, legacy sediments, and hydrologic disruption leading to a lower water table, tree and shrub encroachment is a major concern. Progressively higher cover of woody species leads to the loss of sedges and native forbs through shading. Because tall woody species (i.e., over three feet tall) are the concern from shading, the metric evaluates only cover from taller-statured individuals.*
>
> *Native shrubs should be sparse in wet-mesic prairies. Higher coverage of woody species is an indicator of degradation due to fire suppression, hydrologic disruption leading to a lower water table, and nitrogen deposition. Progressively higher cover of woody species leads to the loss of sedges and native forbs through shading. Because the primary concern is from shading, the metric evaluates only cover from taller-statured individuals (i.e., over three feet tall) of either trees or shrubs.*

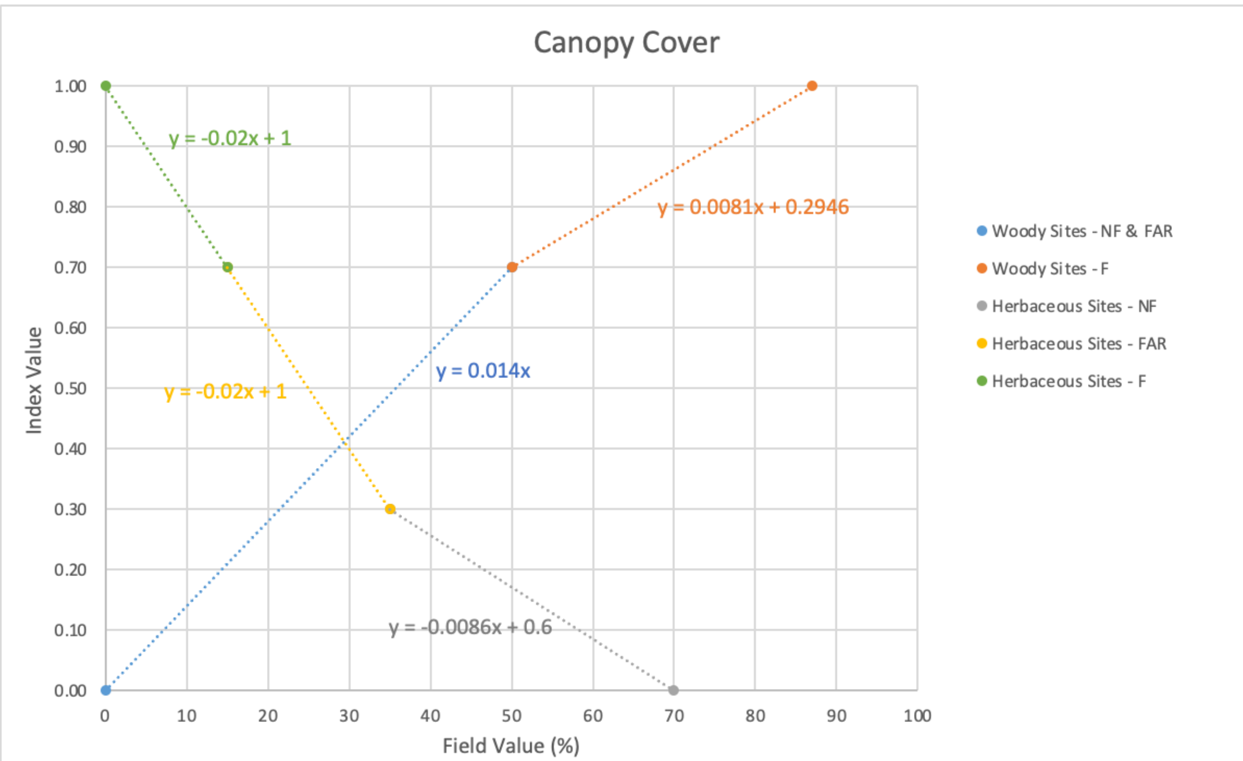
Cover values from the 'excellent' and 'good' condition tiers were used to develop thresholds for the functioning range of index values. Values from southern sedge meadows (0-20%) and wet mesic prairie (0-10%) were averaged to yield a cover value of 15% for the 0.70 index value and 0% was used for the 1.00 index value. Cover values from the 'poor' condition tier were used to develop thresholds for the not-functioning range of condition. Values from southern sedge meadow (40-70%) and wet mesic prairie (31-70%) were averaged to yield a cover value of 35% for the 0.30 index value and 70% for the 0.00 index value.

Threshold values are presented in Table 7-2, and reference curves in Figure 7-2.

Table 7-2: Threshold values for Percent Canopy Cover.

Index Value	Field Value (%)	
	Woody vegetation is the reference vegetation type	Woody vegetation is not the reference vegetation type
0.00	0	≥ 70
0.30	-	35
0.70	50	15
1.00	≥ 87	0

Figure 7-2: Reference curves for Percent Canopy Cover.



LIMITATIONS AND DATA GAPS:

The canopy cover reference curves were developed using the best available information at the time of regionalization. Validation and further refinement are needed as data are collected in Wisconsin or as new regional or national datasets become available.

A major challenge with this metric is the applicability of reference curves in oak openings, oak savannah, and oak and pine barrens in Wisconsin. The WISQT TC did not stratify these systems separately from other woody communities. These systems have naturally lower canopy cover than other woodland or forest systems, and high canopy cover values can indicate a system with reduced function. Because these communities would naturally sustain lower canopy cover, they would benefit from their own reference curve(s) and criteria, particularly to address the loss of functional capacity as the canopy closes. We believe this metric should still be applied in these systems but would expect them to generally score lower than their forested counterparts, and would note that at higher canopy cover values, index values are likely not a reflection of their functional capacity.

Woody vegetation is only characterized in the WISQT using structural metrics. As such, scoring will not accurately account for any functional capacity improvements associated with non-native species removal. Removal of non-native woody vegetation will result in lower scores for the woody cover and woody stem basal area metrics until native woody vegetation is reestablished. Over the course of the monitoring period, scores may continue to be lower than existing condition scores, depending on the length of the monitoring period and the success of any woody vegetation restoration efforts. Additional vegetation metrics may be used as performance standards or to monitor and determine successful establishment of riparian and wetland vegetation communities but are not included in the WISQT BETA version.

7.3. Herbaceous Cover

SUMMARY:

Herbaceous species are an important component of the riparian community as they often provide surface roughness and cover in the early stages of succession following fluvial disturbances (Youngblood et al. 1985; Winward 2000). Herbaceous vegetation also contributes to bank stability and floodplain roughness (Winward 2000). Some riparian communities naturally support only herbaceous species, including those that support broad, highly connected floodplains with anaerobic soil conditions, or those that have natural disturbance (flood or fire) regimes that do not favor the persistence of woody species (Youngblood et al. 1985; West and Ruark 2004; WDNR 2015). Herbaceous vegetation is a valuable structural component of plant communities, not only in grassland systems, but also in forested communities (Gilliam 2007). Higher herbaceous cover provides more leaf and stem surfaces to intercept precipitation and trap sediment. Areas that are devoid of herbaceous cover expose the riparian area to potential erosive forces.

Because of the contribution of herbaceous vegetation to overall vegetation structure of riparian areas, an herbaceous cover metric is important to include in the WISQT. The herbaceous cover metric is based on a visual plot-based vegetation assessment. The field value for this metric reflects the relative cover of the herbaceous strata, which includes all herbaceous vegetation and all woody vegetation < 1m (3.28 ft) tall. Methods are outlined in the User Manual.

REFERENCE CURVE DEVELOPMENT:

The reference curve for the herbaceous vegetation cover metric was adopted from the MiSQT v1.0 (MI EGLE 2020), using literature from Summers et al. (2017).

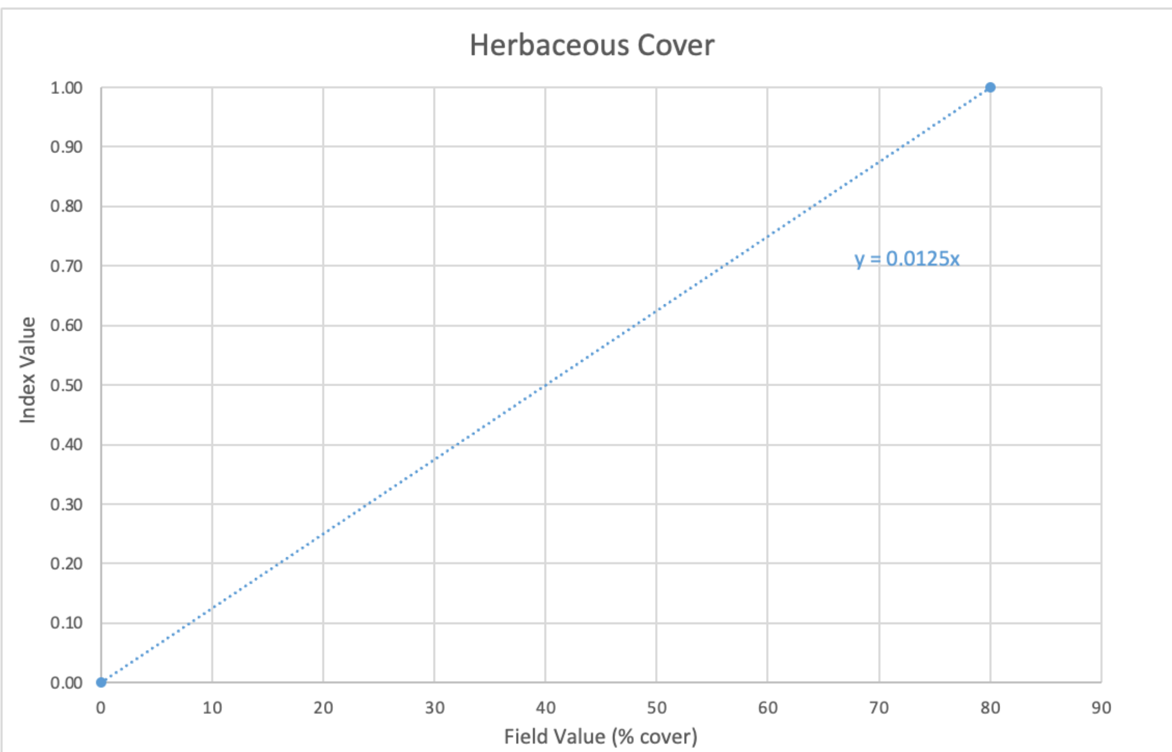
Riparian datasets were not available in Wisconsin to inform this reference curve; therefore, the WISQT TC considered the herbaceous cover metric and reference curves applied in neighboring states (MNSQT SC 2020b; MI EGLE 2020) to develop threshold values in Wisconsin. As noted in the MNSQT v1.0 Science Support Document (MNSQT SC 2020b), in the absence of anthropogenic disturbances, herbaceous cover is often high because of favorable climate conditions for plant growth. High canopy coverage can reduce herbaceous growth, but even in those instances, coverage in most areas tends to be high. While datasets were not available to tease apart the interaction of shrub and tree canopy versus herbaceous strata, the MNSQT v1.0 considered relative herbaceous cover values over 80% to be high based on their collective expertise. In the MiSQT, the herbaceous cover metric was based on total, or absolute areal cover, and total herbaceous cover values over 80% were used to define the 1.00 index value (MI EGLE 2020). The WISQT TC decided to adopt the same 80% cover value for the 1.00 index value in Wisconsin. Because of a lack of data, threshold values between functioning, functioning-at-risk and not-functioning were not defined. Instead, the WISQT TC decided to assign 0% cover to the minimum index value of 0.00, as no herbaceous cover reflects no function for this metric. This is consistent with the MiSQT v1.0 reference curve for herbaceous cover.

Threshold values are shown in Table 7-3 and the curve is shown in Figure 7-3.

Table 7-3: Threshold values for Herbaceous Cover.

Index value	Field Value (% cover)
1.00	≥ 80
0.00	0

Figure 7-3: Reference curve for Herbaceous Cover.



LIMITATIONS AND DATA GAPS:

The herbaceous vegetation metric reference curve was adapted from other state SQTs after consideration by the WISQT TC. Data collection in Wisconsin is needed to provide further refinement, including possible stratification.

Because a single reference curve was developed for this metric, there is no difference in index values between herbaceous and woody communities. It is likely that as woody vegetation develops, it could affect the cover provided in the understory, or herbaceous layer. These communities may naturally sustain lower herbaceous cover values and would benefit from their own set of reference curves and criteria. We believe this metric should still be applied in these systems but would expect them to generally score lower than herbaceous communities.

7.4. WOODY STEM BASAL AREA

SUMMARY:

Note: this metric is not applicable when the reference vegetation community is herbaceous.

The woody stem basal area metric is an estimate of the average amount of the effective riparian area occupied by woody stems. Woody stems intercept and slow flood and overland flows to protect against associated erosive forces. A higher basal area of woody stems will provide more attenuation of flows and protect the stream channel.

Woody stem basal area is assessed by stem counts and diameter measurements of stems at breast height (4.5 feet/1.37 meters) in plots. Woody stems near the ground surface function much like herbaceous stems and are difficult to effectively count and quantify. Stem occupancy per sample area is averaged across all sample plots to compute a woody stem basal area for the entire riparian area of the stream reach.

REFERENCE CURVE DEVELOPMENT:

The reference curve for this metric was adapted for use in the WISQT from the MNSQT v1.0, which was developed by the MNSQT Steering Committee based on regional expertise and regional and national basal area datasets (Table 7-4).

The compiled data indicated a wide range of functioning field values, and the MNSQT v1.0 reference curves assign a value of 60 ft^2/ac (13.8 m^2/ha) to the 1.00 index value under the assumption that once a certain basal area is achieved, it is likely to increase over time given the climate and conditions in forested regions where woody growth is pervasive. The WISQT TC agreed with this data and logic, retaining this field value as representative of the 1.00 index value.

Table 7-4: Datasets used to develop threshold values for Woody Stem Basal Area.

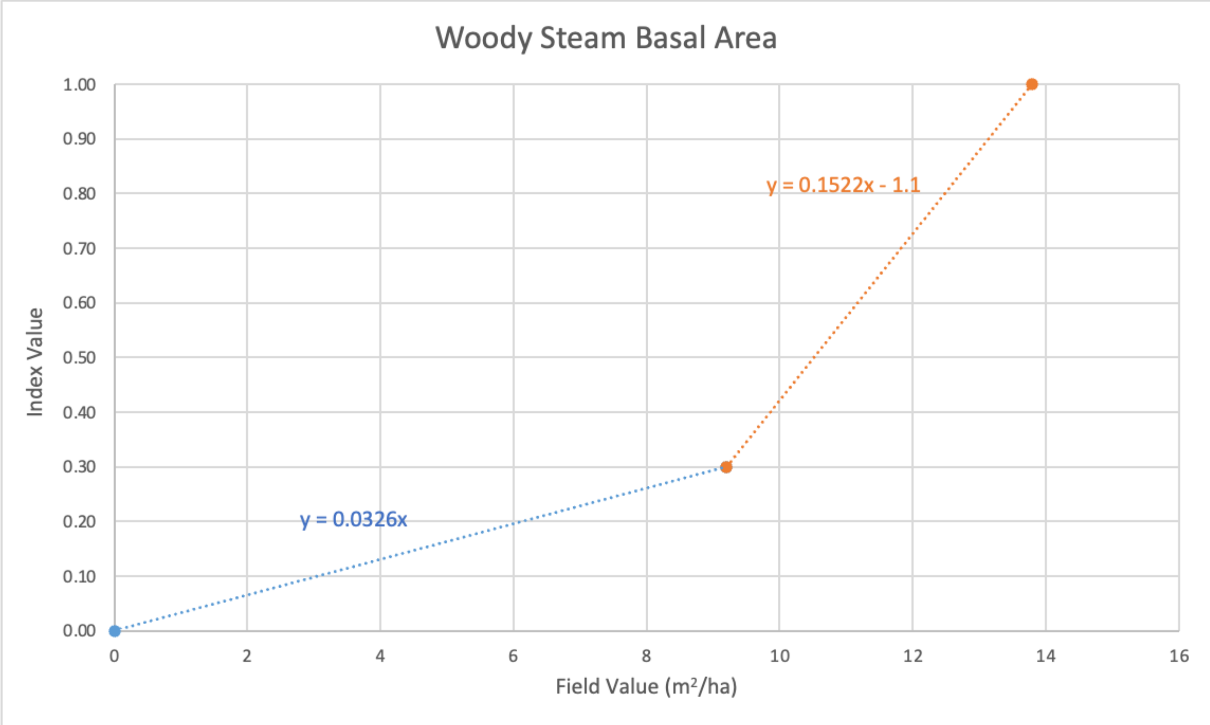
Field Value (ft^2/ac)	Field Value (m^2/ha)	Forest Type	State or Region	Reference
Not-Functioning Condition				
40	9.2	All Forests	MD	USFWS 2013
Functioning Condition				
60	13.8	All Forests	MD	USFWS 2013
60 – 80	13.8 – 18.4	Northern Hardwoods	NH	Leak et al. 2014
80	18.4	All Forests	MN	Miles et al. 2007
44.9	10.3	~30 yr. old *Unmanaged* - Northern Dry-Mesic Mixed Forest, Red-Pine-White Pine Woodland Type (FDn33a)	MN	Young et al. 2017
75.8	17.4	~30 yr. old *Managed* - Northern Dry-Mesic Mixed Forest, Red-Pine-White Pine Woodland Type (FDn33a)	MN	
137.7	31.6	~100 yr. old *Unmanaged* - Northern Dry-Mesic Mixed Forest, Red-Pine-White Pine Woodland Type (FDn33a)	MN	
152.6	35.0	~100 yr. old *Managed* - Northern Dry-Mesic Mixed Forest, Red-Pine-White Pine Woodland Type (FDn33a)	MN	
120	27.6 (Avg)	~50 yr. old Uplands (Aspen, Jack Pine, etc.)	MN	Sebestyen et al. 2011
54.5	12.5 (Avg)	49 to 100 yr. old Peatlands (Black Spruce & Hemlock)	MN	

In the MNSQT v1.0, a value of 40 ft^2/ac, or 9.2 m^2/ha, was assigned to a 0.00 index value based on forest stand guidelines from the state of Maryland for forested riparian buffers summarized in (USFWS 2013; MD DNR 1999; Palone and Todd 1997). A common piece of feedback related to this decision is that the reference curve does not account for young trees found after restoration and during the monitoring period. To address this concern, and after considering the functional capacity definitions outlined in Chapter 1, the WISQT TC decided that this value was more appropriate as the threshold between functioning-at-risk and not-functioning (0.30), as values below this represent a not-functioning condition (USFWS 2013). The WISQT TC decided to set the minimum index value 0.00 to 0 ft^2/ac or m^2/ha, as a riparian area with no trees meeting the measurement criteria would provide no function for this metric. Threshold values are shown in Table 7-5 and the curve is shown in Figure 7-4.

Table 7-5: Threshold values for Woody Stem Basal Area.

Index value	Field Value (ft^2/ac)	Field Value (m^2/ha)
1.00	≥ 60	≥ 13.8
0.30	40	9.2
0.00	0	0.0

Figure 7-4: Reference curve for Woody Stem Basal Area.



LIMITATIONS AND DATA GAPS:

Woody stem basal area varies greatly across plant communities due to differences in species composition and stand age classes. This metric does not account for these differences. In addition, the basal area reference datasets are based on a broader analysis of forested communities, and do not specifically address values within riparian areas, which may differ from upland forest stands. Additional data collection within forested riparian communities would be useful to validate or inform updates to the reference curve.

Woody vegetation is only characterized in the WISQT using structural metrics. As such, scoring will not accurately account for any functional capacity improvements associated with non-native species removal. Removal of non-native woody vegetation will result in lower scores for the woody cover and woody stem basal area metrics until native woody vegetation is reestablished. Over the course of the monitoring period, scores may continue to be lower than existing condition scores, depending on the length of the monitoring period and the success of any woody vegetation restoration efforts. Additional vegetation metrics may be used as performance standards or to monitor and determine successful establishment of riparian and wetland vegetation communities but are not included this version.

Chapter 8 Bed Form Diversity Parameter

Functional Category: Geomorphology

Geomorphology Functional Statement: Transport of wood and sediment to create diverse bed forms and dynamic equilibrium.

Function-based Parameter Summary:

Bed forms include the various channel units that maintain heterogeneity in the channel form, including riffles, runs, pools and glides (Rosgen 2014). The location, stability, and depth of these bed features are responsive to sediment transport processes acting against the channel boundary conditions. Bed form diversity is a function-based parameter used to assess these bed form patterns, specifically riffle-pool and step-pool sequences that comprise the dominant streambed forms in alluvial and colluvial valleys, respectively. This parameter evaluates bed form pattern in relation to expected patterns in channels with similar morphology. As such, this parameter is not a direct measure of fluvial processes but is an indicator of hydraulic and sediment transport processes (Knighton 1998). It is one of the original parameters described in Harman et al. (2012); readers should refer to this document for a more detailed description of how sediment transport processes affect the development of sand and gravel bedforms.

Numerous classifications of bed form exist and, at a broad level, can be grouped into three categories: sand bed forms (e.g., ripple, dunes, plane beds, and antidunes), gravel/cobble bed forms (e.g., riffle, run, pool and glide) and step-pool bed forms (Knighton 1998). Bed form diversity is important because channel patterns provide a diversity of habitats that aquatic organisms need for survival. For example, macroinvertebrate communities are often most diverse in riffle habitats due in part to greater hyporheic flow. Meanwhile, pools provide fish habitat, predator and thermal refugia, energy dissipation, support thermal regulation, and are an indication of how the stream is transporting and storing sediment (Allan and Castillo 2007; Knighton 1998; Hauer and Lamberti 2007). Without the diversity of riffles and pools, there is a potential for loss of biological diversity (Fischenich 2006; Mathon et al. 2013).

Harman et al. (2012) lists quantitative metrics that can be used to assess bed form diversity including: percent riffle and pool, facet (riffle/pool) slope, pool spacing, and pool depth variability. Stream assessment methods implemented by EPA (2016) use coefficients of variability to quantify bed variability throughout stream reaches; although this metric relies on data from equally spaced transects, and thus differs from the geomorphic survey methods used to inform other metrics in the WISQT. Many qualitative methods are also available to assess bed forms and in-stream habitats (Somerville and Pruitt 2004) but were not considered for the WISQT because quantitative measures are available and regularly used by practitioners.

The WISQT TC selected three metrics to quantify the bed form diversity parameter: pool spacing ratio, pool depth ratio, and percent riffle. Selection of these metrics was primarily based on practitioner familiarity and their ability to quantify in-stream habitat. These metrics are often used in quantitative geomorphic assessments of riffle-pool and step-pool sequences (Harrelson et al. 1994; Knighton 1998; Rosgen 2014; ELI et al. 2016). All three metrics should be evaluated together to characterize the overall bed form diversity of a project reach.

Pools and riffles provide valuable habitat and are needed to support various aquatic species and dissipate energy within a reach. The riffle is the natural grade-control feature of the stream, providing floodplain connection and vertical stability (Knighton 1998). The pool spacing ratio quantifies the frequency of pools within a reach and the percent riffle metric quantifies the relative prevalence of riffle habitat length throughout the reach. Pool depth ratio provides information of how the stream is transporting and storing sediment. For example, if the outside meander bend in a transport system has filled with sediment, this can indicate an aggradation problem, as the channel cannot transport the sediment load through the meander bend.

Reference stream data in Wisconsin were not available for developing reference curves for bed form diversity metrics. However, Hey (2006) shows that reference reaches can be used from other locations if the stream type (Rosgen 1996) and boundary conditions are similar. In the Hey (2006) study, reference reaches from the United Kingdom were compared to reference streams in the United States. Based on this understanding, the WISQT TC decided to apply the reference curves proposed in the MNSQT with minor modification. These reference curves rely on datasets from throughout the U.S., where boundary conditions are similar to Wisconsin (herbaceous and woody vegetation along the banks) and using stream types that will be common in Wisconsin restoration projects. As Wisconsin reference data are collected, the reference curves will be re-evaluated and updated as needed.

METRICS FOR BED FORM DIVERSITY:

- Pool Spacing Ratio
- Pool Depth Ratio
- Percent Riffle

8.1. POOL SPACING RATIO

SUMMARY

Adequate pool spacing and the depth variability created from alternating riffle-pool sequences supports dynamic equilibrium and habitat-forming processes (Knighton 1998; Hey 2006). The pool spacing ratio metric measures the distance between the deepest location of sequential geomorphic pools (e.g., channel-spanning lateral-scour / meander bend pools or step-pools, not small pocket pools in riffle sections or created by localized scour around obstructions). The distance between geomorphic pools is divided by the bankfull riffle width to calculate the dimensionless pool spacing ratio, which allows for the comparison of values from different sites and drainage areas. For example, a pool spacing of 75 feet is meaningless without an understanding of stream size or drainage area; however, a pool spacing ratio of 4.0 can be compared across drainage areas if the values are from the same valley morphology, bed material, and boundary condition (Hey 2006).

The median pool spacing ratio from the representative sub-reach is entered as the field value into the WISQT. The median is used instead of the mean because the sample size per reach tends to be small with a wide range of values and it was thought that the median provides a better estimate of central tendency. In addition, using a median value allows practitioners to design with a range of values to create more heterogeneity in meandering streams.

Studies have documented a connection between pool spacing ratios and channel stability and complexity (Langbein and Leopold 1966; Gregory et al. 1994; Laub et al. 2012). If a meandering stream has a low pool spacing ratio, the riffle length is also low, and energy is transferred to the banks and sometimes the floodplain. Evaluations of numerous stream restoration and mitigation projects in North Carolina, New York, and other states have shown that sites constructed with low pool-spacing ratios resulted in excessive bank erosion and sometimes floodplain erosion.

In addition to the issues caused by low pool spacing outlined above, large pool spacing values are also problematic. A large pool spacing ratio essentially means that there are a small number of geomorphic pools in the reach. In alluvial valleys, this might mean that the reach is overly straight, and the habitat value is diminished because the length of pool habitat has been reduced. In colluvial or otherwise confined valleys, the lack of pools might mean there is not sufficient energy dissipation to achieve dynamic equilibrium.

Reference Curve Development:

As reference data from Wisconsin were not available, the WISQT TC decided to adopt threshold values and reference curves developed for the MNSQT (MNSQT SC 2020b) with minor modifications. These threshold values and reference curves rely on reference datasets from other regions with similar stream types and boundary conditions and will be reevaluated by the WISQT TC and SC once Wisconsin data are available. Datasets are described in Section 1.7, and the rationale used to support reference curve development is summarized below.

The reference curves are stratified by Rosgen stream type to account for the natural variability in pool spacing due to differences in valley type and slope (Hey 2006; Knighton 1998). Different stream types exhibit different types of pools: C and E stream types have lateral scour pools, whereas A and B stream types have cascade/step pools (Rosgen 2014). Stream size was not pursued as an additional form of stratification because the metric is a dimensionless ratio, using bankfull width as the denominator, which accounts for differences in stream size. Boundary condition was not explicitly used for stratification; however, all reference data were from areas with similar climates with streambanks dominated by woody vegetation.

For A and B stream types (see Table 8-1 for dataset summary):

Conceptually, low pool spacing ratios provide greater grade control than greater pool spacing ratios by increasing roughness and providing greater energy dissipation. Downstream riffles, cascades, or steps provide the grade control for upstream cascades or steps. Therefore, as the value increases, the functional capacity decreases. The threshold values were developed by the MNSQT SC (2020b) based on a review of several unpublished and published datasets presented in Table 8-1 (and described in Section 1.7) as well as the MNSQT technical committee's experience with bed form diversity in upper midwestern stream systems.

Table 8-1: Pool Spacing Ratio data used to inform reference curves for A and B stream types.

Statistic	Number of Sites	Stream Types	Slope Range (%)	Average	Minimum	Maximum
Harman & Clinton (NC & WV)	6	Aa+, A, B, Ba	3.3 to 15%	1.9	0.7	7.9
Jennings & Zink (TN)	4	B, Ba	5.2 – 7.1%	2.1	0.9	3.6
Zink et al. (TN & NC)	12	A, B	2 – 10.4%	1.5	0.1	7.1
Rosgen (2014)	-	B	-	-	0.3*	2.5*
**Typical values*						

A summary of threshold values is provided below:

- Functioning: A field value ≤ 4.0 was selected for the 1.00 index value. All values equal to or less than 4.0 receive a 1.00. This incentivizes practitioners to select the range that best fits the site rather than chasing a 1.00, and all values in this range are commonly found in reference streams.
- Functioning-at-risk: A field value of 5.0 was selected for the 0.70 index value because most of the reference data fell below 5.0.
- Not-Functioning: A field value ≥ 6.5 was selected for the 0.00 index value, which is near the largest maximum value found across the datasets. This value was set instead of extrapolating the regression line to show an increase in the rate of loss as pool spacing increases. For example, a high pool-to-pool spacing ratio in a step-pool system could result in headcutting in the absence of adequately sized bed material. These vertical stability problems have been observed by members of the MNSQT TC while inspecting stream restoration projects in B stream types.

Threshold values and reference curves are presented in Table 8-4 and Figure 8-1. A broken linear fit was applied to threshold values to develop the reference curve for Wisconsin.

For Bc stream types (see Table 8-2 for dataset summary):

Reference curves and threshold values were originally developed for use in the MNSQT (MNSQT SC 2020b) and were informed by the negative relationship between pool spacing and slope, a review of several unpublished and published datasets presented in Table 8-2 (and described in Section 1.7) as well as the experience of the technical committee in evaluating stream restoration projects. Bc streams were separated out from A and B stream types because Bc streams have lower slopes (< 2%; Rosgen 1996), which affects pool spacing. The average pool spacing ratios for Bc streams (1.2 – 6.6) are higher than the A and B streams (1.5 – 1.9), which matches the literature showing that pool spacing increases with decreasing slope. The average, minimum, and maximum values presented in Table 8-2 vary widely.

Table 8-2: Pool Spacing Ratio data used to inform reference curves for Bc stream types.

Statistic	Number of Sites	Stream Types	Slope Range (%)	Average	Minimum	Maximum
Lowther (NC)	2	Bc	0.5	6.6	4.7	8.5
Jennings & Zink (TN)	4	Bc	0.25 – 1.96	3.5	1.8	4.5
Zink et al. (TN & NC)	2	Bc	< 2	1.2	0.1	3
Rosgen (2014)	-	B	-	-	0.3*	2.5*
MI EGLE	4	Bc	-	4.2	2.3	5.5
**Typical values*						

A summary of assigned threshold values is provided below:

- Functioning: A field value of ≤ 5.0 was assigned a 1.00 index value. The field value is slightly higher than the A and B stream types to represent the increasing pool spacing with decreasing slope. In these lower slope systems, pools can be farther apart than steeper systems with a lower risk of bed degradation.

- Functioning-at-risk: A field value of 6.0 was assigned a 0.70 index value. Values are slightly higher than the A and B stream types to represent the increasing pool spacing with decreasing slope.
- Not-Functioning: A field value of 8.0 was set at 0.00 index value, which is near the largest maximum value found across the datasets. The MNSQT TC recognized that pools this far apart would provide very little bed form diversity and could lead to headcutting.

Threshold values and reference curves are presented in Table 8-4 and Figure 8-2. A broken linear fit was applied to threshold values to develop the reference curve for Wisconsin.

For C and E stream types (see Table 8-3 for dataset summary):

Reference curves and threshold values were originally developed for use in the MNSQT (MNSQT SC 2020b) and were informed by a review of several unpublished and published datasets presented in Table 8-3 (and described in Section 1.7) as well as the collective expertise of the technical committee. Additional stratification by stream size (drainage area) was not considered, as earlier SQT efforts concluded that reference data did not reveal a substantial difference in pool spacing between C and E stream types over a range of drainage areas.

Table 8-3: Pool Spacing Ratio data used to inform reference curves for C and E stream types.

Statistic	Number of Sites	Stream Types	Drainage Area (mi^2)	Average	Minimum	Maximum
Lowther (NC)	16	C, E	0.1 - 8.2	3.3	1.7	5.4
Jennings & Zink (NC)	20	C, E	0.05 - 2.3	4.1	1.5	9
Rinaldi and Johnson (MD)**	18	C, E	-	-	1.2	4.3
Rosgen (2014)	-	C, E	-	-	5.0*	7.0*
MI EGLE	11	C, E	-	5	1.9	7
Leopold et al. (1994)**	-	C, E	-	-	5.0*	7.0*

**Typical values*

***May include both reference and non-reference streams.*

Original research by Leopold et al. (1994) showed that pool spacing ratio ranged from 5.0 to 7.0. This was not necessarily for reference quality streams alone and the data tended to come from large rivers that could be viewed from aerial photos. Rosgen (2014) reports the same range for lateral scour pools in his field guide. Rinaldi and Johnson (1997) show that this range is lower, at least in Maryland. However, their study was not limited to reference streams.

From the datasets (Lowther [NC], Jennings & Zink [TN], and MI EGLE) the average ratios were 3.3, 4.1, and 5.0. The overall range from these data sets was 1.5 to 9.0, but few sites were above 6.0. However, it is likely that these studies included pools not associated with meander bends, which are not counted as pools for the pool spacing metric in the WISQT method, and pool identification methods were not included in reports. Therefore, the lower end of the range may not well represent the WISQT method, which excludes these pools from the pool spacing ratio calculation.

Of all the data available, more weight was placed on the Lowther (NC), Jennings & Zink (TN), and MI EGLE datasets because they included reference sites only. The WISQT TC's collective expertise was also used because pool identification methods were unknown for these datasets.

A summary of assigned threshold values is provided below:

- Functioning: Field values ranging from 3.5 to 6.0 were assigned an index value of 1.00. The average ratios across the Lowther (NC), Jennings & Zink (TN), MI EGLE datasets, along with the WISQT TC's collective expertise were used to inform the minimum field value. Median pool spacing values below 3.5 tended to create stability problems, e.g., excessive bank erosion. Erosion quickly got worse with decreasing ratio values. Median pool spacing values above 6 started to affect habitat diversity. As the ratio gets larger, the number of pools decreases. In addition, to account for the potential that pools in riffles were included in some of the datasets, the field value was set at a 3.5. The maximum field value was set to 6.0 because few sites were above 6.0 for the Lowther (NC), Jennings & Zink (TN), and MI EGLE datasets.
- Functioning-at-risk: The regression lines were extrapolated from the functioning and not-functioning thresholds because the datasets did not provide explicit field values for this condition category, and professional judgement could not discern these differences.
- Not-functioning: A field value of 1.0 was set as the index value of 0.00. This was the lowest minimum value observed across the compiled datasets. Pool-to-pool spacing ratios below this value essentially means that reach is almost all pool and that that riffles and/or cross-overs are nonexistent; it is devoid of a riffle-pool sequence. A field value of 9.0 was also set as the index value of 0.00. The was the largest maximum value observed across the compiled datasets. Pool-to-pool spacing ratios above this value indicate that the reach is composed of almost all riffle. Again, the reach is devoid of a riffle-pool sequence.

Threshold values and reference curves are presented in Table 8-4 and Figure 8-3. A broken linear fit was applied to threshold values to develop the reference curve for Wisconsin.

Table 8-4: Threshold values for Pool Spacing Ratio.

Index Value	Field Values by Stream Type		
	A and B	Bc	C and E
1.00	≤ 4.0	≤ 5.0	3.5 – 6.0
0.70	5.0	6.0	-
0.00	≥ 6.5	≥ 8.0	≤ 1.0, ≥ 9.0

Figure 8-1: Pool Spacing Ratio reference curve for A and B stream types.

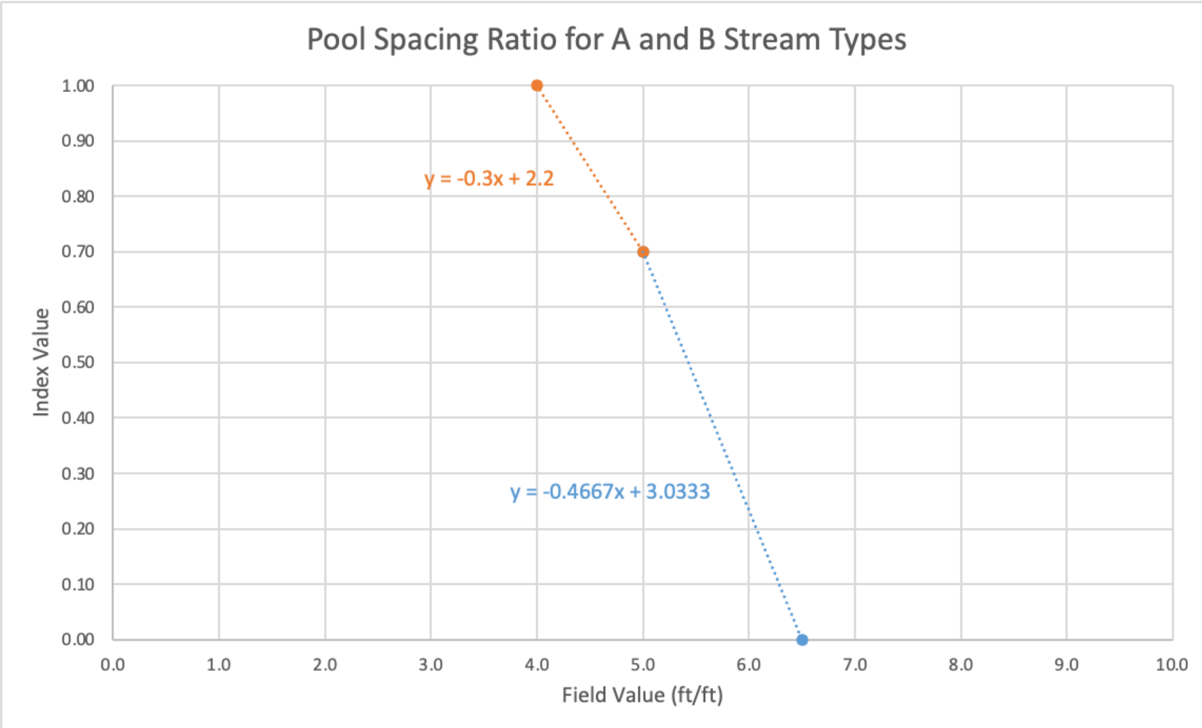


Figure 8-2. Pool Spacing Ratio reference curve for Bc stream type.

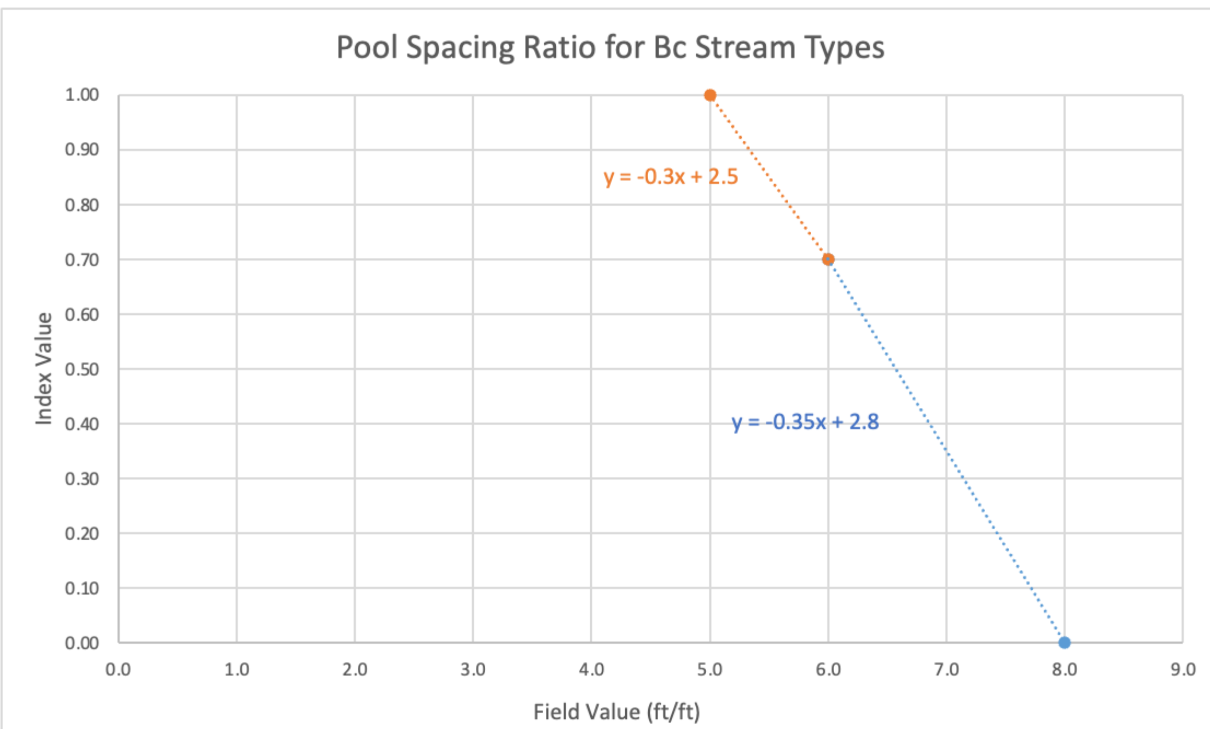
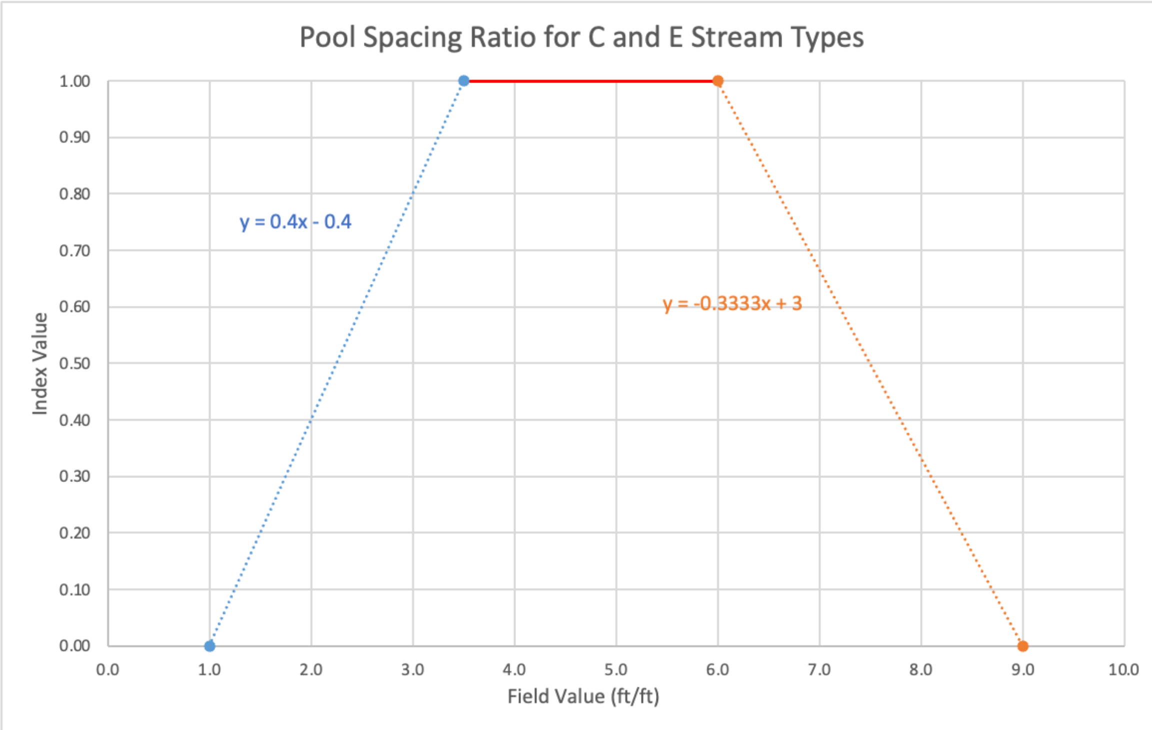


Figure 8-3. Pool Spacing Ratio reference curve for C and E stream types.



Limitations and Data Gaps:

Further refinement and stratification of threshold values and reference curves will occur as data are collected in Wisconsin.

The presence of bedrock can influence pool spacing, and thus it may not be appropriate to include bed form diversity metrics when evaluating natural bedrock channels. Pool development in bedrock channels is controlled by the nature of the rock material, e.g., fractures, as opposed to lateral dissipation of energy through a meandering channel. This consideration is only applicable to channels that are dominated by bedrock (e.g., bedrock is the median size of the bed material) and not channels that simply have bedrock outcrops.

If bankfull dimensions are not accurately determined for a site, then the pool spacing ratio will not accurately represent bed forming processes. Information on verifying bankfull information is provided in the User Manual.

Reference curves were not developed for naturally occurring F and G stream types. If the stream is a naturally occurring F stream type, e.g., located in a canyon or gorge setting, this metric should not be evaluated, as no reference curves have been developed for this stream type. Additionally, pool spacing ratio is not applicable to multi-thread channels (D or DA) or ephemeral channels because a predictable pool spacing is not typically found in these environments (Bull and Kirkby 2002). F and G channels that represent degraded streams should be compared against the reference stream type, as informed by channel evolution processes (Cluer and Thorne 2013; Rosgen 2014) and as described in the User Manual. Selection of the appropriate reference stream type is important for consistently applying this metric and determining a condition score in the tool.

Naturally straight channels, like perennial headwater streams with sand beds, are not appropriate for this metric. Pool formation in these systems is typically created by the presence of large wood, and the spacing is not predictable. Because meander bends are not present, lateral-scour pools (called geomorphic pools in the SQT) are not present. Pool spacing in alluvial valleys is only associated with lateral-scour pool types; therefore, pool spacing should not be assessed.

8.2. Pool Depth Ratio

Summary

The pool depth ratio metric measures the bankfull depth of the deepest point of each pool within the sampling reach. All pools, including both geomorphic pools and significant pools, are included in this metric (note: this is different than the pool spacing metric). The bankfull pool depth is normalized by a bankfull mean riffle depth to calculate the dimensionless pool depth ratio; pool depth ratio is the maximum bankfull pool depth divided by the mean bankfull riffle depth from a representative riffle. Each significant pool in the reach is assessed. Then, the average pool depth ratio is calculated and entered as the field value into the WISQT. The average is used instead of the median because typically the sample size is larger and the range lower than the pool spacing ratio.

Reference curve development:

The threshold values and reference curves were originally developed for the MNSQT (MNSQT SC 2020b) using the reference datasets described in Section 1.7, typical values, and the committees collective experience. The WISQT TC decided to use the MNSQT curves and values, with minor adjustments, which are summarized below. Because average pool depth ratios were similar among stream types within the reference datasets, ranging between 2.1 and 2.4 except for the Lowther dataset (NC) (Table 8-5), no stratification by stream type was pursued.

Table 8-5: Pool Depth Ratio data used to inform reference curves.

Reference Dataset	Stream Type	Number of Sites	Average	Minimum	Maximum
Jennings & Zink (TN)	A, B	4	2.1	1.8	2.3
Rosgen (2014)	A, B	-	-	1.5*	2.5*
Jennings & Zink (TN)	Bc	4	2.4	2.2	2.9
Lowther (NC)	Bc	2	2.3	1.6	3.1
MI EGLE	Bc	4	2.3	1.9	2.6
Jennings & Zink (TN)	C, E	23	2.2	1.7	3.3
Lowther (NC)	C, E	16	1.4	0.9	2.1
MI EGLE	C, E	11	2.3	1.3	3.4
Rosgen (2014)	C, E	-	-	2**	4**

**Typical values for step-pool channels*
***Typical values for C and E streams*

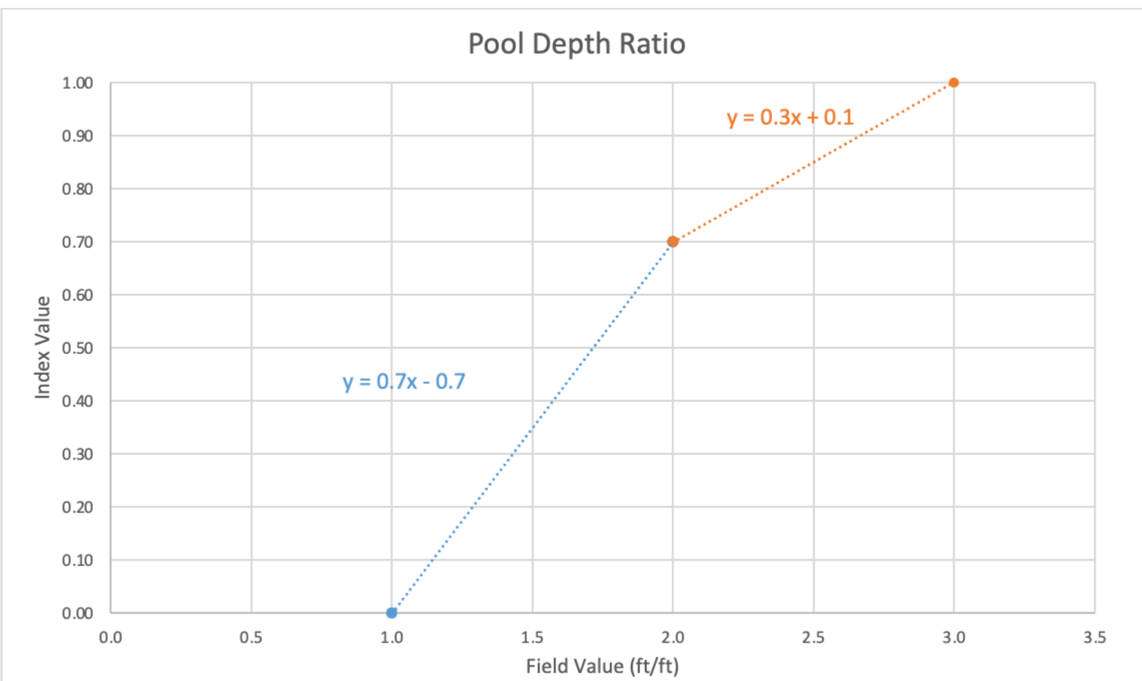
Threshold values and reference curves are presented in Table 8-6 and Figure 8-4. A summary of assigned threshold values is provided below:

- Functioning: As in the MNSQT, field values of 2.0 and 3.0 were used to as the 0.70 and 1.00 index values, respectively. Average values were used to inform the 0.70 threshold values; these were used rather than the minimum to reward/incentivize deeper pools. The literature shows that deep pools are important for a wide range of functions, e.g., thermal regulation and refugia. Maximum values were used to inform the 1.00 threshold value to acknowledge this process within deeper pools. In addition, a 3.0 ratio for the maximum index value acknowledges that when a pool is three times deeper than the riffle, functional capacity plateaus.
- Not-Functioning: Field values ≤ 1.0 were used to define the 0.00 index value. Because the metric is a ratio; the field value must be greater than 1.0 for a feature to be considered a pool. Thus, the WISQT TC decided that a ratio of 1.0 or less represented a bed form feature that did not function as a pool.

Table 8-6: Threshold values for Pool Depth Ratio.

Index Value	Field Value
1.00	≥ 3.0
0.70	2.0
0.00	≤ 1.0

Figure 8-4: Reference curve for Pool Depth Ratio.



LIMITATIONS AND DATA GAPS:

Further refinement and stratification of these curves will occur as data are collected in Wisconsin.

The presence of bedrock can influence pool depth, and thus it may not be appropriate to include bed form diversity metrics when evaluating natural bedrock channels. Pool development in bedrock channels is controlled by the nature of the rock material, e.g., fractures. This consideration is only applicable to channels that are dominated by bedrock (e.g., bedrock is the median size of the bed material) and not channels that simply have bedrock outcrops.

If bankfull dimensions are not accurately determined for a site, then the pool depth ratio will not accurately represent bed forming processes. Information on verifying bankfull information is provided in the User Manual.

8.3. PERCENT RIFFLE

SUMMARY

The percent riffle metric measures the length of riffles (including runs) within the representative sub-reach. The total length of riffles and runs is divided by the total representative sub-reach length to calculate the percent riffle.

Pools and riffles provide valuable habitat for various aquatic species and dissipate energy within a reach. The riffle is the natural grade-control feature of the stream, providing floodplain connection and vertical stability (Knighton 1998). Much of the discussion regarding stream function presented in the pool spacing ratio and pool depth metric summaries applies to this metric as well. While the pool spacing ratio quantifies the frequency of pools within a reach, this metric quantifies the relative prevalence of riffle habitat length throughout the reach.

Streams that have too much riffle length also have a low percentage of pools. Conversely, streams that have a low percentage of riffle also have a high percentage of pool. The appropriate proportion of riffles and pools is necessary to support dynamic equilibrium and habitat for in-stream biota. Percent riffle works with the pool spacing and pool depth ratio metrics to characterize bed form diversity.

REFERENCE CURVE DEVELOPMENT:

The threshold values and reference curves were originally developed for the MNSQT (MNSQT SC 2020b), using reference datasets described in Section 1.7 and the technical committee’s collective expertise. The WISQT TC decided to use the MNSQT curves and values, with minor adjustments, which are summarized below. Stratification by Rosgen stream type was used to account for the natural variability in the extent of riffle, run, cascade, and step features because it combines valley type and slope, which are known drivers of bedform (Hey 2006; Rosgen 1994).

For Aa+ stream types:

As with the MNSQT, the WISQT TC decided to not include reference curves for Aa+ streams due to lack of sufficient data and few restoration/impact sites at this slope.

For A and B stream types:

Threshold values for the functioning range were originally developed for the MNSQT and relied mostly on the Harman & Clinton dataset (NC & WV) because it best matched the data collection methods outlined in the SQT (Table 8-7).

Table 8-7: Percent Riffle data used to inform reference curves.

<table>
<tr><th>Reference Dataset</th><th>Stream Type</th><th>Number of Sites</th><th>Slope (%)</th><th>Average</th><th>Minimum</th><th>Maximum</th></tr>
<tr><td>Zink et al. (TN & NC)</td><td>Aa+</td><td>1</td><td>> 10</td><td>90</td><td>-</td><td>-</td></tr>
<tr><td>Zink et al. (TN & NC)</td><td>A, B/Ba</td><td>12</td><td rowspan="2">2 – 10</td><td>44</td><td>18</td><td>65</td></tr>
<tr><td>Harman & Clinton (NC & WV)</td><td>A, B/Ba</td><td>4</td><td>61</td><td>54</td><td>69</td></tr>
<tr><td>Jennings & Zink (TN)</td><td>C, E</td><td>3</td><td>< 2</td><td>50</td><td>44</td><td>53</td></tr>
<tr><td>MI EGLE</td><td>C, E</td><td>11</td><td>< 2</td><td>40</td><td>19</td><td>54</td></tr>
</table>

Threshold values and reference curves for A and B stream types are presented in Table 8-8 and Figure 8-5. A summary of the threshold values is provided below:

- Functioning: As noted in the MNSQT (MNSQT SC 2020b), field values ranging from 50% to 60% were set as the 1.00 index value based on the range of average and maximum values from Harman & Clinton (NC & WV) and Zink et al. (TN) datasets. This acknowledges that a reach should be comprised of at least half riffle, run, cascade, and step features for grade control and habitat diversity purposes. As riffle extent departs from this ideal range, function is lost. The decreasing curve loses function at a slightly faster rate because projects can have stability problems if the reach has too much pool length, which impedes sediment transport and transforms the reach to a sediment sink.
- Functioning-at-risk: The regression lines were extrapolated from the functioning and not-functioning thresholds because the datasets did not provide explicit field values for this condition category.
- Not-Functioning: Field values of 0% and 100% were used to define the 0.00 index value, which means that 100% and 0% riffle length represents no functional capacity for this metric.

For C and E stream types:

Threshold values and reference curves for C and E stream types are presented in Table 8-8 and Figure 8-6. A summary of the threshold values is provided below:

- Functioning: As noted in the MNSQT (MNSQT SC 2020b), field values ranging from 45% to 65% were set as the 1.00 index value. In general, this range is larger than the functioning range for A and B streams. The 45% value reflects the lower range presented in the MI EGLE and Jennings & Zink (TN) datasets. The MNSQT TC's expertise was used to set the 65% field value based upon their collective observation that values in excess of that figure were outside the range of reference condition. More specifically, values above 65% were judged to not be optimal from a riffle-pool sequence and bed heterogeneity perspective.

- Functioning-at-risk: The regression lines were extrapolated from the functioning and not-functioning thresholds because the datasets did not provide explicit field values for this condition category.
- Not-Functioning: Field values of 0% and 100% were used to define the 0.00 index value, which means that 100% and 0% riffle length represents no functional capacity for this metric.

Table 8-8: Threshold values for Percent Riffle.

Index Value	Field Value (%)	
	A and B	C and E
1.00	50 – 60	45 – 65
0.00	0, 100	0, 100

Figure 8-5: Percent Riffle reference curve for A and B stream types.

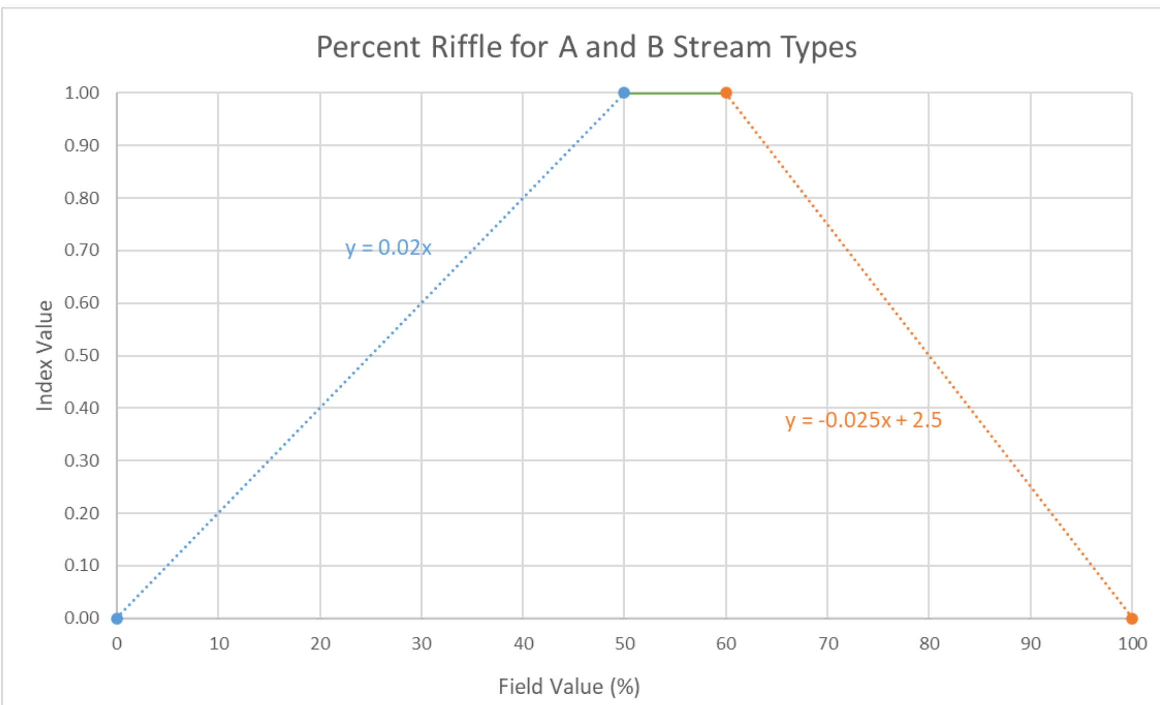
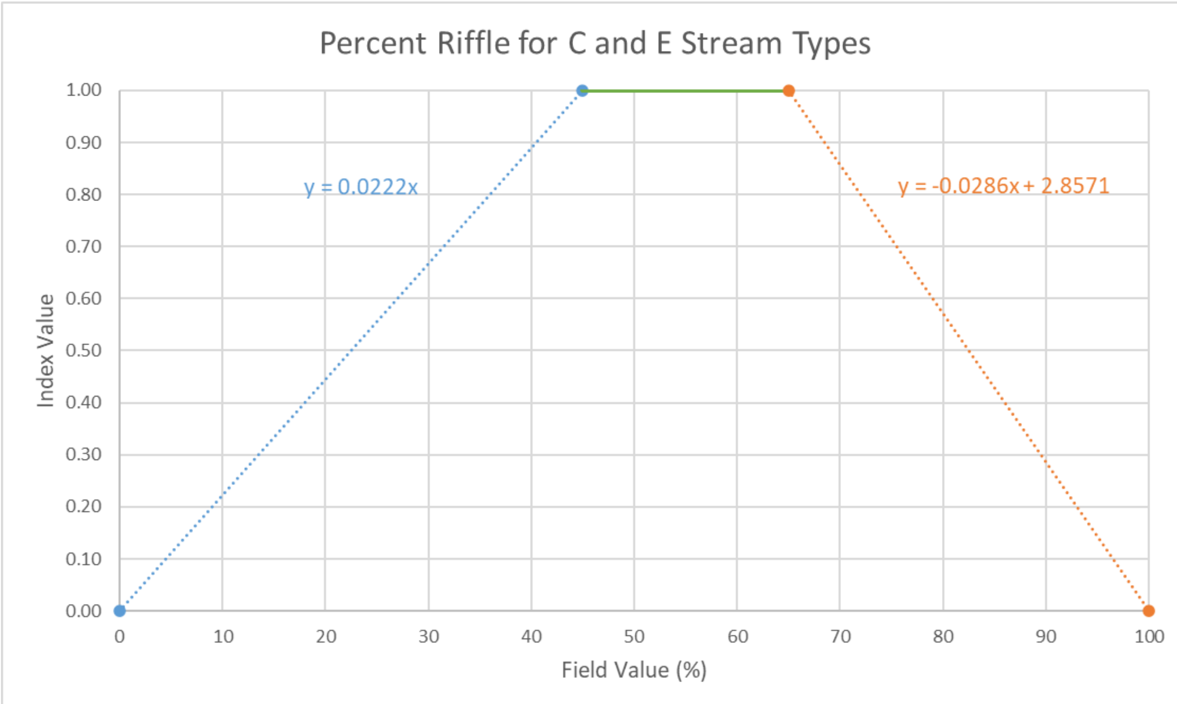


Figure 8-6: Percent Riffle reference curve for C and E stream types.



LIMITATIONS AND DATA GAPS:

A review of the southeast data (see Harman & Clinton dataset [NC & WV] and Table 8-7) confirmed threshold values presented above. However, further refinement and stratification of these data and reference curves should occur as data are collected in Wisconsin.

Chapter 9 Bed Material Characterization Parameter

FUNCTIONAL CATEGORY: Geomorphology

GEOMORPHOLOGY FUNCTIONAL STATEMENT: Transport of wood and sediment to create diverse bed forms and dynamic equilibrium.

FUNCTION-BASED PARAMETER SUMMARY:

The ecological effects of fine-sediment accumulation are ubiquitous and wide-ranging (Wood and Armitage 1997). The size and stability of bed material has been linked to macroinvertebrate abundance and diversity (Hussain and Pandit 2012). Additionally, multiple fish species build spawning beds out of gravel, and fine sediment accumulation can reduce the quality of fish spawning habitats and egg survival (summarized in Wood and Armitage 1997). Characterizing bed material provides insight into sediment transport processes (Bunte and Abt 2001) and whether these processes are functioning in a way that supports suitable habitat for a functioning ecological community (Allan and Castillo 1997).

Evaluating a stream’s bed material can provide insight into whether sediment transport processes are functioning to transport and distribute sediments in a way that can support the stream ecosystem. There are many ways that sediment transport can be directly measured and modeled; however, many of these approaches are time and data intensive (Harman et al. 2012). Monitoring the ecosystem responses to reach-scale impacts or restoration efforts necessitate a simpler indicator, such as estimates of percent fine sediments which can serve as a useful indicator of fine sediment accumulation (BLM 2017) and correlate with declines in important macroinvertebrate taxa (Benoy et al. 2012).

Harman et al. (2012) presented two measurement methods to evaluate this parameter, a size class pebble count analyzer and riffle stability index. The size class pebble count analyzer can be used to compare grain size distributions at a project site with an appropriate reference site and determine if the distribution is statistically different. Because this approach relies on a statistical comparison between two sites, it does not lend itself to reference curve development and was not considered for inclusion in the WISQT. The Riffle Stability Index evaluates the mobile percent of particles within riffle systems and provides an estimate of the degree of increased sediment supply to riffles in mountain streams (Kappesser 2002). This method has been primarily applied in steeper (2-4% slopes) systems (e.g., Rosgen B3 and F3b) and its applicability in lower gradient systems (e.g., C4 and B4c stream types where most mitigation/restoration activities occur) is not known.

There are other methods for developing grain-size distributions and performing associated calculations (Bunte and Abt 2001). Laub et al (2012) provides several metrics that use grain size distributions to assist in determining bed complexity: calculations for heterogeneity, sorting, Fredle index, a gradation coefficient, and a sediment coefficient of variation. Kaufmann et. al (2007) developed the Index of Relative Bed Stability (RBS) that evaluates a stream’s thalweg profile, slope, channel/bank cross sections, substrate pebble-count (105 particle count) and large woody debris count to evaluate sedimentation. The WISQT TC explored using the RBS in the WISQT but elected not to include it due to the need for further method refinement and testing, the challenge of estimating proposed condition scores, and the need to translate the SQT’s large woody debris index metric into a volumetric measure for use in the RBS. With additional testing and modification, these metrics could be added to future versions of the WISQT.

This parameter currently includes three metrics, measured together, and additional research may identify opportunities for refinement and simplification of the metric or metrics and their methods.

METRICS FOR BED MATERIAL:

- Percent fines (% < 2mm)
- Percent fines (% < 6.35mm)
- Median particle size (d50)

9.1. PERCENT FINES (% < 2MM AND % < 6.35MM)

SUMMARY:

Streambank erosion from development or poor land management practices is a leading driver of excess sedimentation in surface waters (Benoy et al. 2012). It is estimated that 40% of waterways in agricultural settings are affected by sedimentation driven by land management practices (EPA 2002).

Fine sediments represent smaller bed material grain sizes and can be used to evaluate whether there are changes in deposition of fine sediment within a project reach. When streambeds have increased or excessive sedimentation, or “fining”, streambed habitat such as pools or riffles are degraded, with negative implications for aquatic species habitat, food acquisition, and reproduction (Zweig and Rabeni 2001; Sutherland et al. 2002; Griffith et al. 2009).

Research from agricultural streams in New Brunswick and Prince Edward Island, Canada (Benoy et al. 2012) has shown correlations between Ephemeroptera-Plecoptera-Trichoptera (EPT) relative abundance (%) and geomorphic criteria (% fines < 2mm, % fines < 6.35mm, and median particle size). Benoy et al. (2012) also found that these geomorphic criteria were strongly related to land use disturbance (i.e., agricultural coverage and riparian zone integrity).

REFERENCE CURVE DEVELOPMENT:

A percent fines metric is included in the Stream Quantification Tool for the Alaskan Interior (AKSQTint) and was based on Bureau of Land Management Aquatic Inventory Monitoring (BLM AIM) methods, with reference curves informed by BLM AIM data (BLM 2017). BLM AIM datasets are only available for BLM lands, and as such, these data are not available to inform a reference curve for the WISQT. Instead, the WISQT TC looked to the literature to determine if a similar approach could be applied in Wisconsin. Benoy et al. (2012) proposes provisional thresholds for deposited sediments developed using geomorphic criteria from data collected within agricultural watersheds in New Brunswick and Prince Edward Island, Canada.

Reference curves were created using the results from Benoy et al. (2012). The “ecological threshold”, or the regression-tree analysis for recommended geomorphic criteria was used to establish the threshold between functioning-at-risk and functioning (0.70 index value). The 0.00 and 1.00 index values were then estimated from the trend lines in the scatter plots published in this study.

Threshold values are presented in Table 9-1 and reference curves for percent fines < 2mm and < 6.35mm are presented in Figures 9-1 and 9-2, respectively.

Table 9-1: Threshold values for Percent Fines < 2mm and < 6.35mm.

Index value	Field Value	
	% Fines < 2mm	% Fines < 6.35mm
1.0	≤ 5	≤ 5
0.7	14.8	16.9
0.0	≥ 32	≥ 35

Figure 9-1: Reference curve for Percent Fines (< 2mm).

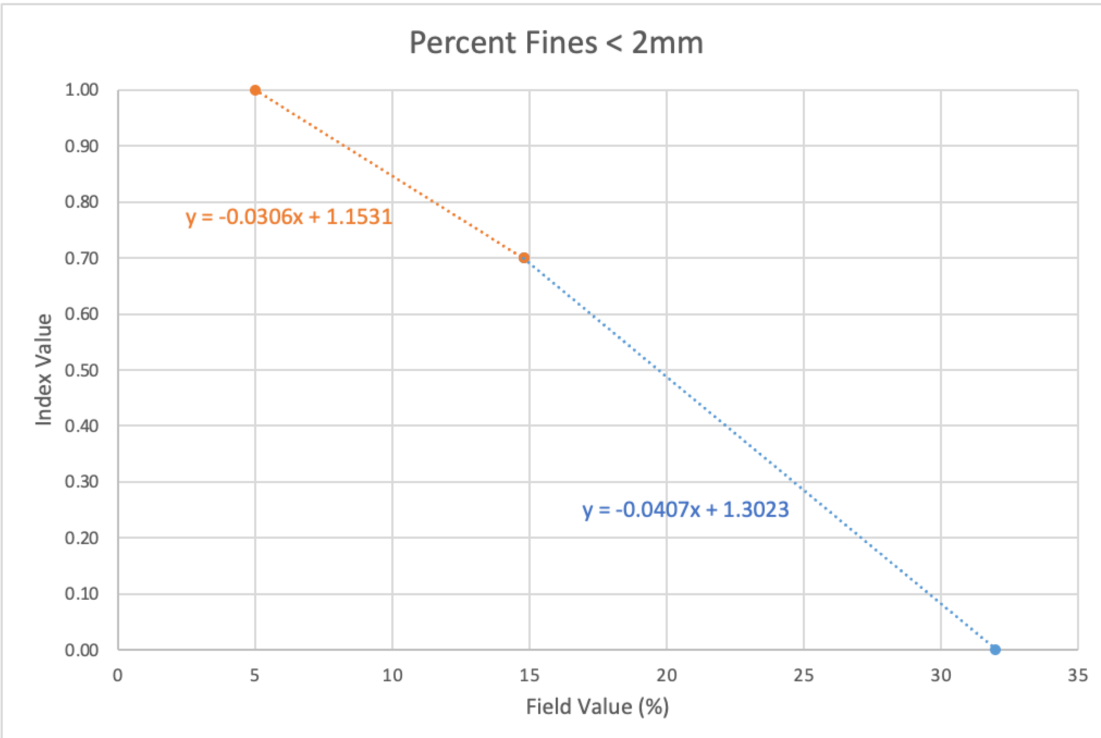
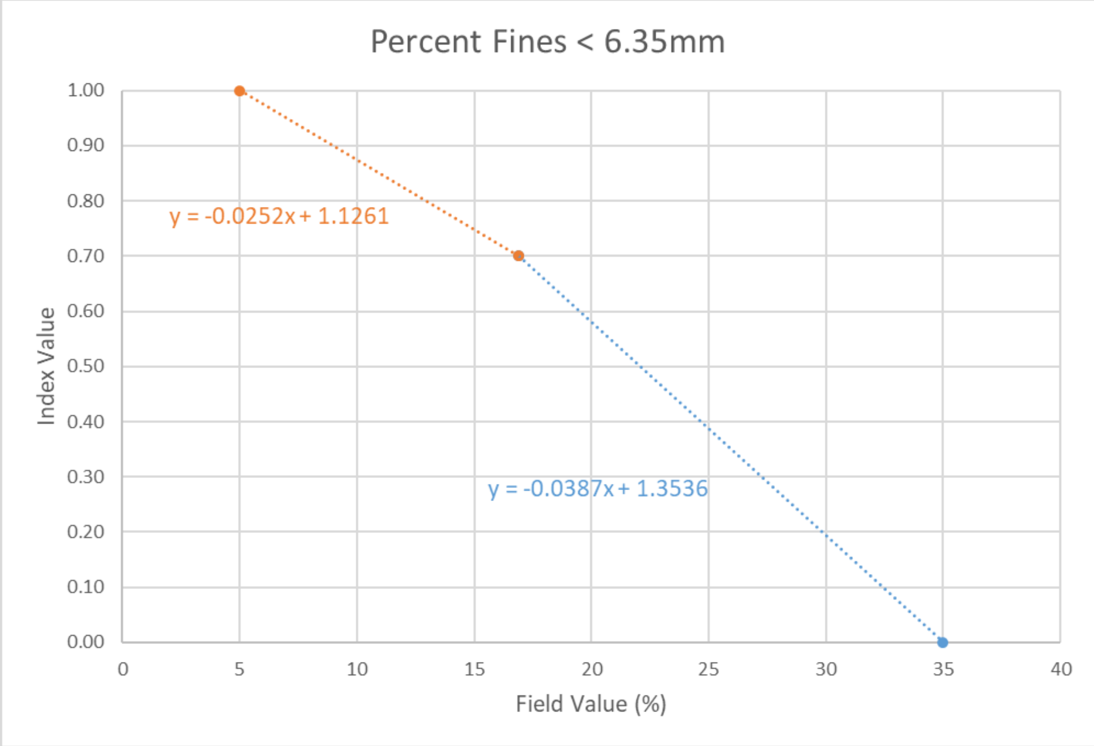


Figure 9-2: Reference curve for Percent Fines (< 6.35mm).



Limitations and Data Gaps:

This parameter and its metrics are only applicable in coarse gravel and cobble-bed streams and is only applicable where fine sedimentation is expected. For example, restoration projects with coarse gravel streambeds and sandy sediment supply from eroding stream banks are ideal candidates for this assessment. On the impact side, projects in coarse gravel bed streams that might increase sediment supply from bank erosion are good candidates for this assessment. The method is not applicable in sand bed streams or small gravel bed streams.

Percent fines are new metrics and data collection from reference quality streams is needed to confirm the applicability of these metrics and reference curves in Wisconsin. Additional testing in watersheds with different land uses or stressors will shed additional insights into these metrics and reference curves.

9.2. Median Particle Size (d50)

Summary:

As a complement to the percent fines metrics, the WISQT TC included a median particle size metric as a part of an assessment of sedimentation in streams. Although only a few states have specific guidance related to median particle size (mostly included in Total Maximum Daily Load requirements), there is recognition that optimal populations of macroinvertebrate communities, as well as the other functions of gravel bed systems, are supported by median particle sizes larger than 37mm and increasing toward 69mm (Benoy et al. 2012). The median particle size metric is designed to further account for the impacts of streambed fining, or reduction of sediment, on stream functions.

Reference Curve Development:

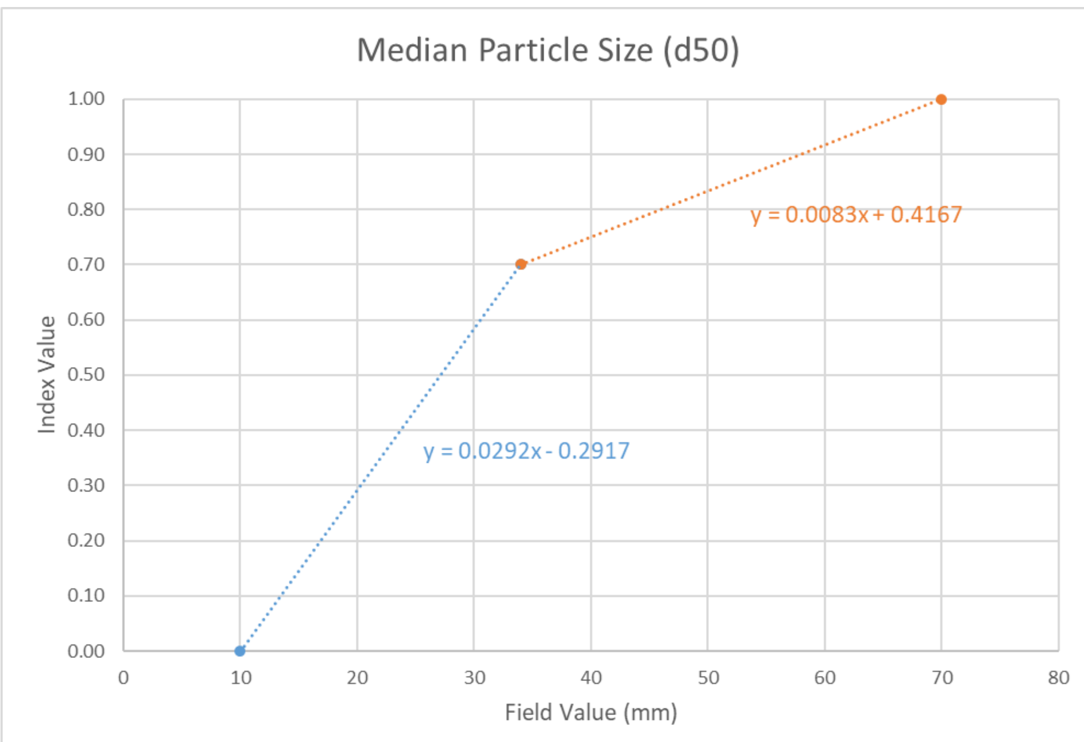
Accounting for the median particle size is unique among existing SQTs and the WISQT TC developed a reference curve using the results from the thresholds for deposited sediment from Benoy et al. (2012). The "ecological threshold", or the regression-tree analysis for recommended geomorphic criteria from Benoy et al. (2012), was used to establish the threshold between functioning-at-risk and functioning (0.70 index value). The 0.00 and 1.00 index values were then estimated from the trend lines in the scatter plots published in this study.

Threshold values are presented in Table 9-2 and the reference curve is presented in Figure 9-3.

Table 9-2: Threshold values for the Median Particle Size (d50).

Index value	Field Value (d50)
1.00	≥ 70
0.70	34
0.00	≤ 10

Figure 9-3: Reference curve for Median Particle Size (d50).



Limitations and Data Gaps:

This parameter and metric are only applicable in coarse gravel and cobble-bed streams and is only applicable where fine sedimentation is expected. For example, restoration projects with coarse gravel streambeds and sandy sediment supply from eroding stream banks are ideal candidates for this assessment. On the impact side, projects in coarse gravel bed streams that might increase sediment supply from bank erosion are good candidates for this assessment. The method is not applicable in sand bed streams or small gravel bed streams.

The median particle size is a new metric and data collection from reference quality streams is needed to confirm the applicability of this metric and reference curve in Wisconsin. Additional testing in watersheds with different land uses or stressors will shed additional insights into this metric and its reference curve.

Chapter 10 Temperature Parameter

FUNCTIONAL CATEGORY: Physicochemical

PHYSICOCHEMICAL FUNCTIONAL STATEMENT: Temperature and oxygen regulation; processing of organic matter and nutrients.

FUNCTION-BASED PARAMETER SUMMARY:

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

Temperature assessments commonly focus on mean and maximum water temperatures, with maximum water temperatures often used to inform numeric water quality standards. While comparisons of site condition can be made to numeric standards (e.g., maximum temperature thresholds for aquatic biota), the use of regional reference data can provide a better indication of the degree of degradation and restoration potential than a comparison to temperature standards alone (Roni and Beechie 2013). Emerging monitoring and modeling capabilities are advancing the science on stream temperature, allowing for greater understanding of the temporal and spatial variability of temperature regimes in streams, and expanding the potential range of temperature variables that could inform condition (Steele and Fullerton 2017).

The WISQT TC considered several temperature metrics described in Lyons et al. (2009), including summer mean, July mean, daily maximum, and upstream/downstream delta (reach temperature difference). Because field values in the SQT are often informed by a single year of monitoring data, which can be influenced by interannual variations in climate, the WISQT TC decided not to include daily maximum, but instead focus on summer mean. While there are multiple reach-specific factors that would influence the natural difference in temperature between the upstream and downstream extent of a project, the comparison of temperatures coming into a project versus leaving a project provides invaluable information in evaluating change as a result of a project and the WISQT TC decided that upstream and downstream monitoring should inform field value calculation of the summer mean temperature.

METRIC FOR TEMPERATURE:

- Summer Mean Temperature

10.1. SUMMER MEAN TEMPERATURE

SUMMARY

The summer mean temperature metric is the average of continuously recorded temperatures measured during the summer months of June, July, and August. Temperature measurements are collected in-situ during summer and measured using in-water temperature sensors installed following procedures outlined in *Guidelines and Standard Procedures for Continuous Temperature Monitoring* (WDNR 2004). The summer average temperature metric is one of three criteria used to determine thermal class and distinguish between fish assemblages (Lyons et al. 2009). The summer mean is a more robust metric to assess change resulting from reach-scale or project-scale activities than the July mean temperature or daily maximum temperature which would be more susceptible to interannual variations in climate.

REFERENCE CURVE DEVELOPMENT

Reference curves were based on state thermal criteria, historic datasets, and studies performed in Wisconsin (Lyons et al. 2009; Diebel et al. 2015). State thermal criteria are identified in Lyons et al. (2009) and are stratified by thermal classes, including coldwater, cold-transition, warm-transition and warmwater (Figure 10-1). The reference curves in the WISQT follow the same stratification.

Figure 10-1: Water temperature criteria for classifying Michigan and Wisconsin streams into thermal classes and subclasses. Reprinted from Lyons et al. (2009).

Class and subclass	Jun–Aug mean	Jul mean	Maximum daily mean
Coldwater	<17.0	<17.5	<20.7
Coolwater	17.0–20.5	17.5–21.0	20.7–24.6
Cold transition	17.0–18.7	17.5–19.5	20.7–22.6
Warm transition	18.7–20.5	19.5–21.0	22.6–24.6
Warmwater	>20.5	>21.0	>24.6

Threshold values used to develop reference curves are shown in Table 10-1 and Figure 10-2, and were developed based on the following criteria:

- For coldwater streams, the water temperature criteria for summer mean temperature (June-August) were used to define the 0.70 index value (Figure 10-1). The lower limit of the cold-transition temperature class was used to define the threshold between functioning-at-risk and not-functioning (0.30), and a linear regression was extrapolated from the 0.70 and 0.30 index values to define the reference curve within the functioning-at-risk and not-functioning range. The WISQT TC considered extrapolating a linear relationship using these two points to also characterize the functioning range, but this would yield a 1.00 index value equating to 15.7º Celsius (C), which would not accurately characterize the temperature requirements of sensitive coldwater species. The WISQT TC also considered results from Diebel et al. (2015), which modeled fish species response to temperature, flow yield, and watershed area. Diebel et al. (2015) showed that multiple trout species were likely to occur in systems colder than 14º C, the minimum temperature modeled in the study. Ultimately, the WISQT TC decided to define the 1.00 index value using the lower end of the range of laboratory preferred temperature for Brown Trout, 12.5º C, published in Lyons et al. (2009).

- For coolwater streams (cold transition and warm transition), the water temperature range for summer mean temperature (June-August) in Figure 10-1 was used to define the functioning range of condition (0.70 – 1.00). Linear regression equations were extrapolated from these two points to develop reference curves.

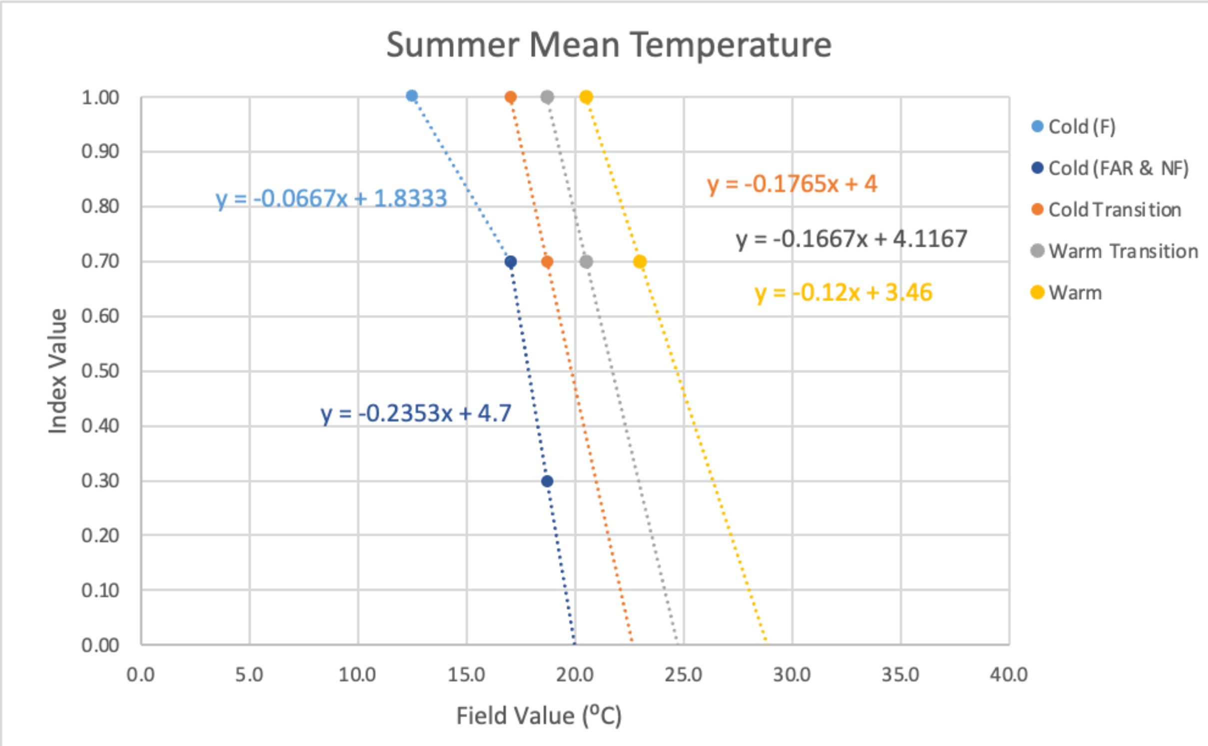
- For warmwater streams, the water temperature criteria for summer mean temperature (June-August) were used to define the 1.00 index value (Figure 10-1). To define the lower end of the functioning range, the WISQT TC considered the partial dependence plots from Diebel et al. (2015) for Golden Shiner, Smallmouth Bass, Stonecat, and Rosyface Shiner.

  Golden shiner distribution did not have a significant relationship with temperature, however, the remaining three species exhibited optimal July mean temperatures between 21 and 22°C which is consistent with the July mean temperature criteria in Lyons et al. (2009). Rosyface shiner and Stonecat are considered more sensitive, with Rosyface shiner being most sensitive to warmer temperatures. The sites from Lyons et al. (2009) with Stonecat and Rosyface Shiner had mean July temperature > 23.5°C. The WISQT TC considered using this value to define the 0.70 index value but adjusted to 23.0°C based on the thermal criteria laid out in Lyons et al. (2009) where the difference between the July mean temperature (21°C) and the summer mean temperature (20.5°C) is 0.5°C. Linear regression equations were extrapolated from the 1.00 and 0.70 index values to develop reference curves.

Table 10-1: Threshold values for Summer Mean Temperature.

Index Value	Field Value (ºC)			
	Coldwater	Cold Transition	Warm Transition	Warmwater
1.00	≤ 12.5	≤ 17.0	≤ 18.7	≤ 20.5
0.70	17.0	18.7	20.5	23.0
0.30	18.7	-	-	-

Figure 10-2: Reference curves for Summer Mean Temperature.



LIMITATIONS AND DATA GAPS

Since the summer mean temperature is the only metric in the WISQT to characterize the temperature regime of a reach, only decreased function associated with increases in summer temperature is quantified. Some human activities, such as flow augmentation or hypolimnetic reservoir releases, may cause a stream to be colder than the natural condition. This metric does not capture the potential for reduced functional capacity due to these changes.

The statewide mapping for temperature tier is based on modeled values and reach-specific conditions may differ from the modeled conditions. In selecting the appropriate temperature tier, users should also consider the most thermally-sensitive species expected to occupy the reach.

Chapter 11 Nutrients Parameter

FUNCTIONAL CATEGORY: Physicochemical

PHYSICOCHEMICAL FUNCTIONAL STATEMENT: Temperature and oxygen regulation; processing of organic matter and nutrients.

FUNCTION-BASED PARAMETER SUMMARY:

Nutrients in stream ecosystems are, by definition, necessary for growth and survival of aquatic species. Of the nutrients in stream ecosystems, nitrogen and phosphorus are the most important (Allan and Castillo 2007). Excessive nutrients from nonpoint source pollution, particularly runoff from agricultural lands, is one of the leading causes of impairment to streams in the United States (EPA 2005). In the upper Midwest, human land use is the dominant factor influencing phosphorous levels in streams (Robertson et al. 2005). While there is a minimum amount of nutrients necessary to support aquatic life, nutrient concentrations often greatly exceed optimum values which can lead to excess algae growth and result in degraded aquatic habitat and physicochemical conditions, altered fish and invertebrate communities, occasional fish kills, and aesthetic degradation.

WDNR considered several nutrient-related metrics for evaluating phosphorous in streams (WDNR 2021) and concluded that primary production metrics were the most appropriate as phosphorus response indicators. Macroinvertebrate and fish metrics were also considered but the relationships between these metrics and phosphorus, as assessed using currently available data, were not strong response indicators (WDNR 2021). The primary production metrics considered by WDNR (2021) include the Diatom Phosphorus Index (DPI), benthic algal biomass, benthic chlorophyll α, algal toxins, Diatom Nutrient Index (DNI) and Diatom Biotic Index (DBI). Additional discussion of these metrics and their consideration can be found Section 5.7 of the Waterbody Assessment Rule Package: Technical Support Document (WDNR 2021). The WISQT TC decided to include the Diatom Phosphorus Index and filamentous benthic algal biomass in the WISQT to be consistent with the metrics recommended by WDNR (2021).

METRICS FOR NUTRIENTS:

- Benthic Algal Biomass
- Diatom Phosphorus Index (DPI)

11.1. BENTHIC ALGAL BIOMASS

SUMMARY

Biomass and coverage of filamentous benthic algae in streams will increase with high phosphorous concentrations. As such, a visual assessment of filamentous benthic algal biomass in streams using a quantifiable system such as a viewing bucket is an efficient approach to determine whether a site clearly is, or is not, exhibiting a nutrient response (WDNR 2021).

The viewing bucket method is included in the EPA's *Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers* (Barbour et al. 1999) and is used in several states' monitoring programs. The WISQT TC decided to include this metric as a rapid alternative to the DPI. This metric can be evaluated in the field and does not require additional lab processing.

REFERENCE CURVE DEVELOPMENT

Reference curves are based on the response scores provided in the *Waterbody Assessments Rule Package: Technical Support Document* (WY-23-13; WDNR 2021). The WISQT TC decided to align the threshold values with the use attainment for aquatic life presented in WDNR (2021), where mean viewing bucket scores below 1 represent attainment, or functioning condition, values greater than 2 indicate impairment and values between represent a grey zone that is functioning-at-risk (Figure 11-1). Because field values are based on a visual estimate and not related to total phosphorous values, a linear curve was applied between points to develop the reference curve.

Threshold values and reference curve are presented in Table 11-1 and Figure 11-2.

Figure 11-1: Stream benthic algal biomass phosphorous response indicator using viewing bucket method. Reprinted from WDNR (2021).

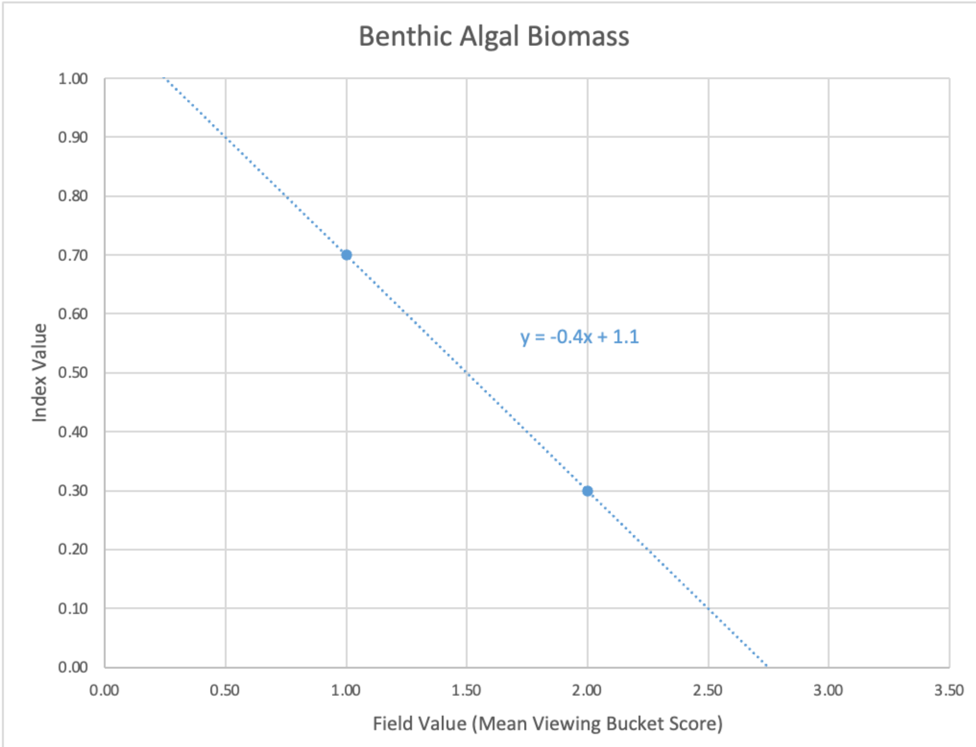
Benthic algal biomass, viewing bucket score (0-3)	Attainment decision	
	Aquatic Life Use	Recreation Use
< 1	Attained[1]	Attained
1 - 2	Inconclusive; assess benthic diatoms using DPI	
> 2	Not attained	Not attained

[1] If the mean score is <1 but 20% or more of individual transect points score a 3, a benthic diatom assessment under par. (b) is required to make an attainment determination.

Table 11-1: Threshold values for Benthic Algal Biomass.

Index Value	Field Value (mean score)
0.70	1
0.30	2

Figure 11-2: Reference curve for Benthic Algal Biomass.



LIMITATIONS AND DATA GAPS:

The Benthic Algal Biomass metric is only applicable in wadeable streams with a coarse, stable substrate and where light penetrates to allow benthic algae to attach and grow (WDNR 2020). As such, sampling is most effective when there is little overhead shading or a relatively open canopy. Users need to ensure canopy coverage is representative of the overall reach canopy cover at the time of sampling. Further, because this metric is assessing algae attached to the streambed sediments, this metric will not yield accurate results when the stream has experienced recent high flows.

11.2. DIATOM PHOSPHORUS INDEX

SUMMARY

Diatoms respond to physical and chemical impacts including nutrients, trophic status, acidification, organic pollution, and sedimentation (Rinella and Bogan 2007). WDNR (2021) considered three diatom indices in the development of their methods but selected the weighted average Diatom Phosphorus Index (DPI) as their recommended metric over the Diatom Nutrient Index (DNI) or Diatom Biotic Index (DBI) because it shows a stronger correlation with total phosphorus. While diatom indices measure biological responses, the Diatom Phosphorus Index was placed in the physiochemical functional category because the index serves as an indicator of ecological condition associated with organic enrichment and nutrient enrichment processes in streams. This categorization is consistent with other SQTs that include chlorophyll α as a metric for the nutrient parameter in the physicochemical functional category.

The DPI is reported as µg/L. Additional information on the development of this method and index can be found in WDNR (2021). This metric is applicable in wadeable streams only.

REFERENCE CURVE DEVELOPMENT

Reference curves are based on the data provided in the *Waterbody Assessments Rule Package: Technical Support Document* (WY-23-13; WDNR 2021), as well as the WDNR Reference Dataset (Section 1.7). Summary statistics from the WDNR Reference Dataset are provided in Table 11-2.

Table 11-2: Statistics for total phosphorous from WDNR Reference Dataset.

Statistic	Value (µg/L)
MIN	7
5TH	15
Q1	29
Median	51
MEAN	86
Q3	104.5
95TH	273
MAX	778

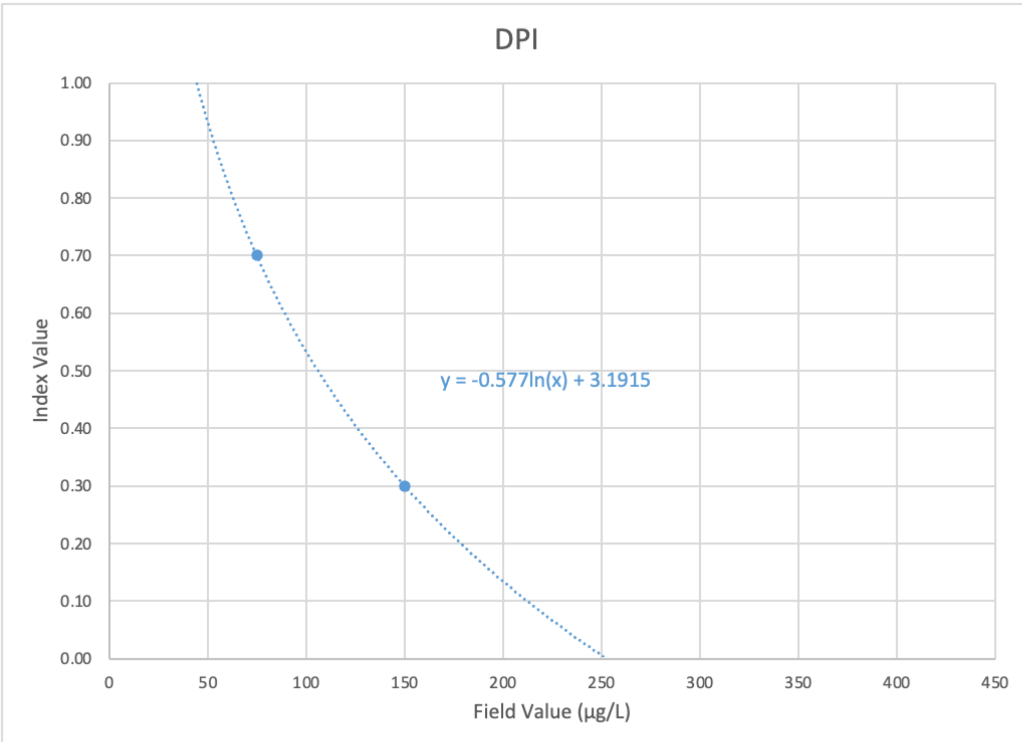
The WDNR Reference Dataset was compared to the threshold values for aquatic life used in WDNR (2021). With a median value of 51 µg/L, almost half of the sites would meet WDNR's attainment value of < 45 µg/L. The not attaining aquatic life use threshold of > 150 µg/L falls in between the third quartile (Q3, also the 75th percentile) and the 95th percentile. The WISQT TC decided to align the threshold values with the use attainment for aquatic life, where values below 75 µg/L total phosphorous represent functioning condition, values greater than 150 µg/L indicate impairment and values between represent a grey zone that is functioning-at-risk (Table 11-3). The full range of field values is consistent with the WDNR Reference Dataset. Because this dataset represents the best available sites across the state, some sites do not represent reference condition, particularly in developed areas of the state.

Because of the logarithmic nature of nutrient values in streams, the WISQT TC decided to apply a logarithmic fit to develop the reference curve (Figure 11-3). Applying a logarithmic curve would estimate the 1.00 index value at 45 µg/L and the 0.00 index value at 252 µg/L. Concentrations below 45 µg/L represent a pristine condition, which is consistent with research predicting reference concentrations of total phosphorous in the upper Midwest in the absence of human influences (Robertson et al. 2006; Dodds and Oakes 2004; Smith et al. 2003). Using the reference curve, a small portion of the sites would yield a score indicating no functional capacity since the 95th percentile is 273 µg/L.

Table 11-3: Threshold values for Diatom Phosphorus Index.

Index Value	Field Value (µg/L)
0.70	75
0.30	150

Figure 11-3: Reference curve for Diatom Phosphorus Index (DPI).



LIMITATIONS AND DATA GAPS

This metric assumes a direct correlation between phosphorus and benthic algae growth. Factors such as water clarity, canopy cover, scouring flows, water temperature, and grazing by fish and invertebrates also affect benthic algae biomass but are not directly accounted for by this metric. Site specific conditions need to be considered when applying this metric.

Chapter 12 Organics Parameter

Functional Category: Physicochemical

Physicochemical Functional Statement: Temperature and oxygen regulation; processing of organic matter and nutrients.

Function-based Parameter Summary:

Physicochemical functions are characterized by the interaction of physical and chemical processes that create the water quality of the stream, as well as facilitate nutrient and organic carbon processes (Harman et al. 2012). Water quality is often characterized by identifying individual water quality parameters, such as temperature or turbidity, and developing metrics specific to those parameters, resulting in only a subset of physicochemical processes being evaluated at a site. Bioassessment methods, which assess the response of biological communities to stressors, can serve as indicators of water quality degradation; often providing insights into the ecological condition of multiple water quality parameters within a single metric.

Macroinvertebrate taxa have diverse feeding habits and have different responses to changes in nutrients, acidification, organic pollution, and sedimentation. As such, macroinvertebrate indices are often used to characterize changes in water quality, including sediment, nitrogen, organic enrichment, and nutrient enrichment. While macroinvertebrate communities are assessed in the biology functional category, certain biological indices have been specifically developed as water quality indicators. This categorization is consistent with other SQTs that include chlorophyll α as a metric for the nutrient parameter in the physicochemical functional category.

Macroinvertebrate indices have been used to characterize water quality in Wisconsin streams since the development of the original Hilsenhoff Biotic Index in 1977 (Lillie et al. 2003). This index considers the tolerance of different taxa to organic pollution and reduced dissolved oxygen levels in streams. Additional data, modification and refinement has led to the improved Hilsenhoff Biotic Index (Hilsenhoff 1987), which estimates the overall tolerance of the community in a sampled area, weighted by relative abundance of each taxonomic group.

Metric for Organics:

- Hilsenhoff Biotic Index (HBI)

12.1. Hilsenhoff Biotic Index

Summary

The Hilsenhoff Biotic Index (HBI) is a quantitative approach to characterizing organics based on the relative abundance of macroinvertebrate taxa with varying tolerances for organic pollution (Hilsenhoff 1987). The HBI was originally developed for use in Wisconsin streams (Hilsenhoff 1977) and has since been updated and regionalized for broad use. The HBI estimates the overall tolerance of the macroinvertebrate community in a sampled area, weighted by the relative abundance of each taxonomic group. Organisms are assigned a tolerance number from 0 to 10 pertaining to that group's known sensitivity to organic pollutants: 0 being most sensitive, 10 being most tolerant. These scores are used to calculate an overall biotic index score, which ranges from 0.00-10.00. See Hilsenhoff (1987) for a listing of tolerance values for stream arthropods. The HBI is used almost exclusively by WDNR to evaluate organic pollution in

Wisconsin streams (Lillie et al. 2003) and was thus selected for inclusion in the WISQT as an indicator of water quality condition.

REFERENCE CURVE DEVELOPMENT

Reference curves are based on the condition category thresholds presented in Hilsenhoff (1987), as well as data from the WDNR Reference Dataset (Section 1.7). The narrative descriptions from Hilsenhoff (1987) (Table 12-1) were evaluated against results from the WDNR Reference Dataset (Table 12-2) which represents data from the best available sites across the state. While many of these sites can be considered reference condition, the dataset contains the best sites available in developed areas of the state, which likely have impacted water quality.

Table 12-1: Hilsenhoff Biotic Index scores as they relate to water quality condition category and degree of organic pollution (Hilsenhoff 1987).

Biotic Index	Water Quality	Degree of Organic Pollution
0.00 - 3.50	Excellent	No apparent organic pollution
3.51 - 4.50	Very Good	Possible slight organic pollution
4.51 - 5.50	Good	Some organic pollution
5.51 - 6.50	Fair	Fairly significant organic pollution
6.51 - 7.50	Fairly Poor	Significant organic pollution
7.51 - 8.50	Poor	Very significant organic pollution
8.51 - 10.00	Very Poor	Severe organic pollution

Table 12-2: Statistics for Hilsenhoff Biotic Index scores from the WDNR Reference Dataset.

Statistic	HBI Value
MIN	1.2
5TH	2.5
Q1	3.4
Median	4.4
MEAN	4.6
Q3	5.4
95TH	7.1
MAX	9.8

Following review of the WDNR Reference Dataset and the water quality condition categories in Hilsenhoff (1987), threshold values were developed as follows:

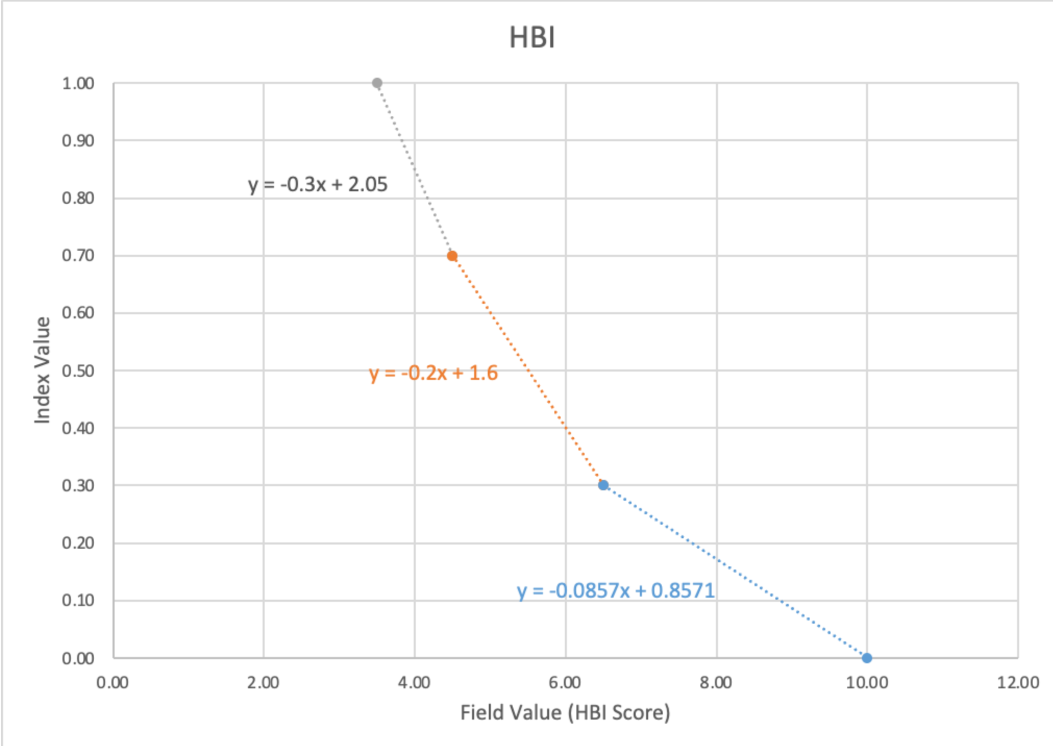
- The maximum index value (1.00) aligns with the threshold for the 'excellent' water quality condition category with no apparent organic pollution (Table 12-1) and reflects an HBI score of 3.5. This is consistent with the 25th percentile HBI score of 3.4 from the WDNR Reference Dataset.
- Scores falling within the 'very good' water quality condition category represent functioning condition, and the threshold between functioning and functioning-at-risk (0.70) reflects an HBI score of 4.5. This is similar to the median HBI score of 4.4 from the WDNR Reference Dataset.
- Scores falling within the 'good' and 'fair' represent functioning-at-risk condition (some and fairly significant organic pollution, respectively), and thus the threshold between functioning-at-risk and not-functioning (0.30) reflects an HBI score of 6.5. In the WDNR Reference Dataset, the 95th percentile of HBI scores was 7.1. Given these sites reflect best-available, as opposed to least-disturbed or reference quality streams, it is known that some sites are degraded. As such, the WISQT TC felt an HBI of 6.5 was an appropriate threshold value for not-functioning, indicating some small portion of the WDNR Reference Dataset are likely not-functioning with respect to water quality.
- The maximum HBI score of 10.0 was used to set the minimum index score of 0.00. The maximum HBI score in the WDNR Reference Dataset was 9.8, indicating values up to 10 could potentially be observed in the field. Scores falling within the 'fairly poor, poor and very poor water quality categories (Table 12-1) are thus consistent with the not-functioning range of condition. These categories represent sites with significant, very significant or severe organic pollution.

Threshold values are identified in Table 12-3. Linear regressions were plotted between each of these threshold values to develop a broken linear reference curve (Figure 12-1).

Table 12-3: Threshold values for Hilsenhoff Biotic Index.

Index Value	Field Value
1.00	≤ 3.5
0.70	4.5
0.30	6.5
0.00	≥ 10.0

Figure 12-1: Reference curve for Hilsenhoff Biotic Index (HBI).



LIMITATIONS AND DATA GAPS

This metric is not applicable in non-wadable streams. WISQT users should be cognizant of the time of year when sampling occurs as there are strengths and weaknesses to both. Spring sampling usually results in more mature larvae, which makes identification easier. However, spring sampling is susceptible to impacts from spring flooding or water quality problems such as limited dissolved oxygen stemming from colder water temperatures. Fall sampling is preferential for capturing the impacts of non-point source pollution for the HBI. As opposed to spring sampling, immature larvae may make identification to species level difficult.

Chapter 13 Macroinvertebrates Parameter

FUNCTIONAL CATEGORY: Biology

BIOLOGY FUNCTIONAL STATEMENT: Biodiversity and the life histories of aquatic and riparian life.

FUNCTION-BASED PARAMETER SUMMARY:

Macroinvertebrates are well established biological indicators of stream ecosystem health. They are ubiquitous, being found in every stream and river, no matter how small or large, meaning that macroinvertebrate-based assessments can be applied universally. Macroinvertebrate communities are responsive to human impacts and water quality changes and are also typically abundant and diverse in streams, making them relatively easy and affordable to collect and analyze. Because macroinvertebrates typically live no more than a year or two, they tend to respond to the current state of the ecosystem. Macroinvertebrates are also relatively sessile; that is, they do not tend to move long distances during their lifetimes, meaning that they are responsive to local conditions.

Multimetric assessments, often referred to as indices of biotic integrity (IBI), include multiple metrics characterizing macroinvertebrate community response to human influence (Weigel 2003). In Wisconsin, Weigel (2003) developed empirically derived macroinvertebrate IBIs (mIBIs), stratified by ecoregion (Northern Forest, Driftless Area, Central-Southeast), that are responsive to both watershed and local scale human influences. Human influences include urban and agricultural land uses, point source pollution, wastewater effluent, and local scale riparian stressors and instream habitat degradation including sedimentation and scouring. WDNR relies on the mIBIs to inform waterbody assessment and has developed condition category thresholds to inform aquatic life use narrative criteria (WDNR 2022). The WISQT TC decided to include the mIBI in the SQT to inform this parameter.

METRIC FOR MACROINVERTEBRATES:

- Macroinvertebrate Index of Biotic Integrity (mIBI)

13.1. MACROINVERTEBRATE INDEX OF BIOTIC INTEGRITY (MIBI)

SUMMARY

The Wisconsin mIBI is a multimetric assessment that uses information on macroinvertebrate taxonomic and functional composition to quantify community response to human influence (Weigel 2003). The mIBI was developed and validated for cold and warmwater wadable streams and is not applicable in non-wadable or ephemeral streams. The mIBI calculation method is stratified by ecoregion: Northern Forest, Driftless Area and Central-Southeast. In all three ecoregions, the mIBI includes the following metrics: species richness, percent ephemeroptera-plecoptera-tricoptera (EPT) taxa, mean pollution tolerance value, proportion of depositional taxa, proportion of diptera, proportion of chironomidae, proportion of shredders, proportion of scrapers, proportion of gatherers, proportion of isopoda, and proportion of amphipoda. The resulting metric scores are scaled to a range of 0-10 and are compared to excellent, good, fair, and poor condition categories (WDNR 2022).

Reference Curve Development

Reference curves are based on the condition category thresholds developed to inform criteria for aquatic life in Wisconsin streams (WDNR 2022) presented in Figure 13-1. The WISQT TC decided to align the threshold values with the condition category thresholds presented in WDNR (2022), where scores falling within the good condition category represent functioning condition, poor scores indicate not-functioning condition, and fair scores represent a grey zone that is functioning-at-risk (Table 13-1). Minimum index values were defined to align with the minimum mIBI scores of 0. Maximum index values were defined to align with mIBI scores within the excellent category, as these sites likely reflect a pristine or unaltered condition.

Figure 13-1: Condition category thresholds for wadable stream macroinvertebrate index of biotic integrity. Reproduced from WisCALM (WDNR 2022).

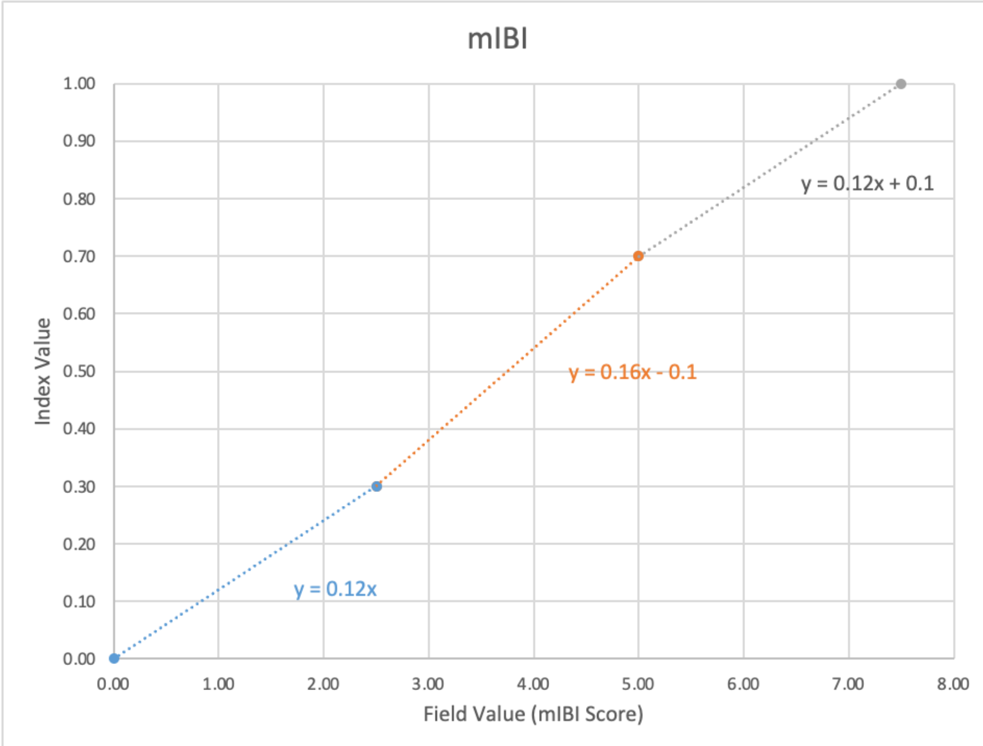
Wadeable Stream M-IBI Thresholds	*Condition Category*
> 7.5	Excellent
5.0-7.4	Good
2.5-4.9	Fair
< 2.5	Poor

Additional stratification was not considered, as the mIBI calculation method is stratified by ecoregion: Northern Forest, Driftless Area and Central-Southeast. As such, the metric calculation itself accounts for differences among ecoregions. Threshold values are identified in Table 13-1. Linear regressions were plotted between each of these threshold values to develop a broken linear reference curve, presented in Figure 13-2.

Table 13-1: Threshold values for Macroinvertebrate Index of Biotic Integrity.

Index value	Field Value
1.00	≥ 7.5
0.70	5.0
0.30	2.5
0.00	0.0

Figure 13-2: Reference curve for Macroinvertebrate Index of Biotic Integrity (mIBI).



LIMITATIONS AND DATA GAPS

This metric is not applicable in non-wadable or ephemeral streams.

Statistical analysis in Weigel (2003) supported the creation of three regions in Wisconsin, but there were differences in data collected in the Central-Southeast region of Wisconsin. These differences were related to data from sites with low levels of impact in predominantly forested watersheds compared with severely impacted sites in urban watersheds. Additionally, greater research is necessary to ascertain whether seasonal differences between sites sampled in the autumn or spring exist. Lastly, sites in the Driftless ecoregion should only be compared between one another if sampling occurred in similar habitats (e.g., run or riffle).

Chapter 14 Fish Parameter

Functional Category: Biology

Biology Functional Statement: Biodiversity and the life histories of aquatic and riparian life.

Function-based Parameter Summary:

Fish are an integral part of functioning stream ecosystems. Fish populations require adequate streamflow, water quality, and habitat availability to support their life history requirements (Harman et al. 2012). Different species are adapted to unique stream temperatures, habitats, and flow regimes and they serve as important indicators of ecological condition. Many environmental stressors can affect biological communities, and these effects can be characterized by assessing fish community structure and composition (WDNR 2018). Fish are long lived and thus the composition of the assemblage reflects the ecological condition over a longer period than macroinvertebrates which have a short lifespan (WDNR 2018).

Wisconsin fish communities vary depending on temperature regimes, including cold, coolwater and warmwater systems. According to Lyons et al. (1992), high quality warmwater streams in Wisconsin include many native species, darters, suckers, sunfish, and species sensitive to water pollution and habitat degradation (Lyons et al. 1988; Lyons 1989), with some tolerant species present, but not dominant. Most species are insectivores, with carnivorous and omnivorous species common but not dominant. As ecological condition declines, species richness is reduced, and tolerant and omnivorous species become more dominant. In severely degraded systems, there is very low abundance and species richness, and the fish present tend to be tolerant omnivores in poor physical condition.

High quality coldwater systems, in comparison, tend to have lower species richness dominated by salmonids and cottids, with many taxonomic groups important to warmwater streams being rare or absent (Lyons et al. 1996). Additionally, coldwater fish communities differ in their response to environmental degradation, with species richness increasing in response to declines in ecological condition (Lyons et al. 1996). Coolwater streams, which are the most common thermal classification in Wisconsin, have summer water temperatures and fish communities that are intermediate between coldwater and warmwater systems (Lyons et al. 2012).

Bioassessment approaches, i.e., fish Indices of Biotic Integrity (fIBI), have been developed to characterize fish assemblages across these thermal regimes in Wisconsin and are included in the WISQT. Fish abundance was included in addition to the fIBI to capture changes in fish populations that would not be captured by the fIBI, specifically changes in abundance and successful reproduction within target fish communities.

Metrics for Fish:

- Fish Index of Biotic Integrity (fIBI)
- Fish Abundance

14.1. Fish Index of Biotic Integrity (fIBI)

Summary

Indices of biotic integrity are commonly used to assess the condition of aquatic ecosystems, and integrate information on community structure, composition, and functional organization (Lyons et al. 1996). In Wisconsin, indices of biotic integrity have been developed to characterize fish assemblages in coldwater (Lyons et al. 1996), coolwater (Lyons 2012) and warmwater (Lyons 1992) systems. The thermal classes and temperature ranges for the three fIBIs are presented in Table 14-1. These fIBIs are used by the WDNR as indicators of aquatic ecosystem condition and to assess against appropriate aquatic life benchmarks (WDNR 2018). The fIBIs reflect structural changes in fish assemblages in response to local and watershed-level disturbance, riparian condition, and local habitat quality. As such, the fIBI reflects the response of the fish assemblage to multiple types, and multiple scales, of environmental disturbance (WDNR 2018).

Table 14-1: Thermal classes and temperature ranges for Fish Index of Biotic Integrity (fIBI).

fiBI Thermal Class	Temperature range for each class
Coldwater	Daily maximum mean water temperature < 22°C
Coolwater*	Daily maximum mean water temperature 20.7-24°C
Warmwater	Daily maximum mean water temperature ≥24°C

**Separate Coolwater fIBIs have been developed for cool-cold transition (20.7-22.5°C) and cool-warm transition (22.6-24.6°C), but the same reference curve applies to both.*

In warmwater systems, the fIBI consists of 12 metrics characterizing species richness and composition (total number of native species; number of darter, sucker, sunfish, and intolerant species; percent tolerant species), trophic and reproductive function (percent omnivores, insectivores, top carnivores, simple lithophilous spawners), and fish abundance and condition (number of individuals [excluding tolerant species] per 300m^2, percent with deformities, eroded fins, lesions, or tumors).

In coolwater systems, there are two fIBIs to characterize fish assemblages. In cool-cold transition streams, the fIBI has 5 metrics: number of darter, madtom, and sculpin species, number of coolwater species, number of intolerant species, percent tolerant species, and percent generalist feeders. In cool-warm transition streams, the fIBI has 5 metrics: number of native minnow, number of intolerant species, number of benthic invertivore species, percent tolerant species and percent omnivores.

In coldwater systems, the fIBI consists of 5 metrics: number of intolerant species, percent tolerant species, percent top carnivore species, percent native or exotic stenothermal coldwater or coolwater species, and percent of salmonids that are brook trout.

Reference Curve Development

Reference curves were stratified based on the three thermal classes (coldwater, coolwater, and warmwater) and temperature ranges are presented in Table 14-1. Reference curves were developed for fish using existing fIBIs and their biotic integrity rating category thresholds (Lyons 1992, Lyons et al. 1996 and Lyons 2012) presented in Table 14-2.

Table 14-2: Condition category thresholds for Fish Index of Biotic Integrity (Lyons 1992, Lyons et al. 1996 and Lyons 2012).

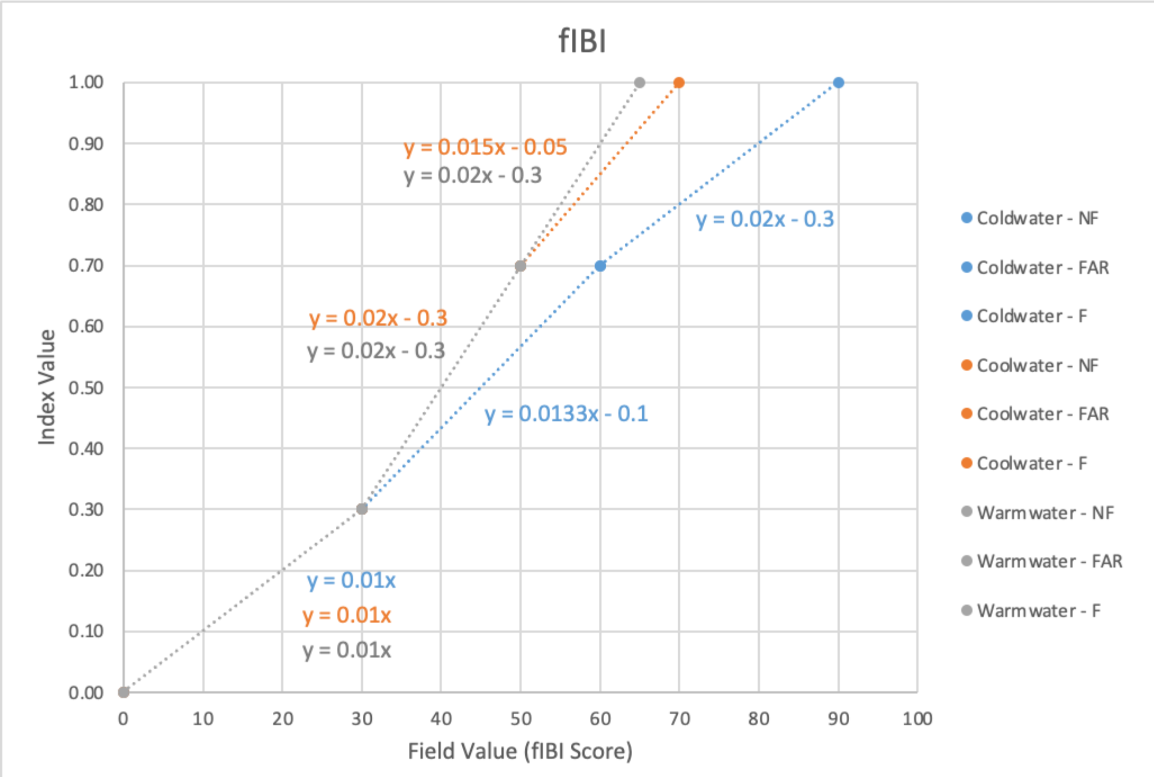
Coldwater	Coolwater	Warmwater	Biotic Integrity Rating
90-100	70-100	65-100	Excellent
60-80	50-60	50-64	Good
30-50	30-40	30-49	Fair
10-20	0-20	20-29	Poor
0 or no score	-	0-19 or no score	Very Poor

The WISQT TC aligned the threshold values with the condition category thresholds presented in Lyons (1992), Lyons et al. (1996) and Lyons (2012), where scores falling within the good condition categories represent functioning condition, scores falling within the poor condition category are not-functioning, a score of 0 represents no functional capacity (i.e., an index score of 0.00), and excellent scores indicate a pristine condition (i.e., an index score of 1.00) (Table 14-3).

Table 14-3: Threshold values for Fish Index of Biotic Integrity.

Index Value	Coldwater fIBI Field Value	Coolwater fIBI Field Value	Warmwater fIBI Field Value
1.00	≥ 90	≥ 70	≥ 65
0.70	60	50	50
0.30	30	30	30
0.00	0	0	0

Figure 14-1: Reference curves for Fish Index of Biotic Integrity (fIBI).



Limitations and Data Gaps

According to Lyons et al. (2012), effective IBI application is dependent upon appropriate temperature and flow classifications for streams. Identification of appropriate temperature regime or flow classes can be complicated by human activities that may alter temperature and flow attributes compared with reference condition. Consideration should be given to the human influences on temperature when determining which fIBI and reference curve to apply at a project site, as inappropriate temperature classification will lead to inaccurate fIBI results.

Note: In 2023, WDNR launched a process to revise the fIBIs used in Wisconsin. Although the data collection methods will not change, the thresholds for the fIBIs may change. This document and related SQT resources will be updated once those revised thresholds are finalized and made publicly available.

14.2. Fish Abundance

Summary

Directly assessing the composition of fish in streams allows SQT users to observe and track the effects of reach- or watershed-based stressors or improvements on fish populations (WDNR 2018). Fish are useful indicators of stream functions because they are long lived and will leave or avoid degraded conditions, which provides important insights into overall stream and catchment condition. WDNR has used observed fish assemblages and catch per unit effort (CPE) metrics to evaluate status and trends in the state's waterbodies for decades. For this reason, the WISQT TC included a fish abundance metric in the WISQT. The field value for the fish abundance metric is the number of fish per mile.

REFERENCE CURVE DEVELOPMENT

Reference curves were developed using data from WDNR fish surveys. Reference curves are stratified based on connection to the Great Lakes (i.e., coastal and inland streams) and, for inland streams, by target species. Inland streams are those that are not connected to the Great Lakes due to the presence of an impassable barrier. For projects located on inland streams, the user can select between smallmouth bass (native), brown trout, or brook trout (native) species. Where a project occurs on a coastal stream (i.e., a stream with a connection to the Great Lakes), the reference curves are for Young of the Year (YoY) trout species and are stratified by lake: Lake Michigan or Lake Superior.

<u>Inland Streams: Smallmouth Bass, Brown Trout, and Brook Trout</u>

Adult smallmouth bass CPE data from wadable stream surveys from 1977-2022 were used to develop reference curves. Adult smallmouth bass include individuals measuring at least 8 inches. The adult population of smallmouth bass is an important determinant of future population success as a small group of adults can sustain a population. Additionally, the CPE of immature smallmouth bass in wadeable streams can vary greatly from year to year depending on environmental conditions.

Reference curves for yearling and adult brook trout and brown trout in wadeable streams were developed using the wadable stream surveys from 2007-2014. The WISQT TC lumped yearling and adult data together to develop this reference curve to capture both mainstem and tributary streams. While tributaries may host more yearlings than adults, mainstem streams may host more adults than yearlings. The combined approach ensures that total fish abundance is accounted for regardless of stream size or order. Brown and brook trout individuals are defined as those measuring at least 4 inches in length as this is the size requirement for recruitment to the fishery.

Reference curves for smallmouth bass, brown trout, and brook trout were developed from the WDNR statewide dataset using the following criteria (Table 14-4 and Figure 14-2):

- No fish indicates no function (0,0.0),
- The 75th percentile was used to set the threshold for Functioning (0.70).
- The 95th percentile was used to set the maximum index value (1.00).

<u>Coastal Streams: Young of Year Trout</u>

The WISQT TC also evaluated catch per unit of effort data for Young of Year (YoY) trout found within the coastal tributaries of Lake Michigan and Lake Superior. YoY data was used instead of adult CPE due to the migratory nature of adults in these systems. The YoY data includes brook, brown, and rainbow trout species from both reference quality and non-reference quality streams.

YoY data for Coho and Chinook salmon from coastal streams were also evaluated but these species were largely absent from Lake Michigan surveys, while the data from Lake Superior lacked length measurements, and the values were lower in CPE than the trout species. For these reasons these species were excluded from the reference curves.

Two options were explored to stratify YoY trout data: one option was to stratify by species and location, for instance, Lake Michigan YoY brown trout; the second option was to lump the species data and to stratify based solely on location (e.g., Lake Michigan YoY and Lake Superior YoY). Stratification based on location was necessary as the two watersheds differ greatly - streams in the Lake Michigan watershed experience greater human disturbance (in-stream barriers, stormwater runoff, impervious surface) than Lake Superior and the CPE in Lake Michigan coastal streams is much lower as a result. The decision to lump trout species together was also driven by interannual variability in species-specific data; the presence of any YoY trout is indicative of a high-quality nursery stream. Additionally, lumping YoY species avoids the risk that WISQT users may quantify changes associated with species-specific stocking or management decisions by WDNR or other agencies.

Reference curves for the Lake Michigan and Superior YoY trout were developed from the WDNR statewide dataset using the following criteria (Table 14-4 and Figure 14-2):

- No fish indicates no function (0,0.0).
- The 75th percentile of all species was used to inform the Functioning (0.70) threshold.
- The 95th percentile of all species was used to inform the maximum index value (1.00).

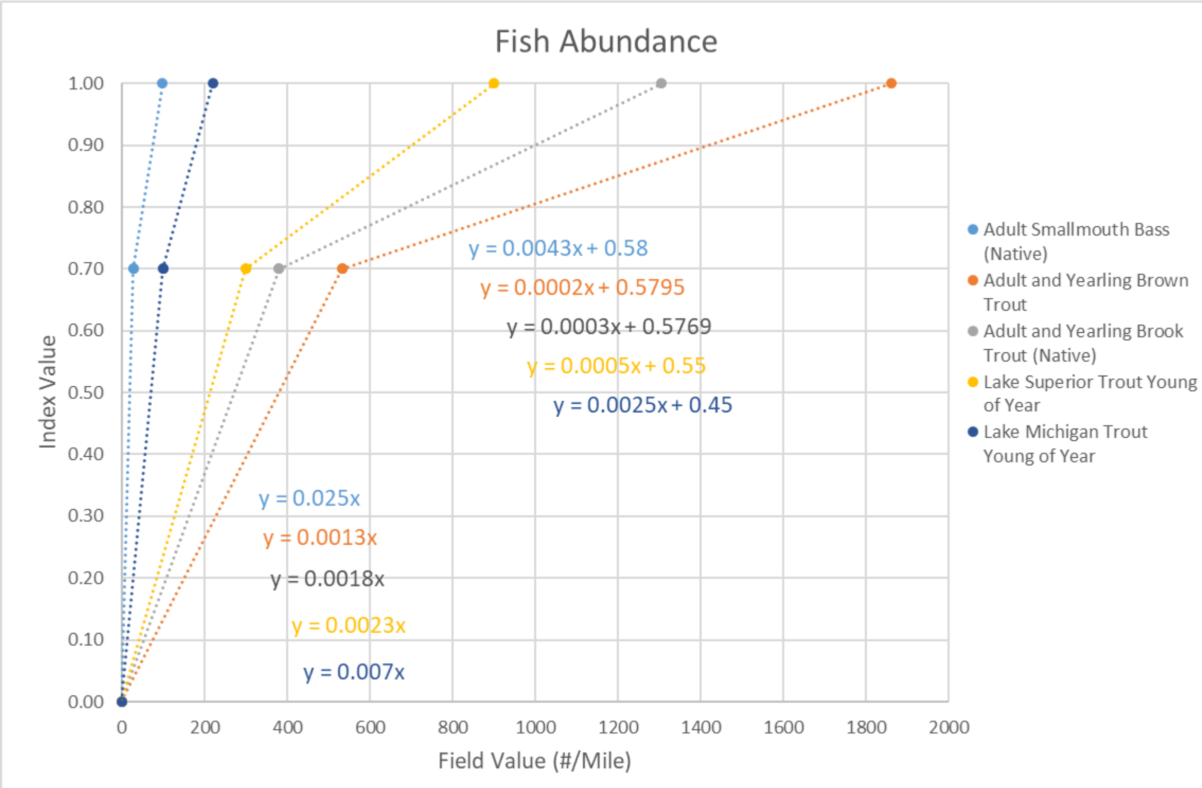
For both inland and coastal systems, the WISQT TC discussed whether to include a threshold value for the 0.30 index value using the 50th percentile from the datasets. Although there was agreement that the 50th percentile of CPE could serve as the 0.30 threshold value for smallmouth bass, this was not the case for the other inland or coastal reference curves where the data are “noisier” given other factors such as stream size, latitude, and interannual variability. As a result, the decision was made to leave the 0.30 threshold undefined for all reference curves which provides a consistent slope across the not-functioning and functioning-at-risk ranges of scoring.

Threshold values and reference curves are shown in Table 14-4 and Figure 14-2.

Table 14-4: Threshold values for Fish Abundance (CPE, number of fish per mile).

Index Value	Inland Streams			Coastal Streams	
	Smallmouth Bass	Brown Trout	Brook Trout	Lake Superior Trout YoY	Lake Michigan Trout YoY
1.00	≥ 98	≥ 1860	≥ 1306	≥ 900	≥ 220
0.70	28	533	380	300	100
0.30	-	-	-	-	-
0.00	0	0	0	0	0

Figure 14-2: Reference curves for Fish Abundance.



LIMITATIONS AND DATA GAPS

There are limitations associated with the data used to inform these reference curves. Data used in the development of reference curves span decades and represent a range of conditions as opposed to sites and time periods specifically identified as indicative of reference conditions. Further, some datasets have low sample numbers, this is particularly true of the Lake Michigan data. Another bias is geographic, although data in the Fisheries Management Information System (FMIS) comes from throughout Wisconsin, a higher percentage of trout data comes from the Driftless Area, Western Corn Belt and North Central Hardwood Forest ecoregions. This bias is also true for smallmouth bass, where a higher percent of that data comes from the Driftless Area ecoregion.

The reference curves developed are focused on specific species, i.e., trout and smallmouth bass, that are predominantly cold or coolwater species. As such, other species like those found in warmwater streams are unaccounted for in this metric. Additionally, reference curves were not created for adult rainbow trout as there are very few streams that support a fishable population of this species and only a couple inland systems have naturally reproducing populations. Should sufficient data exist to develop additional reference curves, future versions of this metric could focus on representative fish species found in a broader array of stream types. Similarly, there are other species of interest that may be targeted by restoration and whose abundance may be impacted by in-stream activities. For example, pike is a species of interest in Wisconsin but given the limited geographic extent of this species within the state, data were insufficient to develop a reference curve. Similarly, coho and chinook salmon are of interest in Wisconsin, but data were insufficient to develop a reference curve or curves.

Lastly, the field value of number of fish per mile (normalized by stream length) does not account for natural variations in fish abundance based on stream size. The number of fish per acre may result in improved reference curves and scoring of reference quality fish abundance. The metric also does not account for natural variations in nutrients and latitude, which are known predictors of fish abundance in Wisconsin. Additional research into other stratifications of this metric may be considered in future versions of the WISQT.

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Chapter 16 WISQT List of Metrics

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Functional Category	Function-Based Parameters	Metrics (Units)	Reference Curve Stratification		Threshold Index Values				Literature and Data Sources Used to Develop Reference Curves
			Type	Description	i= 0.00	i= 0.30	i= 0.70	i= 1.00	
Hydrology	Catchment Hydrology	Land Use Coefficient			98	75	68	≤ 55	Wisconsin SQT Technical Committee (WISQT TC) adapted land use coefficient values from NRCS (1986).
	Reach Runoff	Land Use Coefficient			98	75	68	≤ 55	
		Concentrated Flow Point Index			1.0	0.6	-	0	Developed by the WISQT TC and EPR.
Hydraulics	Floodplain Connectivity	Bank Height Ratio (ft/ft)			-	1.5	-	1.0	Literature values from Rosgen (2009) and Harman et al. (2012).
		Entrenchment Ratio (ft/ft)	Reference Stream Type	B	≤ 1.0	-	1.4	≥ 2.2	Originally developed for the MNSQT (MNSQT SC 2020b); literature values from Rosgen (1996) and Harman et al. (2012); datasets include Jennings & Zink (2017; TN), WY, and Donatich et al. (2020; NC).
				C	≤ 1.0	-	2.2	≥ 5.0	
				E	≤ 1.0	-	2.2	≥ 9.0	
	Bankfull Dynamics	Width/Depth Ratio State (O/E)			≥ 1.8 ≤ 0.2	-	-	1.0	Literature values from Rosgen (2014).

Functional Category	Function-Based Parameters	Metrics (Units)	Reference Curve Stratification		Threshold Index Values				Literature and Data Sources Used to Develop Reference Curves
			Type	Description	i= 0.00	i= 0.30	i= 0.70	i= 1.00	
Geomorphology	Large Woody Debris (LWD)	LWD Index			0	-	1350	≥ 2825	Originally developed for the MISQT v1.0 (MI EGLE 2020) using unpublished dataset from 5 reference condition sites and 11 managed sites in north-central Michigan.
		LWD Frequency (#/100m)			0	-	90	≥ 171	Based on unpublished dataset from 5 reference condition sites and 11 managed sites in north-central Michigan.
	Lateral Migration	Dominant BEHI/NBS			H/VH, H/Ex, VH/VH, VH/Ex, Ex/M, Ex/H, Ex/VH, Ex/Ex	M/H, Ex/L, Ex/VL	-	VL/VL, VL/L, VL/M, VL/H, VL/VH, VL/Ex, L/VL, L/L, L/M, L/H, L/VH, M/VL	Originally developed for the MNSQT (MNSQT SC 2020b) using literature values from Rosgen (2008) and Harman et al. (2012).
		Percent Streambank Erosion (%)			≥ 50	-	11	≤ 5	Literature values from Binns (1992); dataset from Donatich et al. (NC).
		Percent Streambank Armoring (%)			≥ 50	-	-	0	Originally developed for the MNSQT (MNSQT SC 2020b).

Functional Category	Function-Based Parameters	Metrics (Units)	Reference Curve Stratification		Threshold Index Values				Literature and Data Sources Used to Develop Reference Curves
			Type	Description	i= 0.00	i= 0.30	i= 0.70	i= 1.00	
Geomorphology	Riparian Vegetation	Effective Vegetated Riparian Area (%)	Valley Type	Unconfined Alluvial Valleys	0	30	-	100	Originally developed for the CSQT Version 1.0 (USACE 2020b).
				Confined Alluvial & Colluvial Valleys	0	60	-	100	
		Canopy Cover (%)	Reference Vegetation Cover	Woody	0	-	50	≥ 87	Literature values from Dey et al. (2017).
				Herbaceous	≥ 70	35	15	0	Literature values from O'Connor (2020).
		Herbaceous Cover (%)			0	-	-	≥ 80	Originally developed for the MISQT v1.0 (MI EGLE 2020) using literature from Summers et al. (2017).
		Woody Stem Basal Area (m^2/ha)	Reference Vegetation Cover	Woody	0	9.2	-	≥ 13.8	Originally developed for the MNSQT (MNSQT SC 2020b) using data from MD (USFWS 2013), NH (Leak et al. 2014) and MN (Young et al. 2017 and Sebestyen et al. 2011).
	Bed Form Diversity	Pool Spacing Ratio (ft/ft)	Reference Stream Type	A & B	≥ 6.5	-	5	≤ 4.0	Modified from the MNSQT (MNSQT SC 2020b) using literature values from Rosgen (2014), Leopold et al. (1994), and several published and unpublished datasets including Harman & Clinton (NC &WV), Jennings & Zink (TN), Zink et al. (TN & NC), Lowther (NC) Rinaldi & Johnson (MD)and MI EGLE.
				Bc	≥ 8.0	-	6	≤ 5.0	
				C & E	≤ 1.0 ≥ 9.0	-	-	3.5 - 6.0	
		Pool Depth Ratio (ft/ft)			≤ 1.0	-	2	≥ 3.0	Modified from the MNSQT (MNSQT SC 2020b) using literature from Rosgen (2014) and several published and unpublished datasets including Lowther (NC), Jennings & Zink (TN), MI EGLE.
		Percent Riffle (%)	Reference Stream Type	A & B	0, 100	-	-	50 - 60	Modified from the MNSQT (MNSQT SC 2020b) using literature from published and unpublished datasets including Harman & Clinton (NC & WV), Jennings & Zink (TN), MI EGLE and Zink et al. (TN & NC).
				C & E	0, 100	-	-	45 - 65	

Functional Category	Function-Based Parameters	Metrics (Units)	Reference Curve Stratification		Threshold Index Values				Literature and Data Sources Used to Develop Reference Curves
			Type	Description	i= 0.00	i= 0.30	i= 0.70	i= 1.00	
Geomorphology	Bed Material Characterization	Percent Fines (% < 2mm)	Bed Material	Coarse gravel and cobble-bed streams	≥ 32	-	14.8	≤ 5	Literature values and data from Benoy et al. (2012).
		Percent Fines (% < 6.35mm)			≥ 35	-	16.9	≤ 5	
		Median Particle Size (d50) (mm)			≤ 10	-	34	≥ 70	
Physicochemical	Temperature	Summer Mean Temperature (°C)	Stream Temperature	Coldwater	-	18.7	17	≤ 12.5	State thermal criteria and literature values from Lyons et al. (2009) and Diebel et al. (2015).
				Coolwater - Cold Transition	-	-	18.7	≤ 17.0	
				Coolwater - Warm Transition	-	-	20.5	≤ 18.7	
				Warmwater	-	-	23	≤ 20.5	
	Nutrients	Benthic Algal Biomass			-	2	1	-	Literature values from Wisconsin's *Waterbody Assessments Rule Package: Technical Support Document* (WY-23-13; WDNR 2021).
		Diatom Phosphorus Index (DPI) (µg/L)			-	150	75	-	Literature values from Wisconsin's *Waterbody Assessments Rule Package: Technical Support Document* (WY-23-13; WDNR 2021) and an unpublished dataset (WDNR Reference Dataset).
	Organics	Hilsenhoff Biotic Index (HBI)			≥ 10	6.5	4.5	≤ 3.5	Literature values from Hilsenhoff (1987); unpublished dataset (WDNR Reference Dataset).

Functional Category	Function-Based Parameters	Metrics (Units)	Reference Curve Stratification		Threshold Index Values				Literature and Data Sources Used to Develop Reference Curves
			Type	**Description**	**i= 0.00**	**i= 0.30**	**i= 0.70**	**i= 1.00**	
Biology	Macroinvertebrates	mIBI			0.0	2.5	5.0	≥ 7.5	Condition category thresholds for wadable stream macroinvertebrate index of biotic integrity from WDNR WisCALM (2022).
	Fish	fIBI	Stream Temperature	Coldwater	0	30	60	≥ 90	Thermal classes and temperature criteria found in Lyons et al. (1996).
				Coolwater	0	30	50	≥ 70	Thermal classes and temperature criteria found in Lyons (2012).
				Warmwater	0	30	50	≥ 65	Thermal classes and temperature criteria found in Lyons (1992).
		Fish Abundance (#/mile)	Target Fish Community	Smallmouth Bass ≥ 8"	0	-	28	≥ 98	Unpublished WDNR fish survey dataset from 2007-2014.
				Brown Trout ≥ 4"	0	-	533	≥ 1860	
				Brook Trout ≥ 4"	0	-	380	≥ 1306	
				Lake Superior Trout Young of Year	0	-	300	≥ 900	
				Lake Michigan Trout Young of Year	0	-	100	≥ 220	

Note: "-" indicates the field value threshold was extrapolated or interpolated.