Stream Mitigation Accounting Metrics

Exploring the Use of Linear-based, Area-based, and Volume Units of Measure to Calculate Impacts and Offsets to Different Stream Archetypes

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Cover images

Top: Little Santeetlah Creek, North Carolina by Will Harman.

Bottom: Wood River, Wyoming by Will Harman.

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This technical report is the result of a collaborative effort between a nationally represented steering committee and technical team. The steering committee provided guidance regarding the problem statement and critical questions to address, participated in a workshop with the technical team to develop criteria used to evaluate various units of measure in different stream archetypes and assessment assumptions, and provided review comments on various drafts of the report. The steering committee was co-chaired by Tracie Nadeau and Brian Topping with the U.S. Environmental Protection Agency. Steering committee members included: Calvin Alvarez with the U.S. Army Corps of Engineers Alaska District, Brian Cluer with the National Oceanic and Atmospheric Administration, Gabrielle David with the U.S. Army Engineer Research and Development Center, Faith Fitzpatrick with the U.S. Geological Survey, Karl Koller with the Minnesota Department of Natural Resources, Peter Skidmore with the Walton Family Foundation, Eric Somerville with the U.S. Environmental Protection Agency Region 4, and Todd Tillinger with the U.S. Army Corps of Engineers Nashville District.

The technical team used the criteria developed in the workshop to evaluate various scenarios where a unit of measure was applied to a stream archetype under different stream assessment assumptions. The technical team also served as report authors along with the steering committee co-chairs. The technical team included Will Harman with Stream Mechanics, Matt Kondratieff with Colorado Parks and Wildlife, Karin Boyd with Applied Geomorphology, George Athanasakes with Stantec, and Joe Wheaton with the Utah State University. We thank all members of the steering committee and technical team for their time and expertise; this project would not have been possible without their insightful input.

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Summary of Findings

In 2008, the U.S. Environmental Protection Agency (EPA) and the U.S. Army Corps of Engineers (Corps) jointly promulgated regulations revising and clarifying requirements to improve the quality and success of compensatory mitigation (Mitigation Rule; 33 CFR Parts 325 and 332 and 40 CFR Part 230) under Section 404 of the Clean Water Act, including for streams and rivers. The Mitigation Rule codified that compensatory mitigation requirements must be commensurate with the amount and type of impact associated with a particular permit action (33 CFR 332.3(a)(1) and 40 CFR 230.93(a)(1)). This requires that compensatory mitigation accounting protocols calculate the amount of impacts (debits) and offsets (credits) to determine if compensation actions (credits) offset impact actions (debits). These amounts are generally calculated using a common Unit of Measure (UoM); two UoMs widely used or considered in the regulatory program are length and area. The UoM may be the only component in a stream mitigation accounting protocol (i.e., linear feet or area of impact); however, the UoM may also be modified (e.g., multiplied) by the output score of a function- or condition-based assessment, the use of which is promoted by the Mitigation Rule to determine appropriate compensatory mitigation to replace the functions and services lost due to unavoidable permitted impacts (33 CFR 332.3(f)(1) and 40 CFR 230.93(f)(1)). Additional adjustments may be applied when calculating credits and debits to account for other considerations, including compensation method, risk and the likelihood of success, temporal loss, and the distance between the impact and compensation sites (33 CFR 332.3(f)(2-3) and 40 CFR 230.93(f)(2-3)).

The main purpose of this document is to explore the use of various UoMs as applied in stream mitigation accounting protocols, highlighting key questions and an analytical process to inform the development and use of scientifically and mathematically credible UoMs. To that end, the following questions, which address the credibility, applicability, and parity (between the debit and credit sides of the accounting ledger) of the UoM, are the focus of this document:

- Is the use of a given UoM scientifically supported for calculating impacts (debits) and compensation (credits) to achieve compensatory mitigation program goals? – Credibility
- Does the given UoM reasonably apply to different stream archetypes and landscapes nationwide? – Applicability
- Does the given UoM apply equally to the impact (debit) and compensation (credit) sides of a debit/credit ledger? – Parity

To help address these questions and guide report development, both a steering committee (SC) and a technical team (TT) were formed. Members of these groups were drawn from federal and state agencies as well as private organizations and selected to represent credible and regionally diverse expertise in stream assessment, restoration, and compensatory mitigation. Using a suite of impact and offset scenarios, the technical team evaluated four different UoMs for their applicability and effectiveness in satisfying compensatory mitigation requirements under the Mitigation Rule: channel length, channel area, valley length, and valley area. Each UoM, alone or in combination with assessment method outputs, was applied to six different stream archetypes and evaluated against six criteria drawn from Mitigation Rule requirements (Table A). The archetypes are representative of different stream systems in landscapes nationwide but are not exhaustive in their scope. The archetypes differ based on degree of wadeability, number of channel threads, flow duration, and valley type. Included stream archetypes were developed specifically for this exercise using stream elements commonly affected by impact and offset activities and are not derived from any specific stream classification approach. In addition, no specific stream assessment approach was assumed for this evaluation; rather, the uniform application of common elements of an assessment including stratification, scaling, and representativeness, among others, were assumed. Furthermore, two assessment areas were considered – stream channel only or stream channel and the adjacent floodplain (Table A).

Table A. UoM Evaluation Elements.

UoM	Assessment Assumption	Evaluation Criteria	Stream Archetype
Channel Length Valley Length Channel Area Valley Area	No Assessment Stream Only Assessment Stream and Floodplain Assessment	Does the UoM apply equally on debit and credit side?	(1) Wadeable, single-thread, perennial stream located in an alluvial valley.
		Does the UoM incentivize debit and credit determination that supports ecological benefits?	(2) Wadeable, multi-thread (anastomosed), perennial stream in an alluvial valley with low stream power.
		Does the UoM support in-kind mitigation?	(3) Non-wadeable, single-thread stream in an alluvial valley.
		Does the UoM incentivize restoration that is appropriate for the landscape?	(4) Perennial or intermittent, braided, multi-thread channel.
		Is the UoM repeatable?	(5) Single-thread, ephemeral channel in a confined alluvial valley.
		Is the UoM straightforward to measure?	(6) Wadeable, perennial, colluvial valley (step-pool) system.

This evaluation indicated that no UoM used alone, in the absence of supporting stream assessment information, rated highly against many of the evaluation criteria. UoMs in combination with an assessment of the stream channel, or both the stream channel and floodplain, were better at satisfying the evaluation criteria across all stream archetypes. This outcome suggests that a robust approach to stream assessment considering longitudinal and lateral contributors to stream function (e.g., a scientifically informed assessment method), in combination with an appropriate UoM, increases the scientific credibility of mitigation accounting outputs.

Based on the outcomes from the above exercise, the three focus questions can be summarized:

<u>Credibility</u>*: Is the use of a given UoM scientifically supported for calculating impacts (debits) and compensation (credits) to achieve compensatory mitigation program goals?*

- The approach used to assess stream function and/or condition has a greater impact on the scientific credibility of the calculation of debits and credits than does the UoM (i.e., the multiplier). How a stream is assessed (what is encompassed by the assessment approach including assessment area) and how it aligns with the UoM affects the scientific and mathematical credibility of the resulting debit/credit calculation.
- Applying a UoM without first assessing stream function and/or condition ranked moderately well for in-kind mitigation of in-channel only impacts and offsets.
- The use of channel length when coupled with a channel and floodplain assessment approach ranked high for the single-thread channel archetypes but not the multi-thread channel archetypes.
- The valley length UoM, when coupled with an assessment approach considering both the channel and floodplain, ranked highest against the evaluation criteria, in part because it can be applied to both single- and multi-thread channels.
- The use of channel and valley area as UoMs are difficult to consistently measure and may result in unintended mitigation outcomes.

<u>Applicability</u>: *Does the given UoM reasonably apply to different stream archetypes and landscapes nationwide?*

- Channel length can be effectively applied to single-thread archetypes (1, 3, 5, and 6) but generally not to multi-thread archetypes (2 and 4).
- Valley length as a UoM had strengths across all stream archetypes but was most consistent in confined alluvial valleys (stream archetype 5) and wadeable, perennial step-pool streams in colluvial valleys (stream archetype 6).
- Channel area as a UoM generally had mixed results across all stream archetypes but performed best when coupled with stream archetypes 5 and 6.

- Valley area as a UoM applied equally well to all stream archetypes in the evaluation; however, this UoM could be challenging if the active valley width is difficult to define, especially in wide, alluvial valleys.

<u>Parity:</u> ***Does the given UoM apply equally to the impact (debit) and compensation (credit) sides of a debit/credit ledger?***

- Parity for all four UoMs was improved when an assessment approach that included both the stream channel and floodplain was assumed, with the strongest parity between the debit and credit sides occurring when channel length was applied to single-thread systems.
- Channel length in combination with a stream and floodplain assessment produced the strongest parity for all single-thread channel archetypes; however, it did not result in parity for multi-thread channels.
- Both valley length and valley area UoMs, coupled with a channel and floodplain assessment approach, applied equally to the debit and credit sides of the ledger in single- and multi-thread channels.
- Channel area in combination with a stream and floodplain assessment provided parity for all single-thread channel archetypes; however, it did not result in parity for multi-thread channels.

Application of a UoM is an important component of a compensatory stream mitigation accounting protocol, as it provides common units for calculating debits and credits. However, this project has shown that applying a UoM alone, in the absence of an assessment of stream function or condition, may lack the scientific rigor and defensibility needed to assure offsets functionally replace impacts, per the 2008 Mitigation Rule. A robust assessment approach that considers stream channel and floodplain elements affecting stream function supplies the strongest scientific foundation for calculating debits and credits, and the selection of a UoM should be informed by considering the stream archetypes of the applicable region and the assessment method(s) used.

Glossary of Terms

Following are key terms and definitions used throughout this document; the definitions of **bolded** terms are taken from the U.S. Army Corps of Engineers/U.S. Environmental Protection Agency Compensatory Mitigation for Losses of Aquatic Resources; Final Rule (2008; 33 CFR Parts 325 and 332; 40 CFR Part 230).

Adjustment Factors: One of three elements of a mitigation accounting protocol, adjustment factors may be applied to account for considerations and programmatic objectives (e.g., compensation method, likelihood of success, temporal loss) not otherwise addressed in the calculation of debits (impacts) and credits (offsets).

Assessment Outputs: The score(s) or result of stream assessment method application. These could be categorical like good, fair, or poor and based on best professional judgement. Or these could be quantitative outputs that represents aspects of stream function/condition. Represented as numerical scores or ratings, assessment outputs are typically unitless and are sometimes related to reference condition or a range of expected performance as an index value. Assessment output scores can be generated for individual metrics and/or categories and rolled up into an overall reach score or rating representing stream function/condition.

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 (33 CFR 332.2; 40 CFR 230.92).

Credit: A unit of measure (e.g., a functional or areal measure or other suitable metric) representing the accrual or attainment of aquatic functions at a compensatory mitigation site. The measure of aquatic functions is based on the resources restored, established, enhanced, or preserved (33 CFR 332.2; 40 CFR 230.92). Credits result from offset or compensation actions.

Debit: A unit of measure (e.g., a functional or areal measure or other suitable metric) representing the loss of aquatic functions at an impact or project site. The measure of aquatic functions is based on the resources impacted by the authorized activity (33 CFR 332.2; 40 CFR 230.92).

Floodprone Area: The area adjacent to a stream channel that is inundated with flood waters at a stage that is two times the maximum bankfull depth (Rosgen, 1996).

Functions: The physical, chemical, and biological processes that occur in ecosystems (33 CFR 332.2; 40 CFR 230.92).

In-Kind Mitigation: A resource of a similar structural and functional type to the impacted resource (33 CFR 332.2; 40 CFR 230.92).

Interagency Review Team: Group of federal, tribal, state, and/or local regulatory and resource agency representatives that reviews documentation for, and advises the district engineer (Corps) on, the establishment and management of a mitigation bank or an in-lieu fee program.

Meander Width Ratio: The belt width divided by the bankfull width. The belt width is the distance from the outside of a meander bend on one side of the river to the outside of a meander bend on the opposite side. The distance across is measured perpendicular to the valley axis (Rosgen, 1996).

Metrics: A parameter, measure, indicator, or other term used to assess an aspect or characteristic of a stream's condition or function. Example metrics include floodplain connectivity, lateral migration, riparian vegetation, natural cover, and large woody debris.

Out-of-Kind Mitigation: A resource of a different structural and functional type from the impacted resource (33 CFR 332.2; 40 CFR 230.92).

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 (33 CFR 332.2; 40 CFR 230.92).

Reach: A segment of a stream along which similar conditions exist. Stream assessment methods are generally applied at the reach scale and may be applied to more than one reach per project site.

Scaling: A physical dimension that is applied when calculating a stream assessment outcome for an individual metric or the outcome of an assessment method containing multiple metrics. For example, large woody debris (a metric) may be assessed at a scale of 100 meters (328 feet) of reach length, yielding a value of number of pieces of wood per 100 meters (metric scaling). Determining the assessment area to which a stream assessment method is applied and how large an area the assessment outcome represents is the other form of scaling (method scaling). Assessment areas are often informed by, or *scaled* to, the dimensions of the project area stream; for example, the assessment area length may be 40 times the bankfull width and assessment area width may be a minimum of 100 meters from top of bank on each side, and the assessment area may be further limited toa maximum length of stream. While a unit of measure provides a common physical dimension for debits and credits resulting from a mitigation accounting protocol (which may include assessment method outputs and adjustment factors), the term scale is used in this report to describe the physical dimensions, or spatial extent, used to assess individual metrics (metric scaling) or delineate the area assessed by a particular method (method scaling) and is not synonymous with unit of measure.

Site: The entire area where proposed activities are expected to generate stream function or condition improvement or loss. More than one reach may occur within a site and these reaches may be further divided into sub-reaches based on changes in channel/valley morphology and other factors.

Stratification: Process by which a reference or standard performance index for a given assessment metric reflects different hydrogeomorphic landscape settings (e.g., arid vs. wet climate) or stream characteristics (e.g., channel width).

Stream Archetype: This report uses the term stream archetype to represent stream types that are common in compensatory stream mitigation programs; these include single-thread, multi-thread, wadeable, and non-wadeable channels with variable valley morphology (v-shaped, colluvial, and alluvial) and flow regimes (perennial, intermittent, and ephemeral).

Unit of Measure**:** 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).

1.0 INTRODUCTION/PURPOSE

Under Section 404 of the Clean Water Act (CWA), compensatory mitigation may be required to offset permitted impacts to Waters of the United States (WOTUS). In 2001 the National Research Council (NRC) released a comprehensive evaluation of the effectiveness of compensatory mitigation under Section 404 of the CWA, noting concerns with past compensatory mitigation and providing recommendations for improvement (NRC, 2001). In 2008, using the NRC report as an important resource, the U.S. Environmental Protection Agency (EPA) and the U.S. Army Corps of Engineers (Corps) jointly promulgated regulations revising and clarifying requirements to improve the quality and success of compensatory mitigation (Mitigation Rule; 33 CFR Parts 325 and 332; 40 CFR Part 230), including for streams and rivers. The Mitigation Rule, which has prompted the growth of stream compensatory mitigation frameworks nationwide, also codified that compensatory mitigation requirements must be commensurate with the amount and type of impact associated with a particular permit action (33 CFR 332.3(a)(1) and 40 CFR 230.93(a)(1)), and promotes the use of function or condition assessments to determine appropriate compensatory mitigation to replace the functions and services lost due to unavoidable permitted impacts (33 CFR 332.3(f)(1) and 40 CFR 230.93(f)(1)). It is important to note that condition, as defined by the Mitigation Rule (see glossary), is usually measured with point in time metrics (e.g., habitat quality and channel incision), whereas functions are the physical, chemical, and biological processes that support a stream ecosystem (e.g., substrate mobility, nutrient cycling, trophic structure). Generally, existing methods assess condition and/or attributes that indicate stream function.

> The purpose of this document is to highlight key questions and an analytical process informing the development and use of scientifically and mathematically credible units of measure in stream mitigation accounting protocols for federal, state, and tribal regulatory staff and their partners (e.g., IRTs) responsible for developing and implementing stream compensatory mitigation programs nationwide.

Compensatory mitigation accounting protocols calculate the amount of impacts (debits) and offsets (credits) and are used to determine if compensation actions (credits) offset impact actions (debits). Federal and state agencies have used a variety of approaches in developing mitigation accounting protocols, for calculating the number of debits and credits produced by various projects affecting stream resources. These approaches generally begin with an assessment of stream function and/or condition, which can range from quantitative or semi-quantitative function- or condition-based assessment methods that result in output scores to more subjective best professional judgement. Assessment outputs are contextualized through the application of a unit of measure (UoM); in current stream mitigation practice, the UoM is generally linear feet and to a lesser extent, area. Adjustment factors may also be applied in the mitigation accounting protocol, for instance, to consider temporal loss of function (Figure 1). Table 1 presents a selection of these protocols, including the UoM and any adjustment factors, where applicable.

Figure 1. Three Components of a Stream Mitigation Accounting Protocol.

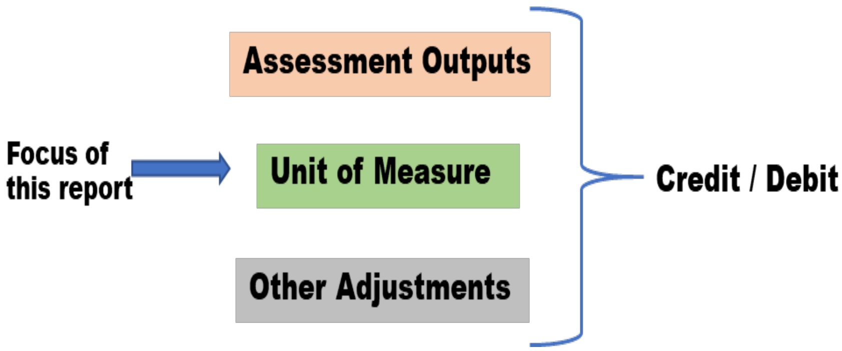


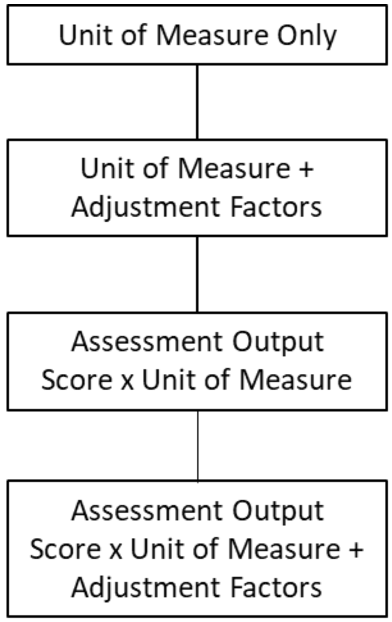
Table 1. Select examples of debiting and crediting approaches that use length and area units of measure, illustrating how assessment outputs, UoM, and adjustment factors are currently applied by some compensatory stream mitigation regulatory programs. Adapted from ELI et al. (2016). Additional examples are provided in the ELI report (2016).

State/Corps District	Stream Mitigation Accounting Protocol (Debits)	Stream Mitigation Accounting Protocol (Credits)
Norfolk District (Virginia; 2004)	***Compensation Requirement = (linear ft. [UoM]) x (RCI) x (IF)*** RCI (assessment output) = reach condition index is a weighted average of categorical condition indices for four parameters (channel condition, riparian buffer, instream habitat, channel alteration) IF (adjustment factor) = impact factor based on the severity of impact (0-1)	***Compensation Credit = restoration credit + enhancement credit + riparian buffer credit + adjustment factor credit*** Credits defined by level of effort (e.g., restoration is 1 credit/unit of measure (linear ft. or LF), enhancement is 0.09-0.3 credit/LF, etc.) and other adjustment factors (e.g., T&E or watershed preservation)

State/Corps District	Stream Mitigation Accounting Protocol (Debits)	Stream Mitigation Accounting Protocol (Credits)
Pennsylvania (2004)	***Compensation Requirement (CR) = (area of impact [UoM]) x (PE) x (RV) x (CI)*** PE (adjustment factor) = project effect factor based on severity of impacts RV (adjustment factor) = resource value based on categories of resource quality CI (assessment output) = condition index value from condition assessment CR is calculated for each aquatic resource function category and summed for total debit.	***Functional Credit Gain (FCG) = (area of project [UoM]) x (RV) x (CV) x (CI diff)*** RV = same as debits CV (adjustment factor) = compensation value based on level of benefit (1-3) CI diff = condition index differential value based on difference in baseline and predicted condition
Omaha District (Nebraska; 2012)	***Impact Units = (Stream Condition Index Score [assessment output]) x (stream length [UoM])*** Includes a condition assessment procedure and impact/mitigation calculator predicting proposed condition.	***Mitigation Units = (Stream Condition Index Score) x (stream length)*** Same assessment and calculator used to compare impact and compensation sites.
Omaha District (Wyoming; 2018)	***Debits = ΔFF x sum [DF]*** ΔFunctional Feet (ΔFF) = (Proposed Condition Score [assessment output] x proposed stream length [UoM]) – (Baseline Condition Score [assessment output] x existing stream length [UoM]) DF (adjustment factor) = debit factors identified in the WSMP v2.	***Credits = ΔFF x sum [CF]*** ΔFunctional Feet(ΔFF) same as debits CF (adjustment factor) = credit factors identified in the WSMP v2.

In practice, all three components (assessment outputs, UoM, and adjustment factors) shown in Figure 1 are not always used in compensatory stream mitigation accounting protocols. For instance, sometimes a stream mitigation accounting protocol will simply use a UoM and not an assessment method. Figure 2 shows the various applications of UoM's, starting with the simplest approach in the first box (UoM only) and progressing to approaches with more complexity and components. The first box simply uses the UoM as feet, area, or other; there is no consideration of stream or floodplain condition and no adjustment factor. Note, volume as a UoM is largely unexplored. The second box includes an adjustment factor with the UoM. This could be additive, subtractive, or a multiplier, such as a ratio that adjusts the number of credits or debits. The third box includes an assessment method with the UoM. This is the first application that includes an assessment of stream condition/function. The final box includes the assessment method but also allows for adjustment factors, providing additional flexibility in the mitigation accounting protocol to address scenarios and situations that cannot be addressed by the assessment method alone.

Figure 2. Various Applications of Units of Measure



There are challenges with both linear-based and area-based units of measure as currently applied in stream compensatory mitigation accounting protocols, and the usefulness of the UoM varies based on the applications shown in Figure 2. For example, the applicability of a UoM can vary depending on things such as stream planform (e.g., single versus multi-thread) and stream size (e.g., wadeable versus non-wadeable). This project explores the use of linear-based, area-based, and volume-based units of measure, including those currently in use, to calculate impacts and offsets to different types of streams. The purpose of this document is to highlight and address key considerations informing the development and use of scientifically and mathematically credible UoM's in stream mitigation accounting protocols for federal, state, and tribal regulatory staff and their partners (e.g., Interagency Review Teams) responsible for developing and implementing stream compensatory mitigation programs nationwide.

The following three questions address the credibility, applicability, and parity (between the debit and credit sides of the accounting ledger) of the UoM as applied, to different stream types and using different stream assessment approaches, in the CWA Section 404 regulatory program. These questions are the focus of this document:

- Is the use of a given UoM scientifically supported for calculating impacts (debits) and compensation (credits) to achieve compensatory mitigation program goals? – Credibility
- Does the given UoM reasonably apply to different stream archetypes and landscapes nationwide? – Applicability

- Does the given UoM apply equally to the impact (debit) and compensation (credit) sides of a debit/credit ledger? – Parity

To guide the development of this report, both a steering committee and a technical team were formed. Together members of these groups, selected to represent credible and regionally diverse expertise in stream assessment, restoration, and mitigation, provided a nationwide perspective. The project steering committee (SC) was comprised of members from federal, state, and non-profit organizations. The role of the SC was to 1) identify relevant science, studies, or practices; 2) inform development of questions or approaches to evaluate various UoM's; 3) collaborate with the Technical Team (TT) to guide development of the technical report; and 4) review and edit draft versions of the report. The TT responsibilities included: 1) review the literature for documents relevant to UoMs in stream mitigation accounting; 2) participate in a workshop with the SC to work through the most challenging issues as identified by EPA and the SC; 3) evaluate various UoMs under assumed assessment and stream archetype scenarios; and 3) assist in writing the report. Sections 2.0, 3.0, and 4.0 primarily describe this project's evaluation approach and results, followed by Section 5.0 that discusses considerations in the application of these results to stream compensatory mitigation.

2.0 FOUNDATIONAL COMPONENTS OF STREAM MITIGATION PROCESS AND ASSOCIATED ACCOUNTING PROTOCOLS

To fully address the questions posed in Section 1.0, it is necessary to place UoM's within the context of the overarching stream mitigation process and accounting protocols. Figure 3 presents a flow chart of a generic stream mitigation process that would satisfy the goals of compensatory mitigation per the Mitigation Rule, showing where the UoM would generally be applied. Table 2 presents more detailed descriptions of each step shown in Figure 3. Figure 4 provides an in-depth look at how the UoM might be applied to an assessment output score. These steps provide the scientific and mathematical underpinnings on which the appropriateness of UoM application is based. It is important to note that the UoM itself and its broader applicability may be influenced by how assessment outputs are generated and used, which can also affect the application of other adjustments and the scientific and mathematical credibility of the resulting credit/debit calculation (see Section 2.1).

Figure 3. Generic Stream Mitigation Process Flow Chart.

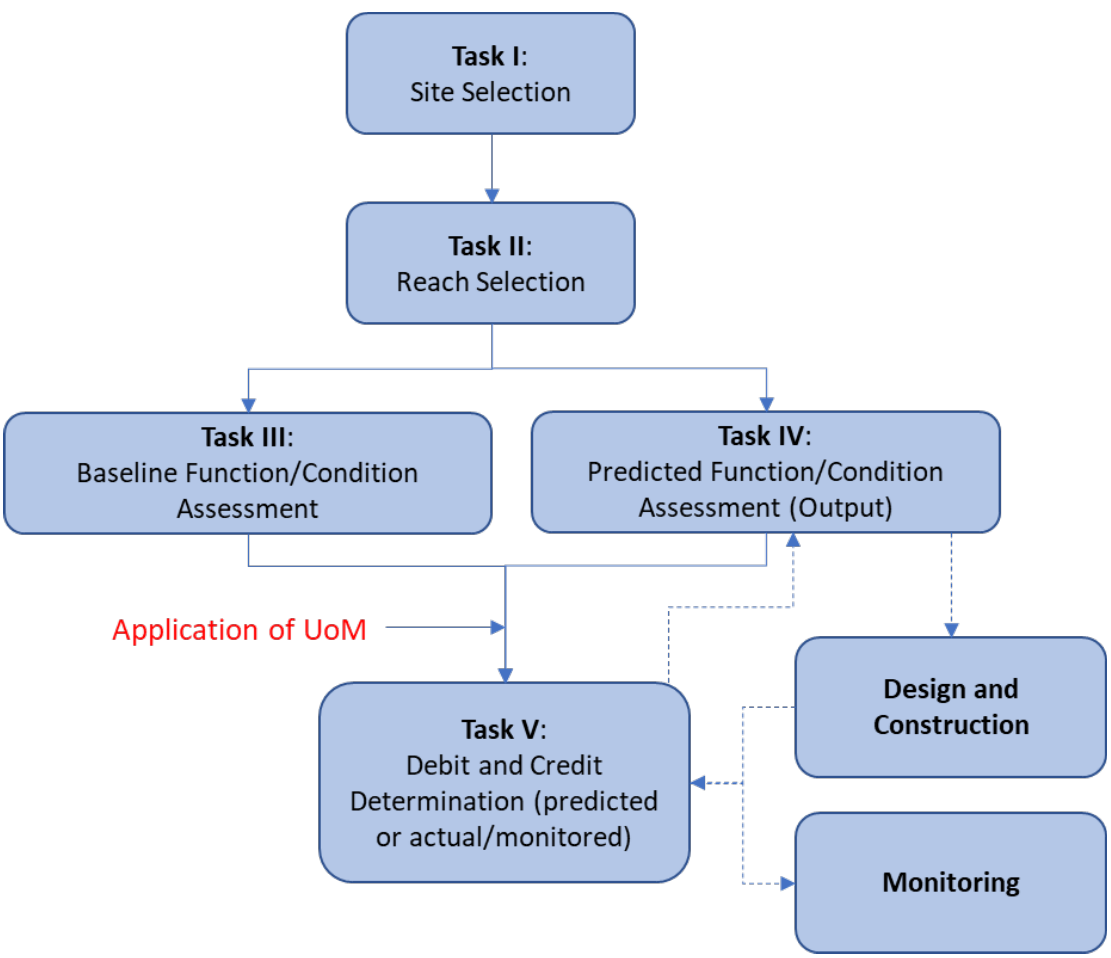


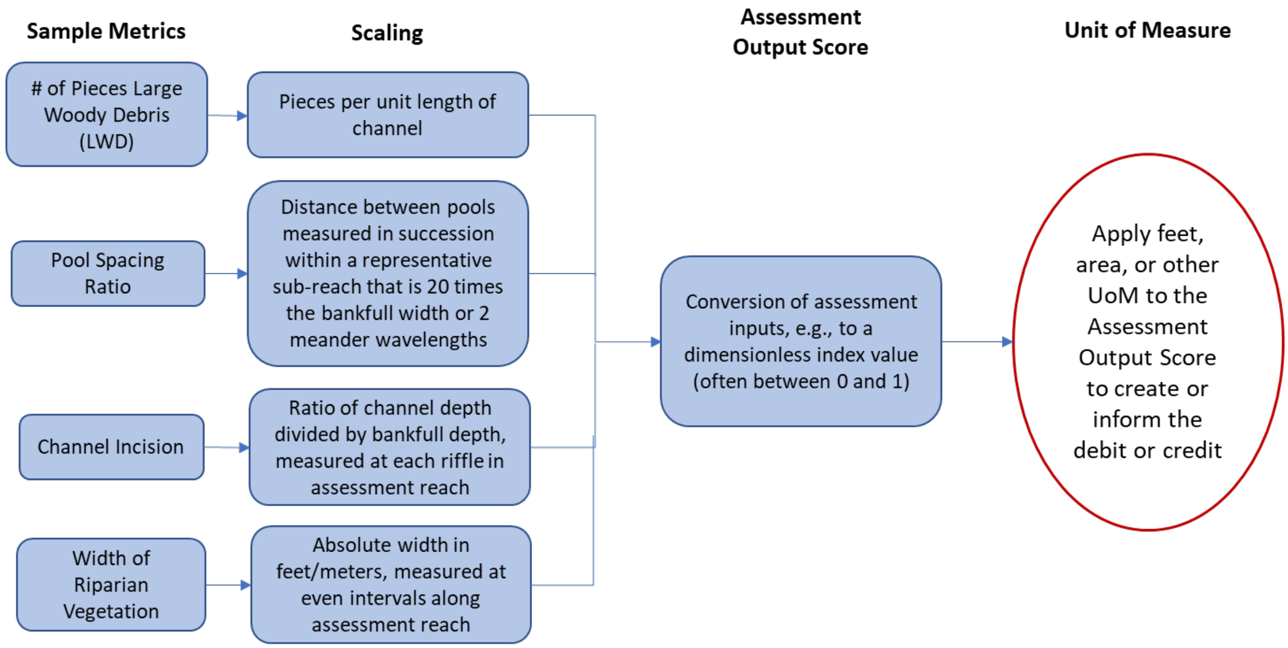
Table 2. Steps in the Generic Mitigation Process: Purpose, Scaling, and Units of Measure.

Task	Purpose	Scaling	Unit of Measure
I. Site Selection	Select a stream mitigation site that provides an ecological match to impacted resources and addresses needs within the same watershed[1]. Factors considered may include watershed setting/context, ecoregion, and stream type. The impact (or debit) site is generally defined by the scope of a permitted activity.	Property/easement boundary (area); scope of permitted activity	Not Applicable (NA)
II. Reach Selection	Select representative stream sections (reaches) for assessment. Some assessment methods evaluate the stream channel only while others may also evaluate the riparian and floodplain area.	• Reach extent (length) • Riparian extent (width or area), where used • Sub-reaches as applicable for certain assessment metric requirements (length or area)	NA
III. Baseline Function/ Condition Assessment	A) Select or develop a stream assessment method to determine the baseline functions/condition at the project reach(es). B) Determine the functions/ condition of the project stream reach before impact or restoration activities occur; evaluate output scores for different levels of assessment (metric, category, overall). See Figure 4.	Directly affects function/condition assessment output scoring. Scaling may be applied at the individual metric level and the units may vary (e.g., unitless, #/length or area, or simply best professional judgement).	UoM potentially applied to baseline assessment output scores (See B in purpose column).
IV. Predicted Function / Condition Assessment (Output)	Use same assessment method from step III (baseline) to predict function/condition after the proposed impact or restoration activities are completed. Predictions are based largely on project design and the anticipated degree to which restoration activities or impacts improve or degrade the function/condition of the resource. and proposed level of restoration. See Figure 4.	Same as step III to predict an output score for function/condition resulting from proposed activities. Predicted assessment function/condition output scores are compared to baseline assessment function/condition output scores to determine the proposed losses or gains in function/condition (i.e., change or delta).	Same UoM as Task III. The actual amount of the resource length, area, or volume being restored or impacted could change as a result of the activity.

[1] Based on the Mitigation Rule, site selection must take place using a watershed approach; however, while in-kind mitigation is preferred, in some cases out-of-kind mitigation, where the proposed mitigation provides a different structural and functional type to impacted resources, may be allowed and accounted for using adjustment factors.

Task	Purpose	Scaling	Unit of Measure
V. Debit/Credit Calculation	Use assessment output scores from metric, categorical, or overall reach score and the UoM to inform the debit and credit calculation. The changes in the condition/function calculations are also affected by application of any adjustment factors as well as project construction and design. The credit calculation is ultimately determined through satisfaction of performance standards through monitoring. The debit calculations are made by predicting the severity of the impacts and are not verified with monitoring.	Scaling occurred in previous phases. No scaling here.	Apply UoM to assessment output to calculate debit or credit amounts.
The following tasks are not directly part of the stream mitigation assessment process; however, they can be influenced by the UoM and assessment method and are therefore acknowledged below.			
Design / Construction	Uses assessment output, as well as site and budget constraints, to produce designs that minimize impacts or maximize ecological gains. This is often an iterative process, as shown by the dashed lines on Figure 2 (predict assessment output, design, calculate debits/credits). Repeat process to optimize results. Construction implements the final design and is verified with an as-built survey.		
Monitoring	Compare function/condition assessment output to performance standards to see if mitigation (restoration) project is achieving predicted function/condition (repeated at different times post construction. For example, annual monitoring). Pre/post-restoration assessment outputs reflect baseline and restored function/condition. The difference between them (delta) is sometimes called functional lift. Performance standards are developed to assess whether the predicted function/condition gains have been achieved through restoration activities and are linked to credit release. Units of measure should be the same between assessment output and performance standards. Note, monitoring is not limited to mitigation projects. Some large-scale impact projects, e.g., reservoirs and flood control projects, are required through permitting to monitor pre- and/or post-construction. Generally, the purpose is to determine if adaptive management measures are necessary. However, monitoring results could also lead to mitigation requirements.		

Figure 4. Unit of Measure Applied to Assessment Output Score, Showing Sample Metrics and Scaling.



2.1 Importance of the Assessment Method

As shown in Table 2 and Figure 4, baseline and predicted function/condition assessments produce the outputs to which a UoM is applied in a mitigation accounting protocol. While stream assessment methods are not the focus of this report, it is important to consider how assessment outputs are generated and used because that, in turn, may affect the scientific and mathematic credibility of applying a particular UoM in mitigation accounting protocols which result in debit/credit calculations. Key elements of stream assessment methods or approaches that can affect the scientific and mathematical credibility of the selected UoM include stratification, scaling, representativeness, regression to the known, and the approach to 'rolling-up' assessment method outputs. These elements are briefly described below and further explored in Section 5.2 (see David et al. 2021 for technical guidance on developing a stream assessment method).

Stratification is a process by which a reference or performance standard index for a given assessment metric reflects different hydrogeomorphic landscape settings (e.g., arid vs. wet climate) or stream characteristics (e.g., channel width). Stratification allows for a single assessment method to account for these differences while maintaining the same scoring structure.

Scaling can occur at two levels with respect to the assessment of stream function or condition; to identify where the assessment method is applied (method scaling) and where individual metrics are measured (metric scaling). For assessment method application, scaling refers to the approach used to determine the area to be assessed, which can be a standard measure of area, such as X stream length by Y riparian width, or a relative assessment area wherein the assessed channel length or area is relative to a dimension of the stream, such as width. An assessment area may or may not include the associated riparian and floodplain area, depending on the specific assessment method that is applied. For individual metrics, scaling identifies the physical area the metric assesses, since some metrics may only assess a portion of a larger project area. For example, riparian vegetation assessment protocols (e.g., Guilfoyle and Fischer, 2006) determine the number and size of plots that will occur adjacent to the stream channel; however, other metrics might be scaled differently. Ultimately, any scaling differences must be standardized to a common dimensionless index scale to generate meaningful assessment method outputs, as shown in Figure 4. In this report scaling, as defined above, refers to the individual metric or assessment method as a whole, whereas the UoM is applied to assessment outputs to achieve a dimensional credit or debit that can be compared across projects.

Representativeness reflects how well a given assessment metric captures the function or condition of an entire delineated assessment area and is often informed by the scaling of metrics and assessment areas. One salient example is how assessment width is established by a particular assessment method—does it encompass the stream and the adjacent floodplain, riparian extent, or valley bottom width? If the stream and floodplain or valley bottom width are included in an assessment, it can affect which UoM is appropriate to apply.

Regression to the known refers to the degree to which an assessment method incentivizes that proposed mitigation (restoration) provides a specific channel form (i.e., the known), regardless of the landscape (that is perhaps most familiar, well-studied, or preferred). Some stream mitigation assessment methods have been developed for single-thread channels and the (predicted) outputs obtained from applying such methods may incentivize single-thread channels even if a multi-thread, braided or anastomosed channel would be more appropriate for the valley type and watershed position.

The final element is the approach to rolling-up output scores resulting from application of an assessment method, which reflects how outputs of individual metrics may be combined into hierarchical levels of outputs. Outputs can be at the individual metric level (e.g., channel bed variability), individual function level (e.g., create and maintain habitat), a category level (e.g., biology), or for the overall assessment area.

Understanding the stream mitigation process as well as the importance of the stream assessment approach will help in evaluating the appropriate use and application of different units of measure presented in the next section.

3.0 APPLICATION OF DIFFERENT UNITS OF MEASURE

This section presents descriptions of various units of measure, and how they may be applied in stream mitigation accounting protocols. Section 3.1 provides an overview of applying the UoM both with and without an assessment of stream condition or function. Section 3.2 provides a categorical overview along with specific ways to quantify the UoM.

3.1 Applications of Units of Measure (UoM)

The simplest application of a UoM is to apply the unit without considering the function or condition of the affected stream, as shown in Figure 2 (see Section 1.0). For instance, one unit of impact is offset or mitigated with one unit of restoration (e.g., 1,000 feet of stream impact is mitigated with 1,000 feet of restoration). This approach offsets the physical amount of impact (length of stream, area, volume), but does not include the baseline and predicted function or condition assessments shown in Figure 3 (see Section 2.0), nor does it include any adjustment factors (see sidebar). It may or may not include selecting a mitigation site that is an ecological match to the impact site (see Section 2.0, Table 2).

Adjustment Factors

Some stream mitigation accounting protocols use adjustments to account for a variety of factors not already considered through the assessment approach or mitigation process. These increase or decrease the amount of debits or credits generated.

For instance, adjustment factors may be used to account for:

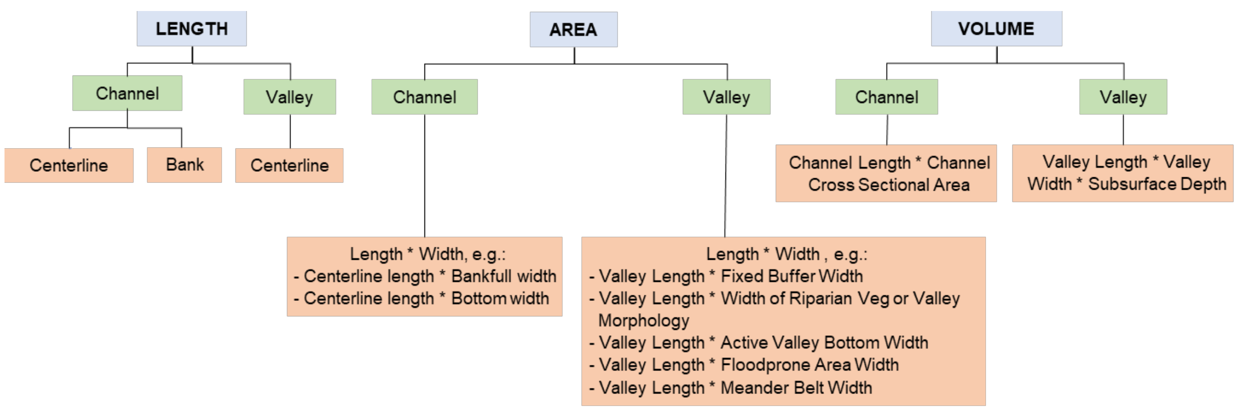
- Temporal loss of function
- Resource type (e.g., difficult to replace resources, aquatic resources of special concern)
- Long-term sustainability (e.g., stewardship; proximity to preserved intact natural areas)

An increasingly common approach applies a UoM to dimensionless stream assessment method output scores (see Figure 4). Assessment approaches used in stream mitigation protocols range from qualitative, best professional judgement evaluations to rapid or intensive quantitative methods. While it is beyond the scope of the current project to describe the various stream assessment methods in use, importantly, applying a formal assessment method, to a lesser or greater extent, provides some understanding of stream function or condition (e.g., David et al., 2021). After a stream assessment has been completed, the UoM is applied in some way to the resulting assessment output scores (e.g., multiplied). This applies the unit (e.g., feet or area) to the dimensionless assessment score such that the debit/credit has units (e.g., feet or area). After the UoM is applied, other adjustments can be made based on programmatic objectives (Figure 2; see also sidebar above).

3.2 Quantifying the Unit of Measure

This section provides descriptions and illustrations on quantifying length, area, and volume as the UoM. Some of the UoM's are currently used or being explored for use in regulatory protocols, and some are simply potential approaches. Figure 5 shows length, area, and volume as a UoM category. Under each category, the UoM is further described for the channel and/or valley. Details are then provided about how the UoM can be calculated. These calculations are examples. They are not an all-inclusive but are those considered to have scientific merit or known to be used in stream mitigation protocols.

Figure 5. Quantification of Units of Measure



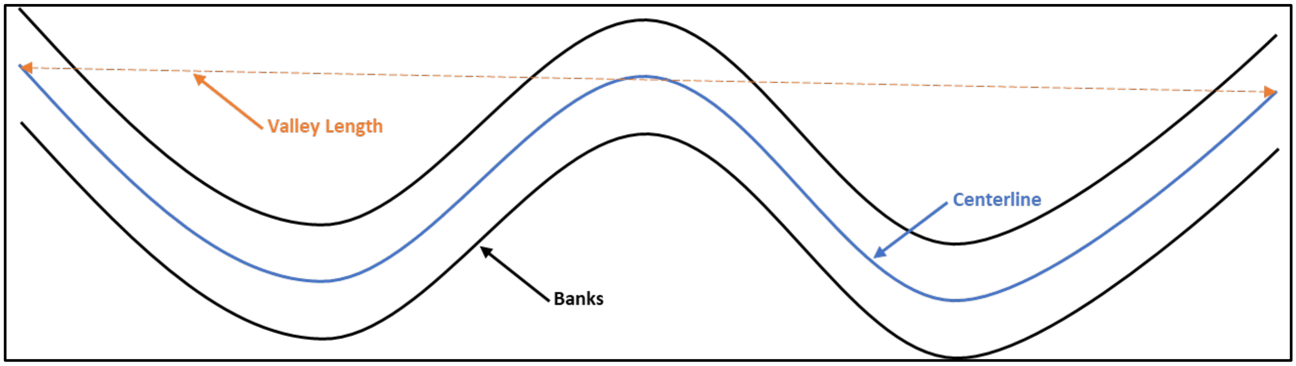
3.2.1 Length

The different measures of length are shown in Figure 6. Channel length is the simplest and most common UoM currently used in stream mitigation accounting protocols (ELI, 2016). In single-thread channels, it is typically quantified as a centerline length. In multi-thread channels, the channel length is typically measured along the primary channel, if one can be determined. If a primary channel cannot be determined, then channel length cannot be applied.

Bank length is a linear distance measured along the stream bank. It can include the length of one bank or both banks depending on program goals and project activities.

Valley length is typically a straight-line measurement from the upstream end of a project reach to the downstream end. If a reach is long and the valley turns, the valley length may be the sum of a series of straight-line segments rather than the length of a single straight line. In either case, the valley length follows the lowest (elevation) portion of the valley.

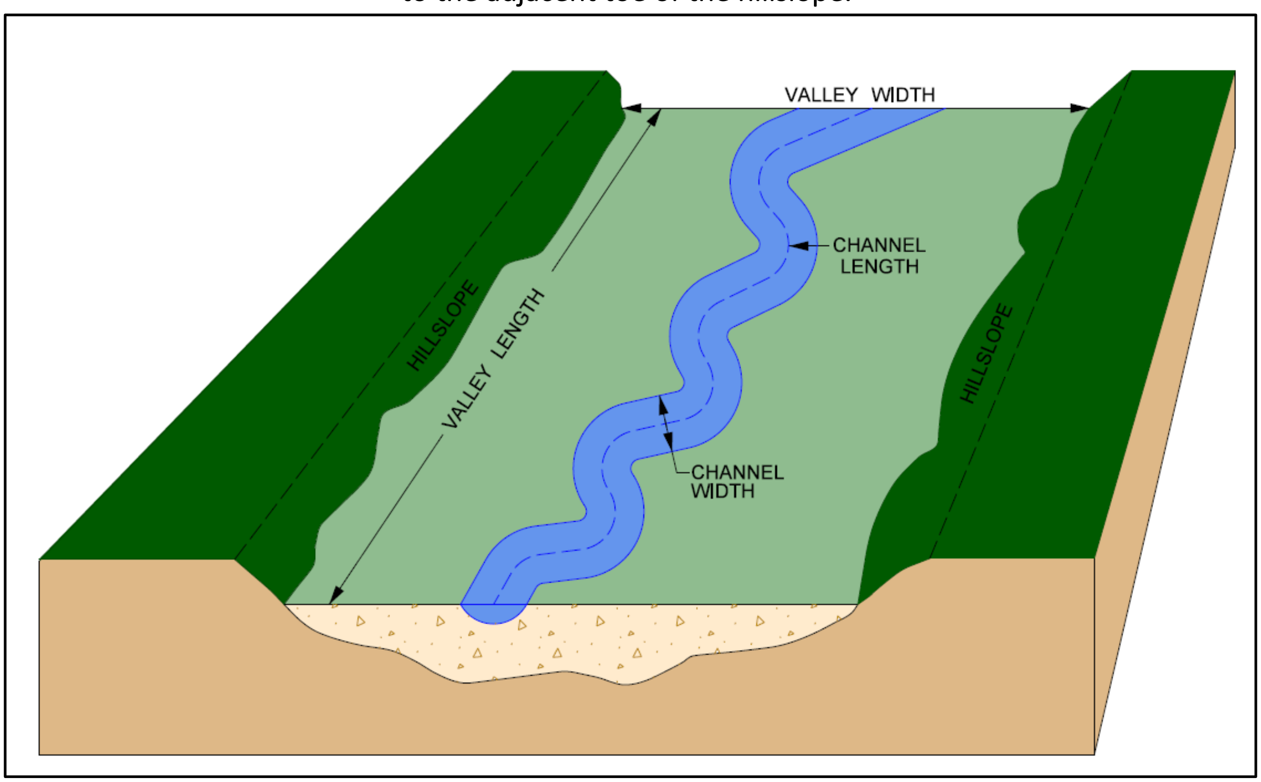
Figure 6. Different Measurements of Length.



3.2.2 Area

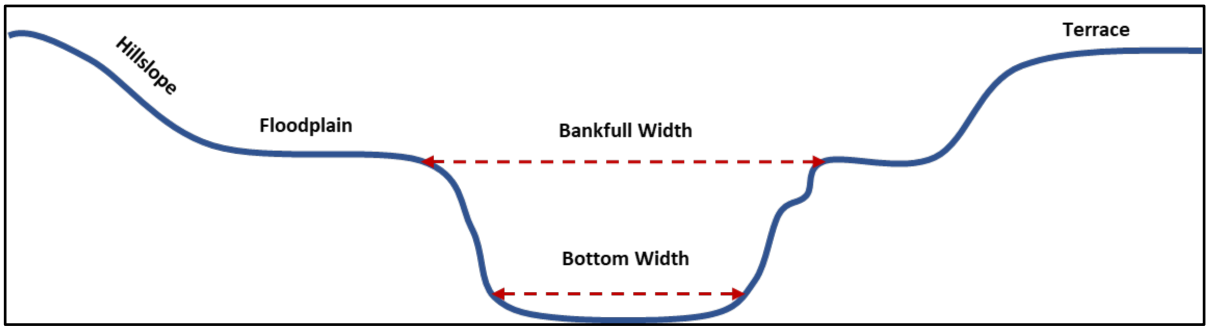
The area UoM also includes a measure of the channel and the valley. Channel area is the product of channel length and width (Figure 7), while valley area is the product of valley length times width or measured as a polygon. The measures of length and width used for these calculations can vary as described below.

Figure 7. Channel and Valley Measurements Used in Area Calculation. In this diagram, channel length is measured along the centerline and channel width is bankfull. Valley width is measured to the adjacent toe of the hillslope.



For channel area, a measure of channel length (e.g., centerline) is multiplied by some measure of channel width, which can vary. Examples of channel width include bankfull and channel bottom width, shown in Figure 8.

Figure 8. Two Examples of Channel Width



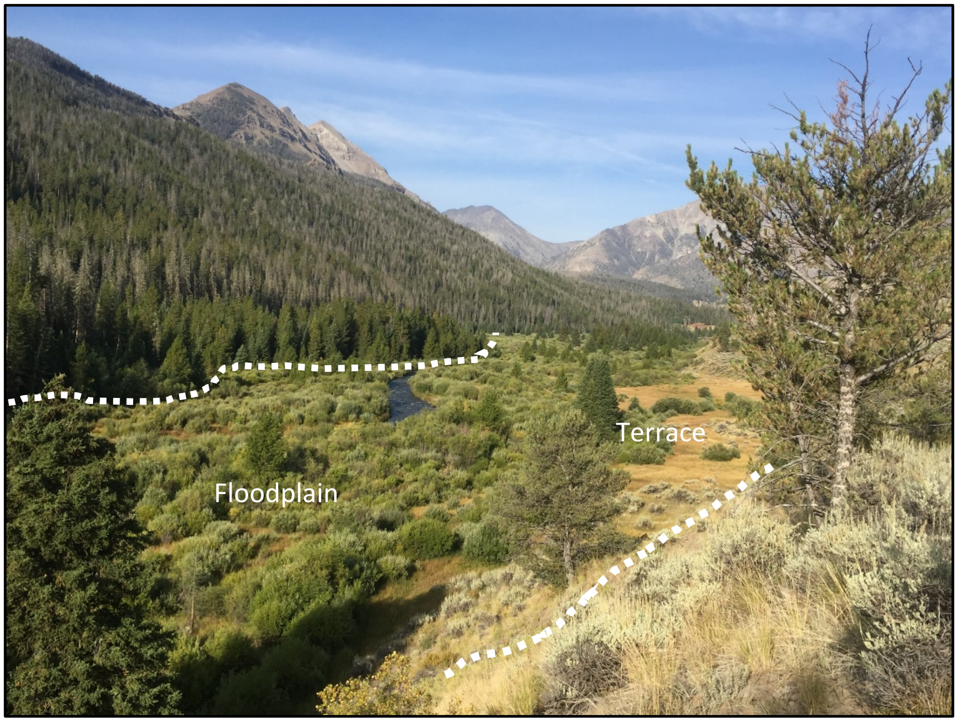
The UoM variations for channel area are shown in equation form below. The equations apply to both single and multi-thread channels. In multi-thread channels, each channel is measured as described and the channel area is then summed across all channels.

(1) Centerline length X Bankfull width
(2) Centerline length X Channel bottom width

For valley area, valley length is multiplied by some form of width. The valley length measurement is described in Section 3.2.1. The valley width measurement can be more difficult to define than stream or valley length due to heterogeneity in valley topography. In mountain regions, the valley width is easy to identify; the valley ends where the hillslope begins. However, in regions where valleys are flat and very wide it can be difficult or even impossible to identify the valley width. In some cases, watershed divides are undefinable and even change based on land use management, e.g., drainage ditches.

Generally, valley width is a measure of the floodplain, low terrace (former floodplain), stream corridor, or riparian width. Measures of valley width can include or exclude the channel(s) (Figure 7). Figure 9 shows a stream channel and the adjacent valley bottom with the valley width marked with a white line. While the valley morphology is obvious in this case and can be seen by a change in elevation from the valley bottom to the hillslope, choosing a width to inform an area calculation is not always obvious. In addition, Figure 9 also shows that widths along the valley length are not consistent and would typically require multiple measurements, introducing more sources of variation. Valley width can also be calculated as a fixed buffer width (Wenger, 1999), the expected riparian extent width (Polvi et al., 2011), an active valley bottom width (O'Brien et al., 2019), a floodprone area width (Rosgen, 1994), or a meander belt width (Rosgen, 2014). These examples of measures of valley width are discussed below.

Figure 9. Valley Bottom Width Measurement Example. The white dashed line represents the edge of the valley bottom; here, the low terrace is included in the valley bottom width.



<u>Fixed Buffer Width</u>

Valley length multiplied by a fixed buffer width is a simple option for computing a valley-related area. It is commonly used in stream mitigation and restoration programs in the eastern United States (ELI, 2016) for determining riparian width but is not generally used as a UoM. The fixed buffer width generally ignores valley morphology and may only capture a small portion of the overall valley bottom. In other cases, it may extend past the valley width boundary and include a portion of the hillslope, e.g., small headwater streams. Wenger (1999) provides three options for calculating buffer width based on a literature review of 140 articles and books dealing with riparian buffer width, extent, and vegetation. Wenger (1999) states that buffer width is applied in the eastern United States in conjunction with reducing sedimentation and nutrient loading (nitrogen and phosphorus). Since nitrogen is more mobile in water than phosphorus, establishing buffer widths is largely aimed at reducing nitrogen concentrations. However, Wenger (1999) acknowledges that reducing nitrogen concentrations is dependent on local hydrology, soil properties, slope, and other factors. With these factors in mind, Wenger (1999) provided the following three options for determining a fixed buffer width and argued that all three were defensible based on the scientific literature. The options are provided in a hierarchical order with option one providing the greatest level of function and option three the least. A list of the options is provided below along with the criteria used to make the fixed buffer width measurement.

Option 1 (Greatest Level of Function)

- Base width of 100 feet plus 2 feet per 1% slope increase (measured perpendicular to the channel).
- Extend to edge of floodplain.
- Include adjacent wetlands.
- Existing impervious surfaces in the riparian zone do not count toward buffer width.
- Slopes greater than 25% do not count toward the width.
- Buffer applies to perennial, intermittent, and ephemeral streams.

Option 2 (Same as Option 1, except)

- Base width is 50 feet plus 2 feet per 1% slope increase (measured perpendicular to the channel).
- Entire floodplain is not necessarily included.
- Ephemeral streams are not included.

Option 3

- Fixed buffer width of 100 feet.
- Applies to all streams on US Geological Survey 1:24,000 quadrangle.

Area Based on Riparian Community and Geomorphology

The challenge with a fixed buffer width, as noted above, is that it ignores the valley morphology. Using a fixed buffer width approach may be practical in very wide valleys but is often problematic in narrower valleys where geomorphic features such as terraces and hillslopes are identifiable. With a fixed buffer width approach, these features may be included in the width even though geomorphically they are not part of the valley.

Another method of measuring width includes the composition of the riparian vegetation and observations about valley morphology. The riparian width or area (if measured as a polygon) is an estimate of the natural or historic extent of the riparian area and floodplain. Riparian width and area are influenced by reach-scale channel and valley characteristics (Polvi et al., 2011) and is delineated using hydrologic, biotic, and geomorphic indicators on the landscape. Merritt et al. (2017) provide three criteria to delineate the edge, and therefore the width, of the riparian zone. These criteria include:

1) Substrate attributes—the portion of the valley bottom influenced by fluvial processes under the current climatic regime,
2) Biotic attributes—riparian vegetation characteristic of the region and plants known to be adapted to shallow water tables and fluvial disturbance, and

3) Hydrologic attributes—the area of the valley bottom flooded at the stage of the 100-year recurrence interval flow (Ries et al., 2004).

In summary, the riparian area using geomorphic criteria has an advantage over a fixed buffer width in valleys with identifiable geomorphic features such as terraces and hillslopes. These features can be used to identify an expected riparian area. The downside of this approach is that it is not applicable in wide, flat valleys where geomorphic features (terraces or hillslopes) cannot be identified.

Active Valley Bottom Width

Active valley bottom width is similar to the riparian width coupled with geomorphology method described above. First, active valley bottom width relies on a determination of what is considered the "active" channel and or floodplain. Active floodplains are generally those that are accessed "regularly" by flood flows. In some applications, this may be those floodplains that flood multiple times per year up to a max of between a five- and a ten-year return interval. Secondly, "active" is often associated with the ability to support riparian and/or wetland vegetation, based on adequate access to higher water availability. By contrast, the entire valley bottom is that part of the stream archetype that could plausibly flood in the natural flow regime (Fausch et al., 2002; O'Brien et al., 2019). It may include the channel, floodplain, fan, and now inactive floodplain. Figure 10 shows an example of the active valley bottom width compared to the total valley bottom width. In this example, the stream has incised due to past land management activities, and the active valley bottom has reduced to a width/area that is much less than the overall valley bottom. Therefore, active valley bottom is not always the same as valley bottom, especially in disturbed landscapes.

Figure 10. Example of Active Valley Bottom Width Compared to Valley Bottom Width.

Floodprone Area Width

The floodprone area (FPA) width is defined as the width associated with flood flows that reach an elevation that is twice the bankfull maximum depth. The measurement is made at a riffle cross-section perpendicular to the fall-line of the valley (Rosgen, 2014). The twice bankfull depth value is based in part on an assessment of dimensionless rating curves that plot mean depth divided by bankfull depth against the corresponding discharge ratio (Dunne and Leopold, 1978) and modeling (Rosgen, 1996). This modeling showed that the ratio of the 50-year flow depth divided by a bankfull depth ranged from 1.3 to 2.7 across the different Rosgen (1994) stream types. The average was 2.0, which was selected to represent the floodprone width elevation. The floodprone width is divided by the bankfull width to calculate the entrenchment ratio (ER). This dimensionless entrenchment ratio is used as a factor in determining stream type in the Rosgen (1994) stream classification method and to assess floodplain connectivity (Harman et al., 2012).

An estimate of the FPA can be computed by multiplying the valley length by the average FPA width. This estimate includes the width of the channel. A method to calculate the FPA width of a floodplain without including the channel width would be to simply subtract the channel width from the FPA width (FPA width minus channel width). Measure of FPA width can be taken at every riffle in valleys with undulating widths (e.g., valley convergence and divergence) or a smaller sample for valleys with a uniform width. These widths can then be averaged before multiplying by valley length.

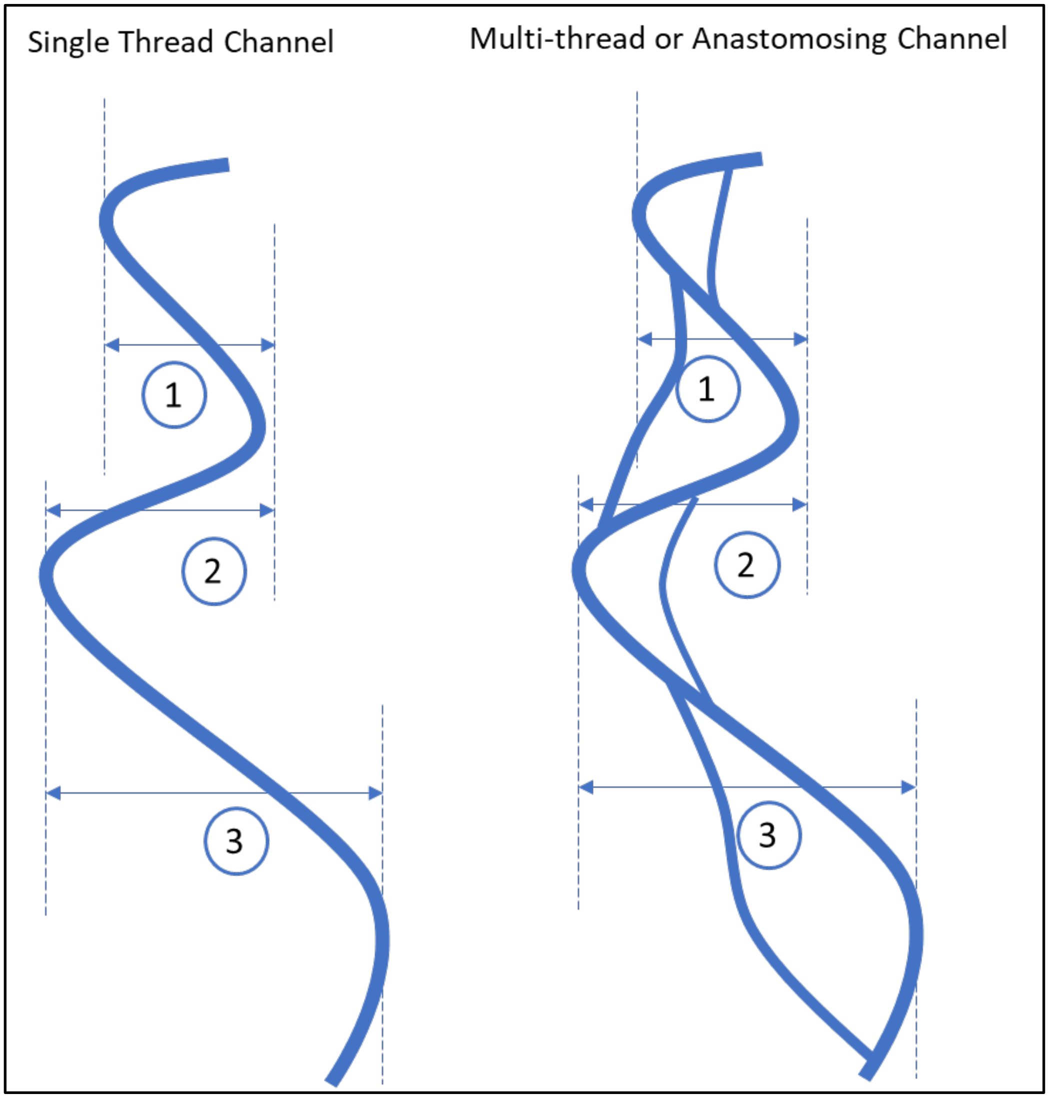
FPA width is similar to the expected riparian area width with geomorphology and the active valley bottom width in that they are based on valley geomorphology. Unlike the riparian width, it does not account for riparian vegetation as an indicator. It is more quantitative, and perhaps more repeatable, than active valley bottom measurements since it uses a consistent elevation (two times the bankfull depth) to determine the FPA width. The disadvantage is that it can be difficult or impossible to measure in wide, flat valleys.

Meander Belt Width

The final example of a valley width measure is the meander belt width, which is defined as the lateral distance (perpendicular to the fall-line of the valley) between the outside edge of two meanders that occupy opposite sides of the valley (Rosgen, 2014). Belt width is used as an index of lateral containment or confinement of a stream when compared to the width of the channel (bankfull width). Meander belt width is measured for single- and multi- thread channels. This method is sometimes used as an alternative to the floodprone area width in unconfined alluvial valleys with very wide floodplains, where there are minimal to no topographic features or where other tributaries are found in the same valley (USACE, 2020). Figure 11 provides an illustration of how the meander belt width ratio can be applied in single-thread and multi-thread channels.

For streams that have been straightened, belt widths may not be evident. In this case, a meander width ratio may be used to establish the belt width that should occur for a given stream and valley type. The meander width ratio is the belt width divided by the bankfull width. Generally, as this ratio increases sinuosity also increases. A meander width ratio between 3.0 and 3.5 is needed to create a sinuosity of 1.2, which is a break between streams classified as meandering versus straight (Rosgen, 1996). To establish a belt along a straight stream using a meander width ratio of 3.5, the bankfull width of the study reach would be multiplied by 3.5 (or other ratio as determined by reference streams in the area). Note, that using the belt width approach only includes the lateral limits of the channel and does not include the remainder of the valley width or riparian vegetated corridor. An additional width may be added to ensure that riparian vegetation is provided to the outside of meander bends, e.g., total width equals the belt width plus additional riparian vegetation width.

Figure 11. Example Belt Widths (Identified Numerically) for Single-Thread and Multi-thread Channels.



In summary, the equation form for calculating valley area is:

(3) Valley length X Valley width

However, valley area can also be calculated using geographic information systems with aerial photographs, digital elevation models, and more. In this case a polygon is delineated, and the area is calculated. In either case, determining the width (or lateral extent) of the valley is required. One of the example methods listed above (fixed width, width using riparian and/or geomorphic indicators, the floodprone area width, or a meander width ratio) or another method will be needed to make the calculation.

3.2.3 Volume

Volume, to the best of our knowledge, has not been used as a UoM within existing compensatory mitigation accounting protocols. Conceptually, channel volume could be measured by multiplying the cross-sectional area of the channel (width times mean depth) by channel length (e.g., centerline; Figure 12). Calculating valley volume would require some form of depth measurement, for example depth from the ground surface to the water table (Figure 13). Example equations include:

(4) Channel length X Channel cross sectional area
(5) Valley length X Valley width X Subsurface depth

Figure 12. Channel Volume Example.

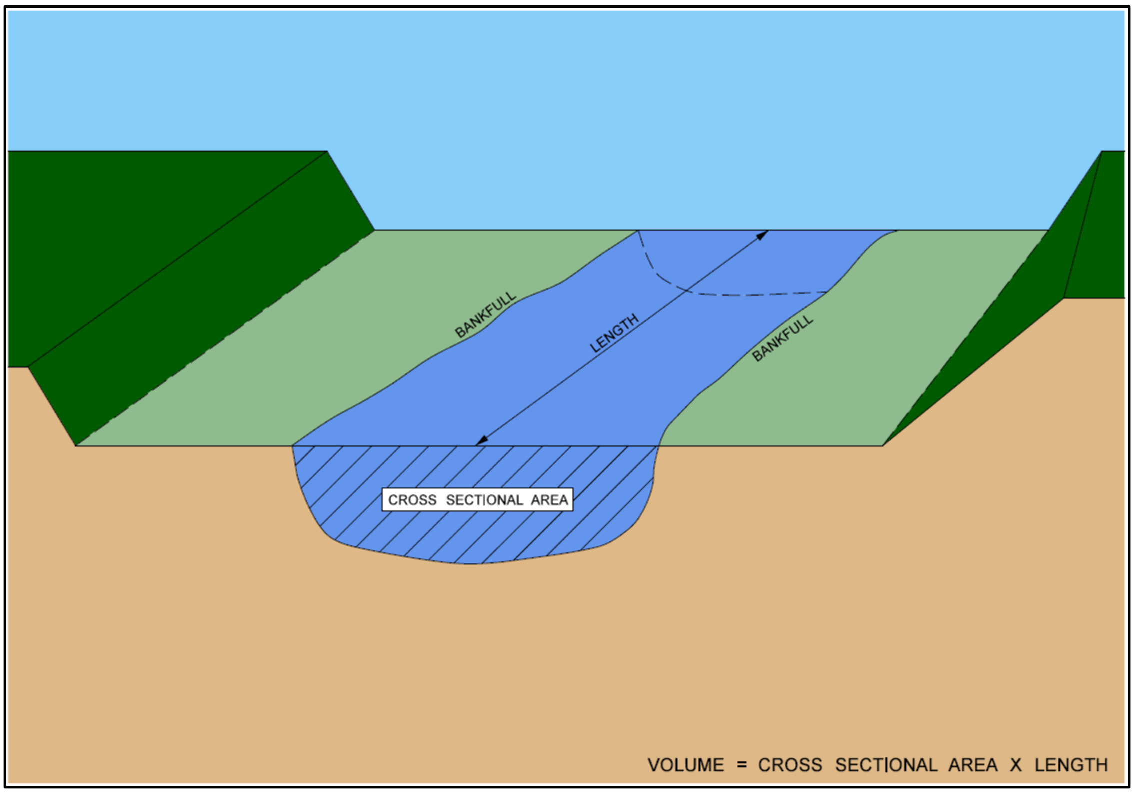
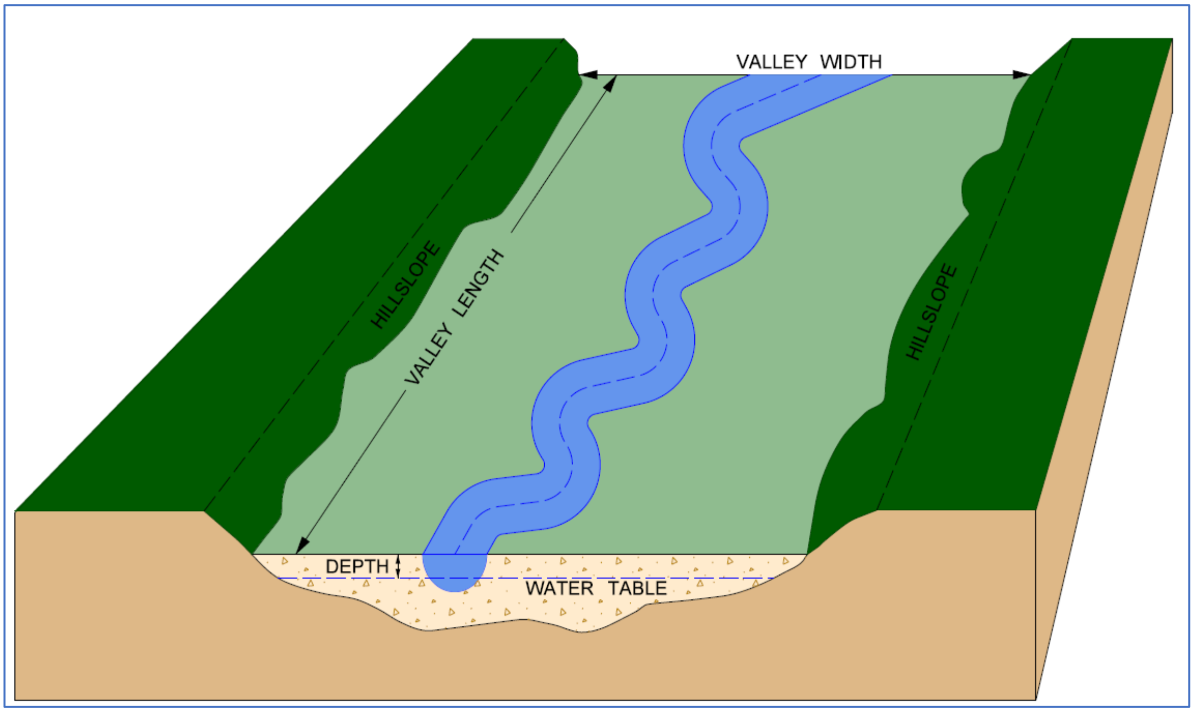


Figure 13. Valley Volume Example.



Of the described measurements, valley depth is the only one that has not been used to inform a compensatory stream mitigation UoM; while uncommon, channel width and depth (cross sectional area) has been used before. The use of valley depth as part of a UoM is intriguing because it captures the subsurface region, including the hyporheic zone and unsaturated zone. No other UoM captures this region. Since a UoM alone does not reflect function or condition, assessment methods that include the subsurface region would be needed to compliment such a UoM. Piezometers, tracers, and seepage meters are common assessment devices used to measure water movement in the hyporheic and unsaturated zone (Environment Agency, 2008; Rivett et al., 2008; Harman et al., 2012).

In application, this approach could potentially show the function or condition change associated with projects that change the depth to the water table. Projects that increase the depth to the water table also disconnect the stream from the floodplain, which causes impairment to aquatic functions (Schoof, 1980; Kroes and Hupp, 2010). Floodplain connection reduces the depth to the water table, which drives many geomorphic and ecological functions (Wohl, 2004; Shields et al., 2010). The challenge with using volume, and more specifically the depth to the water table, as a UoM is that changes in the depth to the water affect ecological function; a protocol that chooses to use this UoM would need to consider how such functional changes are assessed and credibly reflected by the application of the UoM.

3.3 Evaluating Units of Measure

Section 3.2 described different UoM's, how they can be measured, and provided some sample calculations. This section describes the process used to evaluate the UoMs. The process began with a workshop including the SC and TT. The primary focus was to develop a suite of criteria that could be used to evaluate UoM's across a national range of stream archetypes commonly affected by permitting or mitigation activities. Using input from the SC, the TT established the stream archetypes (Section 3.3.1) and finalized the criteria (Section 3.3.2) used to evaluate the UoMs across each of the stream archetypes. The criteria are applied to various UoM and stream assessment scenarios in Section 4.

3.3.1 Stream Archetypes and Flow Regime Included in Evaluation of UoMs

This report uses the term stream archetype to represent fluvial systems that commonly require compensatory mitigation offsets in different landscape settings nationwide. For this report stream archetype does not represent any specific stream classification or approach for contextualizing a stream. The reason for this is to focus on the elements that are commonly impacted and offset by stream compensatory mitigation projects. To consider the suite of stream types resulting from existing stream classification systems would create more scenarios than can be evaluated within this project.

> Stream archetypes as used in this report are based on elements of fluvial systems that are commonly impacted or offset by stream compensatory mitigation projects. They are not based on any specific system of classifying streams.

The stream archetypes used in the evaluation of units of measure (see Table 3) include single-thread, multi-thread, wadeable, non-wadeable, and differing valley morphologies (i.e., v-shaped, colluvial, and alluvial). Single-thread channels versus multi-thread channels are included recognizing that multi-thread channels can be braided or anastomosed. While these two stream archetypes function differently, those differences would be considered in the assessment approach rather than the UoM. Stream-wetland complexes, not included in the evaluated stream archetypes, can be multi-thread or single-thread.

In addition to stream archetypes, flow regime is also used in the evaluation of units of measure. For this purpose, flow regime is characterized as perennial, intermittent, and ephemeral.

3.3.2 Criteria Used to Evaluate Units of Measure

The suite of criteria established to evaluate the applicability of described UoM's to different stream archetypes are worded as questions, such that a "yes" response denotes a strength and a "no" denotes a weakness. The criteria are listed below, along with a rationale for their inclusion and how they might be applied when evaluating a UoM.

Criterion 1. Does the UoM apply equally on the debit (impact) and credit (offset) side of the mitigation accounting ledger?

- = +

Rationale: The Mitigation Rule requires that compensation offset loss from unavoidable impacts. The UoM is a key component of mitigation accounting protocols and therefore influences parity between the two sides of the mitigation accounting ledger.

Application:
Strength – Applies equally on the debit and credit side of the mitigation accounting ledger, e.g., linear feet calculated the same way at both the impact and offset site.
Weakness – Cannot easily be applied equally to both debit and credit sides of the mitigation accounting ledger, perhaps due to changes in stream archetype.

Criterion 2. Does the UoM incentivize debit and credit determination that supports ecological benefits?

Rationale: The Mitigation Rule stipulates that compensation should provide ecological benefits to the surrounding watershed. Given this requirement, it is important to evaluate the ability of a UoM to reflect the ecological functions lost or gained when applied to a project, while recognizing that the UoM is not an assessment of stream function or condition. The UoM should credibly complement the assessment approach to incentivize ecological benefits.

Application:
Strength – The UoM can credibly be used with the assessment approach to reflect the ecological functions associated with a given stream archetype.
Weakness – The UoM cannot be credibly used with the assessment approach to adequately reflect the ecological functions associated with a given stream archetype.

Criterion 3. Does the UoM support in-kind mitigation?

Rationale: Per the Mitigation Rule, in-kind mitigation is preferred to out-of-kind mitigation to offset functional losses in a stream system. Therefore, it is important to evaluate whether a UoM supports in-kind mitigation.

Application:
Strength – Supports and incentivizes in-kind mitigation.
Weakness – Intentionally or unintentionally leads to out-of-kind mitigation, such that compensation can be more easily provided in a different stream archetype than impacted, thereby reducing the likelihood of offsetting impacted functions.

Criterion 4. Does the UoM incentivize restoration that is appropriate for the landscape?

Rationale: The watershed approach as set forth in the Mitigation Rule requires that landscape position and the sustainability of landscape level aquatic functions be considered when developing compensatory mitigation projects. Therefore, an evaluation of a UoM should include an assessment of whether it can adequately reflect watershed context and promotes restoration outcomes that are appropriate and sustainable given the surrounding landscape.

Application:
Strength – The UoM can credibly be used with the assessment approach to incentivize restoration siting and design that is appropriate for a given stream archetype and landscape setting and supports sustainable mitigation projects.
Weakness – The UoM cannot credibly be used with the assessment approach to incentivize restoration siting and design that is appropriate for the landscape and watershed context and may lead to unsustainable mitigation projects. For example, the UoM combined with the assessment approach incentivizes the design of a single-thread transport channel in an unconfined alluvial valley with low stream power and strong vegetated response, where an anastomosed channel would likely be the most appropriate and sustainable choice given the landscape context.

Criterion 5. Can the UoM be repeatably measured?

Rationale: For consistency and defensibility, it is important that different practitioners can measure a UoM and produce a similar result.

Application:
Strength – Different practitioners produce similar results.
Weakness – Different practitioners produce different results.

Criterion 6. Is the UoM straightforward to measure?

Rationale: For consistency, efficiency, and defensibility, it is important that a UoM can be easily measured by a range of practitioners across a variety of stream systems in a reasonable amount of time.

Application:
Strength – Straightforward to measure by a range of practitioners in a reasonable amount of time in a variety of stream systems.
Weakness – Most practitioners would be challenged to measure the UoM in a reasonable amount of time in a variety of stream systems.

4.0 APPLYING UNITS OF MEASURE TO STREAM ARCHETYPES

4.1 Introduction

This section applies the evaluation criteria described in Section 3.3.2 to UoM scenarios. The scenarios include each stream archetype and reflect varying assumptions of assessment approach. The TT evaluated each scenario independently and then met to reach consensus on the evaluation ratings. The SC reviewed and commented on evaluation ratings before they were finalized. The objective was to highlight the strengths and weaknesses of each UoM in the described scenarios. Each criterion was worded as a question, such that a “yes” response denoted a strength and a “no” denoted a weakness. Additionally, “it depends” was used if a strength or weakness was dependent on some other factor, and a rationale of the dependent factors provided.

Only length and area categories of UoM (Figure 6) were evaluated. Channel and valley volume were not evaluated because they are not commonly used or considered as UoMs in stream mitigation accounting protocols (see Section 4.6).

Included stream archetypes are described in detail in Section 4.2. Section 4.3 describes the assessment assumptions. Twelve evaluation scenarios combining various UoMs, stream archetypes and assessment approaches are described in Section 4.4, a summary of evaluation scenario results is provided in Section 4.5 with detailed evaluation matrices available in Appendix A. Finally, Section 4.6 briefly addresses stream archetypes not included in the evaluation and provides general ideas about how these archetypes could be addressed. This information could be helpful for areas having these stream archetypes.

4.2 Application of Evaluation Criteria to Stream Archetypes

The applicability and effectiveness of four different UoMs (channel length, channel area, valley length, and valley area) were evaluated across the stream archetypes. The stream archetypes are provided in table format below (Table 3).

As discussed in Section 3.3.1, these stream archetypes were selected because of their relevance and prominence in stream compensatory mitigation protocols. The descriptions reflect a combination of wadeability, flow duration, and channel form. The stream archetypes do not follow a particular stream classification system. Each stream archetype has an identification number (ID) that is used throughout the evaluation process. These descriptions were used to facilitate UoM evaluation; the use of broader stream archetypes would introduce multiple variables and unnecessary complexity to the evaluation.

Table 3. Stream archetype identification number, description, and rationale for selection.

Stream archetype ID	Stream archetype description	Rationale for selection
1 	Wadeable, single-thread, perennial stream located in an alluvial valley.	This is a common restoration and impact stream archetype in the eastern United States. This stream archetype is naturally a single-thread channel that would exhibit meandering processes.
2 	Wadeable, multi-thread (anastomosed), perennial stream in an alluvial valley with low stream power.	This stream archetype is multi-thread rather than single-thread. This is a common restoration approach in rural regions of the West.
3 	Non-wadeable, single-thread stream in an alluvial valley.	This stream archetype represents a river, as opposed to a wadeable stream.
4 	Perennial or intermittent braided, multi-thread channel.	Represents a stream in a semi-arid to arid region. Sediment supply exceeds sediment transport capacity.
5 	Single-thread, ephemeral channel in a confined alluvial valley.	Represents an ephemeral channel but does not distinguish size. This could be a small headwater ephemeral channel in the East or a mid-size channel in the West.
6 	Wadeable, perennial, colluvial valley (step-pool) system.	Headwater mountain stream. This could represent any mountain system.

4.3 Assessment Assumptions for Inclusion in Scenarios

The third component used to develop the scenarios is the assessment assumptions. The three assumptions used to evaluate the UoM across the different stream archetypes are:

- No assessment method applied,
- Stream assessment only, and
- Stream and floodplain assessment.

The “no assessment method” assumption means that a function or condition assessment method has not been applied at the impact (debit) or offset (credit) site; only the UoM is used to calculate debits and credits (see Section 3.1.1). The “stream assessment only” assumption means that a condition or function-based assessment method has been applied; however, the assessment area is limited to the stream channel and does not include the adjacent riparian area or floodplain.

The “stream and floodplain assessment” assumes that some form of condition or functional assessment was applied to both the stream channel and the adjacent riparian area/floodplain. When an assessment method is assumed, the elements listed in Section 2.1 are used to further define the assumptions. These elements include stratification, scaling, representativeness, regression to the known, and the roll-up approach. These same assumptions are applied to the “stream assessment only” and the “stream and floodplain assessment” such that the only difference between the two is the area assessed: stream channel only or stream channel and the adjacent floodplain.

The assumptions for the stream channel only and stream and the adjacent floodplain assessments include the following:

- Stratification – Differences in ecoregion, hydrologic landscape, stream size, etc., are reflected in standard performance/reference indices, such that method outputs account for such differences.
- Scaling – The reach length of the area assessed is determined by multiplying the bankfull width by 20. Scaling for all metrics and methods is appropriate for the project reach and will support a representative assessment output for the project area.
- Representativeness – The stream only assessment method captures the entire length of the project channel, and primarily focuses on measures of natural channel stability (aggradation, degradation, and lateral migration). Riparian vegetation is assessed but only for the purpose of bank stability. The stream and floodplain assessment includes the same channel measures but also includes measures of floodplain connection and extent of riparian vegetation.
- Regression to the Known – The stream type is appropriate for the valley type.
- Roll-Up Approach – An overall score is provided for the reach that represents an overall function or condition score.

Specific assessment methods used to inform stream compensatory mitigation accounting were not used in the scenarios. Our purpose was not to evaluate assessment methods, but rather, to show how a UoM can be influenced by a formal assessment of stream, or stream and adjacent floodplain, function or condition.

4.4 Evaluation Scenarios (Combining Stream Archetype, UoM, and Assessment Assumptions)

The UoMs (Section 3.1), stream archetypes (Section 4.2), and the assessment assumptions (Section 4.3) were combined to create twelve evaluation scenarios (Table 4).

Table 4. Tweleve Evaluation Scenarios.

Scenario	Unit of Measure	Assessment Assumption	Applied to all Stream Archetypes
A	Channel Length	No assessment	
B		Stream only	
C		Stream and floodplain	
D	Valley Length	No assessment	
E		Stream only	
F		Stream and floodplain	
G	Channel Area	No assessment	
H		Stream only	
I		Stream and floodplain	
J	Valley Area	No assessment	
K		Stream only	
L		Stream and floodplain	

Each scenario was evaluated against the criteria described in Section 3.3.2. A summary of the results is provided in the next section, with the complete evaluation matrices available in Appendix A. Photographic examples of the included stream archetypes are provided in Appendix B.

4.5 Summary of Evaluation Scenario Results

Table 5 provides an abbreviated version of the evaluation criteria and Table 6 summarizes the results of each evaluation scenario. Refer to Table 3 for stream archetype descriptions and Section 3.3.2 for a more detailed description of the evaluation criteria.

Table 5. Scenario Evaluation Criteria.

Criterion ID	Evaluation Criterion
C-1 - = +	Does it apply equally on debit and credit side?
C-2	Does it incentivize debit and credit determination that supports ecological benefits?
C-3	Does it support in-kind mitigation?
C-4	Does it incentivize restoration that is appropriate for the landscape?
C-5	Is it repeatable?
C-6	Is it straightforward to measure?

Table 6. Evaluation Scenario Summary Results. The UoM scenarios are applied to all stream archetypes. The stream archetypes are provided in Table 3. Complete evaluation matrices are provided in Appendix A.

UoM Scenario	Strengths	Weaknesses	Additional Comments
[A] **Channel Length** with no assessment method	• Applies equally on debit and credit side for single thread channels. • Repeatable and straightforward to measure in single-thread channels.	• Does not incentivize landscape appropriate restoration or debit/credit determination that supports ecological benefits. • Generally, does not support in-kind mitigation, with caveats. • Does not work well with multi-thread channels.	• Consistent evaluation responses. • For small channels, economics will likely result in in-kind mitigation. • Could apply in limited settings; for example, where floodplain function is already high and where all impacts/ mitigation are in-stream and the activities are directly related to each other. Another example is that a screening decision is made at another level of the generic stream mitigation process (e.g., site selection), to support in-kind mitigation. • Problematic in stream archetypes 1 and 3 due to differences in stream size.
[B] **Channel Length** with stream assessment only	• Best applied when impacts and restoration are limited to channel (particularly stream archetype 3). • Repeatable and straightforward to measure in single-thread channels.	• Does not consider floodplain condition and function. • Does not work well with multi-thread channels unless there is an identifiable primary channel.	• Generally, “yes” responses included qualifiers to emphasize the need for application of a formal assessment method. • More consistent scoring for stream archetypes 5 and 6, where floodplain functions are naturally limited. • Problematic in stream archetypes 1 and 3 due to differences in stream size.

UoM Scenario	Strengths	Weaknesses	Additional Comments
[C] **Channel Length** with stream and floodplain assessment	• Applies equally on debit and credit side for single thread channels. • Generally, incentivizes landscape appropriate restoration and debit and credit determination that supports ecological benefits, with caveats. • Repeatable and straightforward to measure in single-thread channels.	• Does not work well with multi-thread channels unless there is an identifiable primary channel and a definable floodplain.	• Responses largely consistent, but many strengths dependent on quality of assessment method, including metric stratification and how floodplain elements are weighted by length. • More consistent scoring for stream archetypes 5 and 6, where floodplain assessment may not be needed. • Problematic in stream archetypes 1 and 3 due to differences in stream size.
[D] **Valley Length** with no assessment method	• Applies equally on debit and credit side for single and multi-thread channels, though may be problematic in larger channels. • Repeatable and straightforward to measure in single- and multi-thread channels.	• Generally, does not incentivize landscape appropriate restoration. • Does not incentivize debit/credit determination that supports ecological benefits. • Does not support in-kind mitigation.	• Generally consistent responses. • Ability to provide landscape appropriate restoration may be dependent on using an assessment method. • Problematic in stream archetypes 1 and 3 due to differences in stream size.
[E] **Valley Length** with stream assessment only	• Applies equally on debit and credit side for single and multi-thread channels, though may be problematic in larger channels (stream archetype 3). • Can support in-kind mitigation for stream archetypes 3, 5, and 6, with caveats. • Incentivizes landscape appropriate restoration in stream archetypes 5 and 6. • Repeatable and straightforward to measure in single- and multi-thread channels.	• Does not consider floodplain condition and function. • Incentivizes mitigation activities on shortest channel in single and multi-thread streams. • Incentivizes in-channel benefits only in streams where floodplain functions are naturally limited (stream archetypes 5 and 6).	• Responses variable for ecological benefits and in-kind mitigation, but mostly consistent elsewhere. • In-kind mitigation is supported for stream archetypes 5 and 6 if watershed context is taken into account and for stream archetype 3 if impacts/mitigation are limited to the channel and channel lengths do not change. • Problematic in stream archetypes 1 and 3 due to differences in stream size.

UoM Scenario	Strengths	Weaknesses	Additional Comments
[F] **Valley Length** with stream and floodplain assessment	• Applies equally on debit and credit side for single and multi-thread channels. • Generally, supports in-kind mitigation for multi-thread channels and those with naturally limited floodplains, with caveats. • Incentivizes landscape appropriate restoration at floodplain level. • Repeatable and straightforward to measure in single and multi-thread channels.	• May incentivize straight channels or out-of-channel functions to exclusion of in-channel functions for stream archetypes 1 and 3. • May incentivize mitigation activities on shortest channel in multi-thread systems, or no in-channel mitigation activities. • May not support in-kind mitigation for stream archetypes 1 and 3.	• Responses consistent for stream archetypes 5 and 6 and largely consistent for multi-thread systems (stream archetypes 2 and 4). • Problematic in stream archetypes 1 and 3 due to differences in stream size.
[G] **Channel Area** with no assessment method	• Applies equally on debit and credit side for single-thread channels. however, for multi-thread systems it depends on whether there is a consistent, primary channel.	• Does not incentivize landscape appropriate restoration or debit/credit determination that supports ecological benefits. • Does not support in-kind mitigation. • May not be repeatable or straightforward to measure.	• Responses consistent for ecological benefits, in-kind, and landscape appropriate criteria, less so for others. • May be more straightforward to measure for stream archetypes 1, 3, and 6. • May incentivize overly large channels as mitigation.
[H] **Channel Area** with stream assessment only	• Applies equally on debit and credit side for stream archetypes 5 and 6. • May have more strengths in other areas if impacts and restoration are confined to the channel.	• Ignores floodplain function / condition, which affects ecological benefits and in-kind mitigation criteria for most stream archetypes. • Does not incentivize landscape appropriate restoration for most stream archetypes. • Not repeatable or straightforward to measure for most stream archetypes.	• Responses highly variable for stream archetypes 1-4. • Less problematic with stream archetypes 5 and 6. • May incentivize overly large channels as mitigation.

UoM Scenario	Strengths	Weaknesses	Additional Comments
[I] **Channel Area** with stream and floodplain assessment	• No criterion/stream archetype combination had definitive "yes" responses.	• Does not support in-kind mitigation. • Does not incentivize landscape appropriate restoration. • May not be repeatable or straightforward to measure.	• Responses highly variable for all stream archetypes. • May support ecological benefits criterion if floodplain assessment results can be effectively area-weighted (all stream archetypes). • May incentivize overly large channels as mitigation.
[J] **Valley Area** with no assessment method	• No criterion/stream archetype combination had definitive "yes" responses.	• Does not incentivize landscape appropriate restoration or debit/credit determination that supports ecological benefits. • Does not support in-kind mitigation. • May not be repeatable or straightforward to measure.	• Responses consistent for ecological benefits, in-kind and landscape appropriate mitigation criteria, less so for others.
[K] **Valley Area** with stream assessment only	• "Yes" responses for applies equally on debit and credit side, ecological benefits, and in-kind criteria, but only for stream archetypes 5 and 6. • Repeatable to measure for stream archetypes 1, 2, and 3, though may depend on valley type.	• Does not consider floodplain, especially problematic with multi-thread channels. • Generally, not well-rated for stream archetypes 1 and 3.	• Responses variable, especially for repeatability and straightforward to measure criteria. • Rated most highly for stream archetypes 5 and 6, with caveat that may incentivize mitigation activities in the floodplain rather than in-channel.
[L] **Valley Area** with stream and floodplain assessment	• Applies equally on debit and credit side for single and multi-thread channels. • Incentivizes debit and credit determination that supports ecological benefits and landscape appropriate restoration. • Supports in-kind mitigation.	• May not be repeatable or straightforward to measure, though it may depend on valley type.	• Responses largely consistent, though dependent factors were identified. • Some strengths may not apply where projects focus on valleys that have minimal fluvial engagement. • May incentivize mitigation activities in the floodplain rather than in-channel.

The following are summary observations regarding the evaluation results presented in Appendix A and summarized in Table 6.

General Observations

- In the absence of a scientifically informed assessment of function or condition, none of the UoMs evaluated for either length or area rated strongly for most of the evaluation criteria. Even if they could be easily and repeatably measured and provide mathematical parity on the debit and credit sides of the ledger, application of a UoM alone were not rated strongly for incentivizing ecological benefits, in-kind mitigation, or landscape appropriate restoration (this affects the offset of impacted functions and services).
- UoMs that were applied to the outputs of an assessment method including both the stream channel and associated floodplain had more strengths than weaknesses, especially channel and valley length UoMs, and to a lesser extent, valley area. However, even in scenarios reflecting an assessment of both the stream and floodplain, channel area did not rate highly as a UoM (see further discussion below).
- The strength of a particular unit of measure in meeting the evaluative criteria varies with stream type.

Stream Archetypes

- Stream archetypes 5 and 6 (ephemeral and step-pool, respectively) consistently yielded "yes" responses (strengths) across many UoMs and were rarely qualified by "it depends." A variety of UoMs seem to credibly apply to these stream archetypes.
- Ratings for archetypes 2 and 4 (anastomosed and braided, respectively) and archetypes 5 and 6 tend to be more consistent throughout all scenarios, likely since they share traits that are treated similarly by the evaluation criteria (e.g., more than one channel or a narrow valley).

Units of Measure

- Neither length nor area UoMs inherently account for channel size of the subject stream, unless channel size is considered in advance (e.g., stratification of assessment measures based on channel size).
- A channel area UoM may account for channel size, but several issues were raised with the ease and repeatability of measurement; for instance, channel area may vary depending on stage/discharge and as it evolves.
- Channel area UoMs may also vary depending on what width is measured. For example, top of bank or bankfull width may naturally vary over time, and channel bottom width may vary depending on which features are included and how "bottom" is defined.
- As with channel area, valley area UoMs vary depending on which width is measure. Identifying valley width may be challenging, particularly in wide valleys lacking low topographic relief.

4.6 Stream Archetypes and UoMs Not Evaluated

As previously discussed in Sections 2 and 3, the evaluation scenarios considered are not inclusive of all possible stream archetypes or UoMs (the omission of volume was discussed in section 3.2.3). There are many other stream archetypes that occur nationwide, for instance, tidally influenced streams. While many stream types were not evaluated for the purposes of this report, the described evaluation approach provides an analytical process to guide the evaluation and selection of an appropriate and credible unit of measure for use in stream mitigation accounting protocols which could be used by the agencies and Interagency Review Teams.

5.0 CONSIDERATIONS FOR SELECTING AN APPROPRIATE UNIT OF MEASURE

These considerations are organized by:

1. Stream archetype considerations.
2. Aligning the UoM with the assessment method.
3. Specific considerations about selecting a UoM.
4. Considerations for addressing different UoM's within a mitigation protocol.
5. Revisiting the three overarching project questions.

5.1 Stream Archetype Considerations

Section 3.3.1 defines stream archetypes as fluvial systems that are commonly impacted and used to provide stream compensatory mitigation. Six stream archetypes were identified (Refer to Table 3; see callout box) for this project.

If the stream archetypes identified here are not representative of a region of interest, relevant archetypes could be developed to evaluate applicability of a UoM using the described analytical process.

Stream Archetypes:

1) Wadeable, single-thread, perennial stream, alluvial valley.
2) Wadeable, multi-thread (anastomosed), perennial stream, alluvial valley with low stream power.
3) Non-wadeable, single-thread, perennial stream, alluvial valley.
4) Perennial or intermittent, braided, multi-thread channel.
5) Single-thread, ephemeral channel, confined alluvial valley.
6) Wadeable, perennial, colluvial valley (step-pool) system.

5.2 Aligning the Unit of Measure with the Assessment Approach

As described in Section 4, the stream assessment approach taken, including how function or condition are assessed, affects the scientific credibility of a selected UoM, as the UoM is generally applied as a multiplier. Scenarios in which no assessment of stream function or condition was reflected in the application of a UoM received the lowest ratings against the described evaluative criteria. Conversely, scenarios in which an assessment of both the stream channel and adjacent floodplain/valley bottom were assessed generally received the highest ratings.

Strengths and weaknesses of a UoM often relate to the stream assessment approach used.

Stream assessment approaches currently in use vary widely across several variables (ELI, 2016; David et al., 2021; see Section 2). Table 7 describes key elements of stream assessment methods or approaches that affect the scientific and mathematical credibility of a selected UoM. These elements include stratification, scaling, representativeness, regression to the known, and the approach to “rolling-up” assessment method outputs. A robust, scientifically credible approach to assessing the function/condition of a stream channel and its adjacent riparian area/floodplain may overcome some of the shortcomings identified in the described evaluation when a UoM alone is used to calculate debits and credits in a stream mitigation accounting protocol.

Table 7. Elements of stream assessment methods/approaches that affect the credibility of assessment outputs and inform selection of an appropriate unit of measure for use in a mitigation accounting protocol.

Assessment Approach Element	Assessment Elements Informing Selection of a UoM
Stratification	Are different standard performance or reference condition indices applied to account for different stream settings (ecoregion/hydrologic landscape/stream size, etc.) which reflect differing functional expectations?
Scaling	How does the assessment approach account for the size of the project area or subject stream? Are the scale(s) applied for individual metrics and/or the assessment method standardized to a common dimensionless index scale to generate meaningful outputs that can be compared across projects?
Representativeness	Does the assessment approach capture and reflect total stream function/condition within the assessment area, or is it preferential to only specific attributes, features, or habitat types? Does it include an assessment of the stream and associated floodplain or valley bottom width?
Regression to Known	Do assessment method outputs only incentivize restoration (mitigation) activities that replicate known/well-studied stream types?
Roll-up Approach	How are the different metric outputs combined(rolled-up) into grouped outputs or into an overall output using a particular assessment method/approach? Does the roll-up approach include metric weighting, and if so, how is this done? Are all assessed metrics treated equally regardless of how scaling, stratification, representativeness, and “regression to the known” are considered?

Stratification

Stratification is a process to account for differences in expected metric performance across a range of landscape settings within a region. For instance, stratification at a metric level can account for differences in stream archetypes, ecoregion, size, watershed position, etc. The resulting assessment outputs inform selection of an appropriate UoM to quantify assessed stream function/condition.

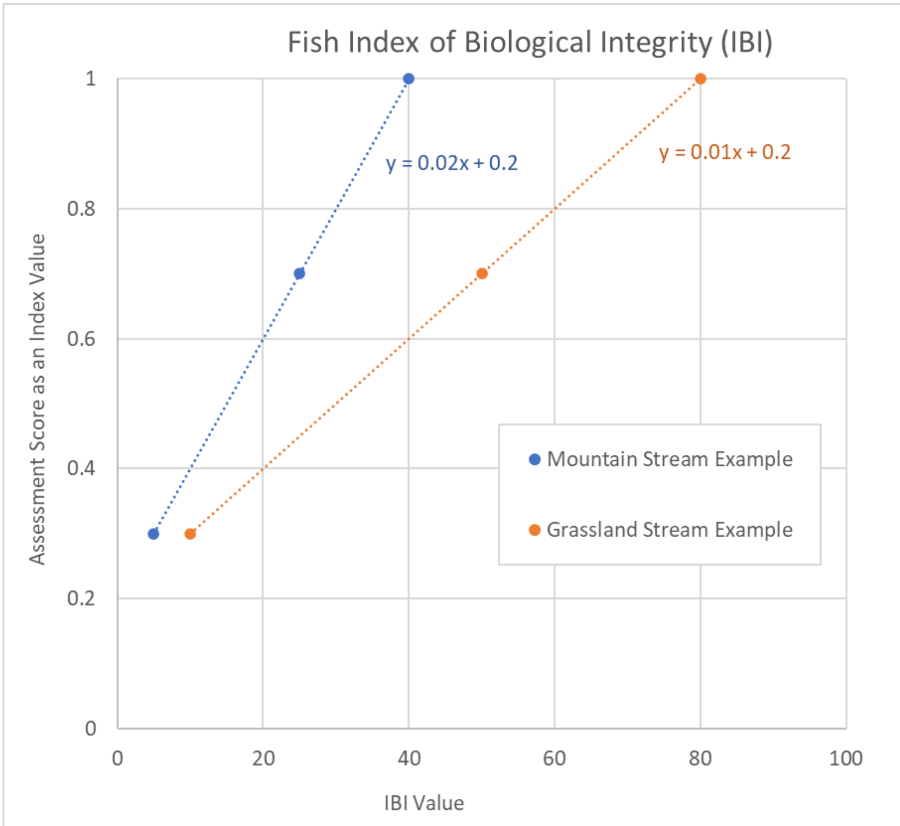
Stratification matches a reference or standard performance index based on different landscape settings or ecoregions to a given metric. Stream assessment methods that include stratification result in more scientifically credible outputs. The easiest way to describe stratification is with an example. Consider the metric of native fish communities measured as an index of biological integrity (IBI) using a stream assessment method that is applied to an entire state. For this example, assume a state with diverse physiographic and ecological regions, like cold, humid mountains and warm, semi-arid grasslands. Fish communities are expected to differ in these two landscape settings.

Stratification allows for function or condition performance indices that account for these differences, allowing the assessment method to apply equally well in the two or more landscape settings in which expected performance of the metric differs. For instance, the fish community IBI example could be stratified by mountain and grassland ecoregions. Alternatively, the index stratification could be based on additional variables such as temperature regime (e.g., cold water and warm water), drainage area, elevation, or stream order. One way to develop stratified indices is to consult a team of experts who are knowledgeable about the region, the metric of interest, and the range of stream conditions that will affect the metric scoring as reflected in the index. Other approaches include using an abundance of raw data and basing stratification on data distribution and known reference site data or using relevant studies and associated data from the scientific literature which link the metric to ecological functioning and basing stratification on trends and thresholds expressed in research results (Harman and Jones, 2017; Nadeau et al., 2018).

> Stratification allows for function or condition performance indices that account for differences in expected performance based on landscape settings and other variables (e.g., stream size).

Below is a sample stratified index using the fish IBI example from above.
Figure 14 shows a hypothetical reference or performance index-based stratification on measured differences in mountain and grassland ecoregions. There can be more than one variable used to stratify a metric, for instance, cold water streams (temperature) with drainage areas less than five square miles (size of drainage area).
Figure 14 shows different index curves for the two stratifications. In applying an assessment method reflecting these stratifications, the user would select the appropriate stratification option, mountain or grassland, to determine the index value (y-axis) of the measured IBI score (x-axis). In this example, a higher index value represents a better condition.

Figure 14. An Example of How Stratification Can Be Used to Develop a Reference or Performance Index



Additional examples of stratification for metrics that are included in stream assessment methods currently in use are provided below (Table 8: Harman et al., 2012; ELI, 2016; Nadeau et al., 2018). A brief description of each metric is provided along with approaches used to measure the metric. The third column provides variables that have been used to develop stratified indices of the metric.

Table 8. Example Stratification Variables for Metrics Used in Stream Assessment Methods.

Metric	Description	Stratification Variables
Floodplain Connectivity	Measures how well the stream is connected to the adjacent floodplain. Example approaches for measuring include flow frequency of overbank events, ratio of the bank depth to the bankfull depth, and floodprone width.	Stream Archetype. Accounts for streams with floodplains (1-4) and streams without floodplains (5-6). Can also account for streams that have been disconnected from floodplains.

Metric	Description	Stratification Variables
Bedform Diversity	A measure of in-stream habitat condition. Common approaches to measuring include pool spacing, width and depth variability, and percent length of bed feature, e.g., riffle and/or pool.	Stream type or valley type. Accounts for differences in bedform diversity resulting from valley slope and valley width. For example, step-pool streams in colluvial valleys versus meandering streams in alluvial valleys. Bed material. Accounts for differences in bedforms associated with variances in bed material sizes. For example, sand versus gravel or cobble.
Riparian Vegetation	A measure of the composition, structure, and condition of the riparian vegetation. Common ways to measure include riparian width, composition, stem density, basal area, percent native vegetation, and more.	Ecoregion is one of the most common ways to stratify. Other examples include reference vegetation type, e.g., herbaceous and forest, and vegetation strata (e.g., canopy, shrub, herbaceous).
Lateral Migration	A measure of bank erosion or bank retreat. Common ways to measure include assessments of bank erosion potential, empirical measurements of bank movement, hydraulic stress against the bank, and length of erosion.	Landscape setting. Accounts for the natural rate of erosion. Some arid streams naturally have high rates of lateral migration. Streams in humid regions have more riparian vegetation and lower rates of migration.
Large Wood	A measure of surface water storage, biodiversity maintenance, and the creation and maintenance of habitat. Common ways to measure include the frequency of large wood in the bankfull channel per feet (100 m) of stream.	Ecoregion. Accounts for density of riparian vegetation and wood recruitment rates in wetter versus drier climates. Stream width. Accounts for larger streams having a smaller quantity of wood because wood is less stable and more easily transported downstream.

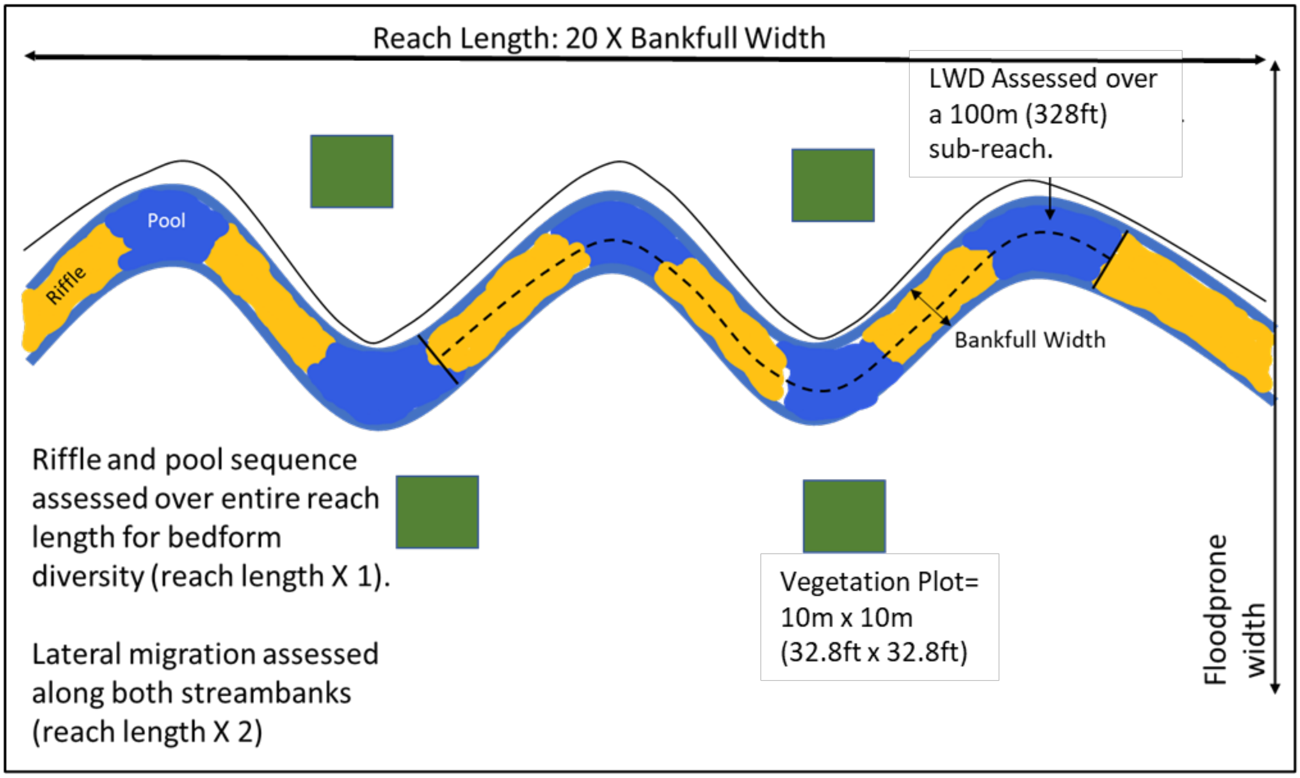
Another approach is to stratify the measurement of a metric based on the stream type being assessed. For example, bedform diversity as a metric is relevant to both wadeable and non-wadeable streams; however, it may be measured differently in wadeable versus non-wadable streams given the logistics of assessing the metric (e.g., wading versus using a boat). Different measurement approaches to the same metric would, in turn, require that performance or reference indices for that metric likewise differ between those stream types.

Finally, stratification has been used to apply metrics and/or parameters only in specific stream archetypes. An example of metric inclusion (or exclusion) by stream archetype is to stratify the application of assessment metrics between perennial and ephemeral flow regimes. This type of stratification process would apply one suite of assessment metrics to an ephemeral stream and a different suite of metrics to a perennial stream. When metrics are stratified in this way, it is important to communicate exactly what the stream assessment output score represents as it may not be directly comparable to stream types that were assessed using a different suite of metrics.

Scaling

The term scaling is sometimes applied to the UoM because the UoM provides units (or a common physical dimension) to the assessment output scores. In this report, however, the term scaling is used within the context of the assessment method or individual metrics. Scaling can refer to the length or area within which an individual metric is assessed (metric scaling). For example, large woody debris (LWD) assessed along a 100-meter stream length or riparian vegetation surveys in 10X10 meter plots. Scaling also occurs in the site selection and reach selection tasks (refer to the generic stream mitigation process flow chart in Figure 3) to determine the physical dimensions of the assessment area to which a stream assessment method is applied. For example, a common stream assessment reach length is twenty times the bankfull or channel width (Harrelson et al., 1994). Figure 15 illustrates these two types of scaling. In this example, the assessment reach length is 20 times the bankfull width, the assessment width is the floodprone width, which is also part of the floodplain connectivity assessment. Vegetation is assessed in 10X10 meter plots. Riffle and pool bedforms are assessed for the entire stream length and lateral migration is assessed along the length of both banks (left and right). In other words, two times the assessment reach length. Finally, large woody debris is assessed along a 100-meter sub-reach (Davis et al., 2001). The purpose of this illustration is to show that scale varies by the metric and the assessment area (length and width). These variations should be considered to inform selecting a UoM that can be credibly applied to the assessment outputs.

Figure 15. Example of Scaling.



Considerations of how scaling as defined affects application of a UoM:

- Awareness of where and how scaling is occurring in the assessment approach is important.
- Figure 15 illustrates different metrics being assessed at different scales (e.g., full stream length, 100 meters (328 feet) within the full stream length, floodplain width, plots, etc.).
- Once there is an awareness of how scaling is occurring for individual metrics, these issues should be addressed within the assessment scoring, for instance through indexing of metric outputs to the same dimensionless scale, such that the outputs are scientifically and mathematically credible.
- Additionally, how the assessment area of a particular assessment method is scaled (method scaling) may affect the mathematical and scientific suitability of a given unit of measure to account for assessed changes in function or condition.

<u>Representativeness</u>

Representativeness refers to the scope of the assessment of function or condition; are all stream functions of the subject reach being assessed, or just a subset of functions? It also refers to spatial representation of the assessed metrics. For example, are both in-stream and out-of-stream metrics that contribute to stream function/condition included? In the example shown in

Figure 15, included metrics measure both in-stream and floodplain attributes that influence stream function or condition. An example of an in-stream metric is bedform diversity and an example of a floodplain metric is vegetated riparian corridor width. Floodplain connectivity is a metric that assesses aspects of the channel and the floodplain. These assessment metrics, and thus the outputs they are used to generate, represent function/condition of the entire reach. As shown in Section 4, the UoM evaluation ratings against the described criteria were higher when both the stream and the floodplain were included in the assessment area, even while the ratings differ across the UoMs considered.

Regression to the Known

"Regression to the known" is a term used in this report to refer to how assessment outputs, and credit or debit calculations reflecting those outputs, may influence the design approach for a stream restoration or mitigation project to offset predicated impacts. Do the assessed functions/conditions include consideration of the larger watershed context, or do they only consider a well-studied or an idealized stream type? For instance, if a stream assessment approach considers a single-thread perennial stream archetype as the ideal against which metrics are scored, other stream archetypes that may be in good condition or high functioning may not score as well; additionally, assessment outputs may incentivize a single-thread channel restoration design even if the landscape setting suggests that a different stream archetype might be ecologically more appropriate or provide greater functions.

For instance, there is an increasing body of research showing that streams in unconfined alluvial valleys often had portions that were multi-threaded seasonal or perennial wetlands, rather than single-thread streams, before European settlement (Castro and Thorne, 2019; Cluer and Thorne, 2013; Merritt et al., 2011; Nanson and Croke, 1991). Anecdotally, it seems restoration practitioners are responding to this research in a few ways. Some practitioners are designing and constructing anastomosed systems rather than single-thread channels. Others design and construct single-thread channels with the understanding that they may evolve into anastomosed systems over time. From the mitigation accounting perspective, if proposed compensatory mitigation for impacts to a single-thread channel is an anastomosed system (multi-thread), then the mitigation accounting protocol, including the UoM, would need to accommodate this change in stream archetype.

Rolling-up Assessment Output Scores

A common approach to generate output scores from a stream assessment method is to first convert measured or observed metric values (which may have a variety of units) to a dimensionless index value having ecological meaning. The index values are then used to calculate assessment output scores for the functions/conditions assessed. The approach to calculating function/condition output scores varies among assessment methods; some combine metric scores, some include weighting of measured metrics, which may or may not reflect statistical analysis of field data, etc. Function/condition output scores may be generated for individual functions (e.g., create and maintain habitat; chemical regulation), and output scores may be further "rolled up" to broader categories (e.g., biological functions), and/or into an overall reach score of function/condition. Importantly, to maintain the greatest scientific validity, stratification should occur as close as possible to the measured value. Each output level (metric, category, and overall/output score) is briefly described below.

Metric-Level Roll Up Scoring

Using the example from Figure 15 above, the riparian vegetation metric was assessed using 10m X 10m plots. Riparian vegetation condition can be quantified using one or more measurements, including stem density (stems per acre), herbaceous cover (percent cover), percent cover of native trees, and so on. These measurements, which represent the entire assessment area, result in outputs that are converted into dimensionless index scores (using a standard performance index or curve which describes the range of expected performance based on available data, reference sites, or current scientific understanding). The next step is to combine the index scores of individual measurements in some way (may or may not include weighting processes) to create a combined index score for the overall riparian vegetation metric. Typically, an index scale is between 0 and 1, where 0 represents no function or condition and 1 represents the highest function or condition. An example of this process is shown in Table 9 for a theoretical riparian vegetation metric. A UoM could be applied to the rolled-up metric score, if desired.

Table 9. Individual Measurements Informing a Riparian Vegetation Metric Are Converted into Dimensionless Index Scores and Then Rolled Up to a Metric Score.

Measurement in Units	Measurement as a Dimensionless Index Value	Metric Score
Stem density in stems/acre	0 to 1.0	Index values for each measure are combined to create a Riparian Vegetation metric score between 0 and 1.0
Herbaceous cover as a percent	0 to 1.0	
Tree cover as a percent	0 to 1.0	
Riparian width in feet	0 to 1.0	

It is important to note that each time measurement scores are rolled up, any choices made about the relative weight (equal or unequal) of individual measurements will be reflected in the rolled-up score.

Category Level Roll Up Scoring

Metric scores may be combined in various ways to create a category-level score. These categories represent a broader level of stream condition or function (e.g., hydrology, geomorphology, water quality, biology). Output scores of condition or function may be provided for each category; a UoM could then be applied at the category level, if desired.

Overall Reach Level Roll Up Scoring
Some stream assessment methods or mitigation accounting protocols may further roll scores up into an overall score representing the condition or function of the assessed stream reach. While providing a single output, this score is also the farthest removed from the data collected for individual metrics and reflects decisions made at each roll-up level (such as weighting, where stratification is applied, etc.), possibly resulting in a loss of information and the sensitivity to detect change. Assessment output scores provided at each level may provide the greatest flexibility in using the results of an assessment method to inform mitigation accounting and decisions made at other steps in the compensatory mitigation process.

5.3 Considerations for Selecting a Unit of Measure

The purpose of Section 5.2 was to illustrate how the approach to stream assessment may address some challenges associated with developing a stream mitigation accounting protocol that is scientifically defensible and mathematically credible. Some challenges may also be addressed by using adjustment factors in the accounting protocol or using eligibility criteria and other requirements at various steps of the generic stream mitigation process (e.g., site selection; see Figure 3 and
Table 2). The UoM simply provides a common unit for debits and credits such that they can be compared with other projects that were assessed in the same way.

Some overarching considerations on how the approach to stream assessment and steps in the generic stream mitigation process may be used to address relevant issues are provided below, as are considerations when selecting specific UoMs.

<u>Overarching considerations when selecting a UoM for use in a stream mitigation accounting protocol</u>

The following considerations were developed based on results from the evaluation scenarios (Appendix A). Refer to Table 6 for evaluation ratings under different stream assessment assumptions.

- An assessment method that includes stream and floodplain metrics improves parity between the debit and credit sides of the ledger.
- A UoM applied without an accompanying assessment ranks poorly against the evaluative criteria; this may be somewhat alleviated for small in channel impacts and corresponding mitigation that occurs in the same stream archetype.

- Creating parity between the debit and credit side of the accounting ledger relies on other factors in the stream mitigation accounting protocol besides the UoM:
    - Using an assessment method, especially one that includes stratification and an assessment of the stream channel and associated floodplain.
    - Matching stream archetypes at the site selection step in the mitigation process.
- Adjustments can be used to address factors that have not already been addressed through the stream assessment approach or other steps in the stream mitigation process. However, their effect should be considered in light of the three main questions of the project (scientifically supported, apply to different stream archetypes, and apply equally on credit/debit side).

Once these overarching considerations are addressed, then the following UoM specific considerations can be addressed. Specific UoMs include channel length, valley length, channel area, and valley area.

<u>Considerations for Selecting Channel Length</u>

- Using channel length as a UoM is straightforward and repeatable in single-thread channels but is more challenging in multi-thread channels because choice of channel to assess in a multi-thread channel system affects outcomes.
- The channel length UoM easily applies to stream archetypes 1, 3, 5, and 6. These are all single-thread channels. They vary in size, flow regime, and landscape setting. However, these differences can be handled with the assessment method.
- Care is needed in the assessment method to ensure that overly sinuous channels are not incentivized.

<u>Considerations for Selecting Valley Length</u>

- The valley length UoM is straightforward and repeatable to measure in both single- and multi-thread channels. This UoM had more strengths than other UoM’s for working in both single- and multi-thread channels.
- Care is needed in the assessment method to ensure that the UoM does not incentivize straight channels in landscapes that support meandering channels.
- Care is needed in the assessment method to ensure that incentives are not created to only work in the floodplain and not the channel for mitigation projects. The TT noted that past mitigation efforts that have focused only on floodplain work have resulted in mostly tree planting without consideration of floodplain connection and in-stream habitat.

Considerations for Selecting Channel Area

- Channel area is not easy or repeatable to measure. The dimension can change over time and with the selection of the channel width and stage to create unintended incentives, e.g., a large or overwide channel.
- There are several things to consider if choosing channel area, including how to consistently measure it and how the assessment approach might incentivize or prevent restoration design inappropriate for the landscape.
- This UoM may be suited for use as an adjustment factor in approved out-of-kind mitigation (e.g., based on a watershed approach), such as between a small perennial stream (stream archetype 1) and a larger perennial stream (stream archetype 3).

Considerations for Selecting Valley Area

- The valley area UoM applies equally well to single-thread and multi-thread channels.
- It supports ecological benefits that are appropriate for many landscape settings.
- Care must be taken in the assessment method to ensure that incentives are not created to only perform mitigation activities in the floodplain at the expense of avoiding needed in-channel and floodplain connection improvements.
- Valley area is not straightforward and easy to measure, especially in wide valleys that lack discernable features like terraces or hillslopes. Determining the valley width component can be challenging, although there are several ways to make the width measurements. This can make repeatability of the area challenging. Refer to section 3.2 for a review of these measurements.
- Valley area as a UoM could also create disparity issues between the credit and debit sides of the mitigation accounting ledger. For example, if a reach of stream is impacted that is 1000 feet long and the valley is 50 feet wide (50,000 ft^2) is a restoration of a stream channel in a valley that is 500 feet long but 100 feet wide (also 50,000 ft^2) applying debits and credits equally?
- It may not be as easily applied in stream archetype 6, headwater mountain streams that naturally do not have floodplains.

5.4 Considerations for Translating Between Different Units of Measure

Translating between different UoMs should be approached carefully because it has the potential to introduce unintended consequences; however, this situation might occur when a different UoM is applied on the debit and credit sides of a stream mitigation accounting ledger. When translating between different UoMs for specific projects the following considerations are offered:

- Consider the first two (of three) main questions guiding this report when developing an approach to translate between the UoMs. These questions are:

  - Is the use of a given UoM scientifically supported for calculating impacts (debits) and compensation (credits) to achieve compensatory mitigation program goals?
  - Does the given UoM reasonably apply to the different stream archetypes and landscapes in your region?
- Review Figure 3, and
- Table 2 showing the generic stream mitigation process. Are there steps other than the UoM that can be used to address the translation in a credible way? One possible approach, using the questions above as a guide, is to develop an adjustment factor to create an equivalency between the units that is scientifically and mathematically defensible.

An assessment method robust enough to apply equally well to the different stream archetypes across a region supports the use of a single UoM. Another approach could be applying different UoMs based on stream archetype; this might raise concerns of translation and parity that might be addressed at other steps in the mitigation process or in the mitigation accounting protocol, for instance through adjustment factors.

5.5 Need for Additional Research

Over the course of this project, the TT and SC identified related topics and data needs that could benefit from further research. These include:

- ***Assessment Methods for Multi-thread Channels.*** Anastomosed and braided streams were listed as stream archetypes. There is increasing interest throughout the country in converting single-thread channels into multi-thread channels using the anastomosed stream archetype. However, stream assessments have historically focused on single-thread perennial stream archetypes. Therefore, new assessment methods for multi-thread, anastomosed systems are needed. Braided streams function differently than anastomosed streams and are more prevalent in arid and glacial regions than humid regions. These multi-thread systems would also benefit from additional research and development of stream assessment methods.
- ***Assessment Methods for Other Stream Archetypes.*** Several stream archetypes, such as stream-wetland complexes and tidally influenced systems are underrepresented in existing stream assessment methods, and assessment methods specific to these systems are needed.
- ***Incorporating Floodplain Function into Assessment Methods.*** Floodplains are an essential component of stream function for many stream archetypes. Incorporating floodplain function more broadly into stream assessments approaches would reflect that importance.

- ***Improvement of Monitoring Metrics***. As the generic stream mitigation process shows, monitoring is required with stream mitigation projects, and sometimes large impact projects, to show that performance standards are being achieved. Stream mitigation protocols would benefit from more research and guidance on how to design and implement monitoring programs that quantify the function/condition improvements that result from stream mitigation activities.
- ***Volume as a Unit of Measure***. Channel and valley volume were listed as possible UoMs in Section 3. Theoretical examples were provided since there were no known applications of volume as a UoM in compensatory stream mitigation projects. Research would be needed to determine how a volume UoM should best be measured, along with examples of unintended consequences. For example, would a volume UoM incentivize incised channels if the depth to water table was used? Would this create a larger volume and therefore a larger UoM result and credit?

5.6 Credibility, Applicability, and Parity Re-visited

In Section 1, we provided three questions which were used to guide the project. These questions are re-visited in this final section based on insights gleaned through the evaluation process.

<u>Credibility</u>*: Is the use of a given UoM scientifically supported for calculating impacts (debits) and compensation (credits) to achieve compensatory mitigation program goals?*

Our findings showed that the ability of a UoM to be scientifically supported for calculating debits and credits was largely dependent on the other supporting elements of the generic stream mitigation process. When evaluating the scenarios in Appendix A, a common response to a particular criterion was, "It depends on the quality of the assessment method." The assessment method, more so than the UoM, plays a larger part in scientifically supporting the calculation debits and credits. Assessment methods that include the stream channel and its associated floodplain, and assessment methods that include stratification procedures led to more strengths ("yes" responses) than those that did not. However, the scenario modeling did show that some UoMs are more easily applied and more repeatable than others.

Channel length, when coupled with a channel and floodplain assessment approach, ranked high for single-thread channel archetypes but not multi-thread channel archetypes. On the other hand, valley length emerged as a UoM with the most strengths and fewest weaknesses under the assumptions included with the scenarios. Like channel length, it is straightforward, repeatable, and easy to measure; however, unlike channel length, it can be applied to both single and multi- thread channels, which makes it more scientifically defensible in those situations. As with all the scenarios, the most strengths were recognized when valley length as a UoM was included with an assessment method that included the channel and floodplain. The most weaknesses were recorded when valley length was applied without any form of assessment.

Results for channel area were the most variable among the evaluations, in part because the evaluators envisioned its measurement in different ways. It was noted repeatedly that the measure was not straightforward or necessarily repeatable. Channel dimensions change spatially and over time. For example, effective restoration may include reducing a stream's cross-sectional area (converting a high width/depth ratio stream to a low width/depth ratio stream) thereby reducing the channel width and overall channel area (length times width). These actions commonly improve functions like floodplain connectivity and thermal regulation (reducing solar inputs and improving summer return flows from the saturated floodplain). Therefore, reducing channel area over time can be a positive change. However, using channel area (length times width) as a UoM would potentially be negative in this scenario because the UoM quantity, if used as the credit, would decrease as the restoration matures. In other words, channel area as a UoM could incentivize the design and construction of overly large channels with low velocities that create higher cross-sectional areas and limited ecological uplift.

Results for valley area were similar to channel area, though somewhat less variable among the evaluations and with slightly more strengths, especially with a channel and floodplain assessment. One area of concern is that this approach, with its greater focus on the overall valley, could emphasize floodplain restoration over in- channel restoration, and may not be as appropriate for systems with naturally less fluvial interaction between the floodplain and channel.

<u>Applicability:</u> ***Does the given UoM reasonably apply to different stream archetypes and landscapes nationwide?***

The scenario evaluation results showed that valley length applied equally well to all stream archetypes used in this project. When valley length was combined with a stream and floodplain assessment method, it received the most favorable results.

Valley area also applied to all stream archetypes; however, there were challenges noted in how valley width was measured. The difficulty in measuring valley width was noted as being more challenging in landscapes with low gradient, wide alluvial valleys, like those in the Midwest, Great Plains, and Eastern U.S. Many of these valleys do not have obvious transitions between the valley bottom and a hillslope. Conversely, identifying valley bottoms in the mountain west was noted as being simple where the transition between the valley bottom and adjacent hillslope is obvious.

Channel length can be effectively applied to single-thread channel archetypes, but not as well to multi-thread channels unless there is an obvious main thread. Even then, it was noted as being difficult to repeatedly measure in multi-thread channels. Some of the issues with channel length can be overcome with the assessment method. If the assessment method includes the channel and floodplain, and stratification, the channel length may be suitable UoM.

Channel area could apply to all stream archetypes; however, there were several challenges identified with the measurement method, notably repeatability and unintended incentives. These are noted under the credibility question above.

Single-thread ephemeral streams in confined alluvial valleys (stream archetype 5) and wadeable, perennial step-pool streams in colluvial valleys (stream archetype 6) were the most amenable to various UoMs and assessment assumptions. In other words, they rated “yes” responses (denotes a strength) across most scenarios. These systems are dominated by channel functions more so than floodplain functions, thus the more robust assessment approach (i.e., including adjacent floodplain area) did not result in substantially higher ratings. It was noted that area as a UoM could still be challenging for these stream archetypes if the active valley width is difficult to define.

<u>Parity:</u> Does the given UoM apply equally to the impact (debit) and compensation (credit) sides of a debit/credit ledger?

This question is the first criterion used to evaluate the different scenarios. Results showed that channel length applied equally to the debit and credit side when both were single-thread channels. However, in the absence of an assessment method, channel length generally did not rate well for supporting in-kind mitigation. As noted above, the exception is a small in-stream impact that is compensated with a small in-stream improvement in the same stream archetype. The strongest parity between the debit and credit side was when channel length was applied to all stream archetypes with a stream and floodplain assessment. However, even then, it did not rate well when applied to multi-thread channels.

Valley length was found to apply equally to both sides of the ledger in single- and multi-thread channels. Like channel length, its ability to support parity between the debit and credit is dependent on the assessment method. Parity is most likely achieved when the assessment includes the stream and floodplain, among other things such as stratification.

Results for channel area found that it applied equally to both sides in single-thread channels but was more problematic in multi-thread channels. Like the others, parity was improved with an assessment method that included the stream and floodplain. However, if impacts and mitigation activities are contained within the channel, these limitations are less significant.

Valley area was found to equally apply to the debit and credit side of the ledger for all stream archetypes, including single- and multi-thread channels. And like the others, when a stream and floodplain assessment is included, there is parity between the debit and credit side. If no assessment is included, or the assessment is limited to the channel, parity is less certain.

5.7 Concluding Statement

Application of a UoM is an important component of a compensatory stream mitigation accounting protocol, as it provides common units for calculating debits and credits. However, this project has shown that applying a UoM alone, in the absence of an assessment of stream function or condition, may lack the scientific rigor and defensibility needed to assure offsets (credits) functionally replace permitted impacts (debits), per the 2008 Mitigation Rule. To be mathematically credible, application of a UoM to outputs from a stream assessment method should consider several factors, such as the actual area assessed by the method as reflected in the outputs and the appropriate level (e.g., metric, function, category, overall) at which to apply any adjustment factors. A robust assessment approach that considers stream channel and floodplain elements affecting stream function supplies the strongest scientific foundation for calculating debits and credits, and the selection of any unit of measure should be informed by careful consideration of the stream archetypes of the applicable region and the approach or method(s) used to assess stream function or condition.

6.0 REFERENCES

Bureau of Land Management. 2017. AIM National Aquatic Monitoring Framework: Field Protocol for Wadeable Lotic Systems. Technical Reference 1735-2. U.S. Department of the Interior, Bureau of Land Management, National Operations Center, Denver, CO.

Castro, J.M., and C.R. Thorne. 2019. The stream evolution triangle: Integrating geology, hydrology, and biology. River Research and Applications 35(4): 315-326.

Cluer, B., and C. Thorne. 2013. A Stream Evolution Model Integrating Habitat and Ecosystem Benefits. River Research and Applications 30(2): 135-154.

David, G.C.L., D.E. Somerville, J.M. McCarthy, S.D. MacNeil, F. Fitzpatrick, R. Evans and D. Wilson. 2021. Technical guide for the development evaluation, and modification of stream assessment methodologies. ERDC Special Report, SR-19980. U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory, Hanover, NH. 97 pp.

Davis, J.C., G.W. Minshall, C.T. Robinson, and P. Landres. 2001. Monitoring Wilderness Stream Ecosystems. General Technical Report RMRS-GTR-70. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden, UT. 137 pp.

Dunne, T., and L.B. Leopold. 1978. Water in Environmental Planning. W.H. Freeman and Co., San Francisco, CA. 818 pp.

Environment Agency. 2008. The Hyporheic Handbook: A handbook on the groundwater–surface water interface and hyporheic zone for environment managers. Science Report: SC050070. Environment Agency, Bristol, UK. 264 pp. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/291621/scho1009brdx-e-e.pdf, accessed 30 August 2021

Environmental Law Institute (ELI), Stream Mechanics, The Nature Conservancy. 2016. Stream mitigation: Science, policy, and practice. 137 pp. https://www.eli.org/sites/default/files/eli-pubs/stream-mitigation-science-policy-and-practice-final-report.pdf

Fausch, K.D., C.E. Torgersen, C.V. Baxter, and H.W. Li. 2002. Landscapes to riverscapes: bridging the gap between research and conservation of stream fishes. Bioscience 52: 483–498.

Guilfoyle, M.P., R.A. Fischer. 2006. Guidelines for Establishing Monitoring Programs to Assess the Success of Riparian Restoration Efforts in Arid and Semi-Arid Landscapes. U.S. Army Engineer Research and Development Center, Environmental Laboratory, Vicksburg, MS.

Harman, W., R. Starr, M. Carter, K. Tweedy, M. Clemmons, K. Suggs, and C. Miller. 2012. A function-based framework for stream assessment and restoration projects. EPA 843-K-12-006, U.S. Environmental Protection Agency, Office of Wetlands, Oceans and Watersheds, Washington, DC.
https://www.epa.gov/sites/production/files/201508/documents/a_function_based_framework_for_stream_assessment_3.pdf

Harman, W.A. and C.J. Jones. 2017. North Carolina Stream Quantification Tool: Data Collection and Analysis Manual (NC SQT v3.0). Environmental Defense Fund, Raleigh, NC.
https://www.edf.org/sites/default/files/Quantification-Tool-User-Manual.pdf

Harrelson, C.C., C.L. Rawlins, and J.P. Potyondy. 1994. Stream Channel Reference Sites: An Illustrated Guide to Field Techniques. General Technical Report RM-245. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. 61pp.

Kroes, D.E., and C.R. Hupp. 2010. The Effect of Channelization on Floodplain Sediment Deposition and Subsidence Along the Pocomoke River, Maryland. Journal of the American Water Resources Association 46(4):686-699.

Merritt, D.M., M.E. Manning, and N. Hough-Snee (Eds). 2017. The National Riparian Core Protocol: A riparian vegetation monitoring protocol for wadeable streams of the conterminous United States. General Technical Report RMRS-GTR-367. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO.
https://www.fs.fed.us/rm/pubs_series/rmrs/gtr/rmrs_gtr367.pdf

Nadeau, T-L., C. Trowbridge, D. Hicks, and R. Coulombe. 2018. A Scientific Rationale in Support of the Stream Function Assessment Method for Oregon (SFAM, Version 1.0). Oregon Department of State Lands, Salem, OR, EPA 910-S-18-001, U.S. Environmental Protection Agency, Region 10, Seattle, WA. 199 pp.
https://www.oregon.gov/dsl/WW/Documents/SFAM-scientific-rationale-v1-1.pdf

Nanson, G.C., and J.C. Croke. 1992. A genetic classification of floodplains. Geomorphology, 4(6): 459-486.

National Research Council. 2001. Compensating for Wetland Losses Under the Clean Water Act. The National Academies Press, Washington, DC.

O'Brien, G.R., J.M. Wheaton, K. Fryirs, W.W. Macfarlane, G. Brierley, K. Whitehead, J. Gilbert, and C. Volk. 2019. Mapping valley bottom confinement at the network scale. Earth Surface Processes and Landforms. https://doi.org/10.1002/esp.4615

Polvi, L.E., E.E. Wohl, and D.M. Merritt. 2011. Geomorphic and process domain controls on riparian zones in the Colorado Front Range. Geomorphology 125(4): 504-516.

Rivett, M.O., P.A. Ellis, R.B. Greswell, R.S. Ward, R.S. Roche, M. Cleverly, C. Walker, D. Conran, P.J. Fitzgerald, T. Willcox, J. Dowle. 2008. Cost-effective mini drive-point piezometers and multilevel samplers for monitoring the hyporheic zone. Quarterly Journal of Engineering Geology and Hydrogeology 41(1): 49-60. http://dx.doi.org/10.1144/1470-9236/07-012

Rosgen, D.L. 2014. River Stability Field Guide (Second Edition). Wildland Hydrology Books, Fort Collins, CO.

Rosgen, D.L. 1996. Applied River Morphology. Wildland Hydrology Books, Fort Collins, CO.

Rosgen, D.L. 1994. A Classification of Natural Rivers. Catena 22:169-199.

Shields, Jr., F.D., R.E. Lizotte, Jr., S.S. Knight, C.M. Cooper, and D. Wilcox. 2010. The Stream Channel Incision Syndrome and Water Quality. Ecological Engineering 36:78-90.

Schoof, R. 1980. Environmental Impact of Channel Modification. Water Resources Bulletin 16(4): 697-701.

U.S. Army Corps of Engineers. 2020. Colorado Stream Quantification Tool: User Manual and Spreadsheets. (CSQT v1.0). U.S. Army Corps of Engineers, Albuquerque District, Pueblo Regulatory Office, CO.

U.S. Fish and Wildlife Service. 2009. A system for mapping riparian areas in the western united states. U.S. Fish and Wildlife Service, Division of Habitat and Resource Conservation, Branch of Resource and Mapping Support, Arlington, VA. https://www.fws.gov/wetlands/documents/A-System-for-Mapping-Riparian-Areas-In-The-Western-United-States-2009.pdf

Wenger, S. 1999. A Review of the Scientific Literature on Riparian Buffer Width, Extent, and Vegetation. Office of Public Service and Outreach, Institute of Ecology, University of Georgia.

Wohl, E.E. 2004. Disconnected Rivers, Linking Rivers to Landscapes. Yale University Press, New Haven, CT.

APPENDIX A: Evaluation of Various Units of Measure Across Stream Archetypes and Assessment Assumptions

Appendix A provides the evaluation of select UoMs across a range of stream archetypes and assessment assumptions. Information from Sections 3 and 4 have been provided for convenience. Key components of the evaluation are the evaluation scenarios, stream archetypes, assessment assumptions, and evaluation criteria.

Evaluation Scenarios

Table A1. Twelve scenarios.

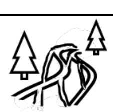
Scenario	Unit of Measure	Assessment Assumption	
A	Channel Length	No assessment	**Applied to all Stream Archetypes**
B		Stream only	
C		Stream and floodplain	
D	Valley Length	No assessment	
E		Stream only	
F		Stream and floodplain	
G	Channel Area	No assessment	
H		Stream only	
I		Stream and floodplain	
J	Valley Area	No assessment	
K		Stream only	
L		Stream and floodplain	

Each scenario represents a 1,000-foot length of stream that could represent an impact or mitigation project. No adjustment factors are included in the evaluation scenarios.

Stream Archetypes

A description of each stream archetype is provided in Table A2. Example photographs of the stream archetypes are provided in Appendix B.

Table A2. Stream archetype identification number, description, and rationale for its selection.

Stream archetype ID	Stream archetype description	Rationale for its selection
	Wadeable, single-thread, perennial stream located in an alluvial valley.	This is a classic restoration and impact stream archetype in the eastern United States. This stream archetype is naturally a single-thread channel that would exhibit meandering processes.
	Wadeable, multi-thread (anastomosed), perennial	This stream archetype is multi-thread rather than single-thread. This is a common restoration approach in rural regions of the West.

Stream archetype ID	Stream archetype description	Rationale for its selection
	stream in an alluvial valley with low stream power.	
3 	Non-wadeable, single-thread stream in an alluvial valley.	This stream archetype represents a river, as opposed to a wadeable stream.
4 	Perennial or intermittent, braided, multi-thread channel.	Represents a stream in a semi-arid to arid region. Sediment supply exceeds sediment transport capacity.
5 	Single-thread, ephemeral channel in a confined alluvial valley.	Represents an ephemeral channel but does not distinguish size. This could be a small headwater ephemeral channel in the East or a mid-size channel in the West.
6 	Wadeable, perennial, colluvial valley (step-pool) system.	Headwater mountain stream. This could represent any mountain system.

Assessment Assumptions

Three assumptions are used to evaluate the UoM across the different stream archetypes. These are:

- No assessment method applied,
- Stream assessment only, and
- Stream and floodplain assessment.

The “no assessment method” assumption means that a function or condition assessment method has not been applied at the impact (debit) or offset (credit) site; only the UoM is used to calculate debits and credits (see Section 3.1.1). The “stream assessment only” assumption means that a condition or function-based assessment method has been applied; however, the assessment area is limited to the stream channel and does not include the adjacent riparian area or floodplain. The “stream and floodplain assessment” assumes that some form of condition or functional assessment was applied to both the stream channel and the adjacent riparian area/floodplain.

When an assessment method is assumed, the elements listed in Section 2.1 are used to further define the assumptions. These elements include stratification, scaling, representativeness, regression to the known, and the roll-up approach. These same assumptions are applied to the “stream assessment only” and the “stream and floodplain assessment” such that the only difference between the two is the area assessed: stream channel only or stream channel and the adjacent floodplain.

The assumptions for the stream channel only and stream and the adjacent floodplain assessments include the following:

- Stratification – Differences in ecoregion, hydrologic landscape, stream size, etc., are reflected in standard performance/reference indices, such that method outputs account for such differences.
- Scaling – The reach length of the area assessed is determined by multiplying the bankfull width by 20. Scaling for all metrics and methods is appropriate for the project reach and will support a representative assessment output for the project area.
- Representativeness – The stream only assessment method captures the entire length of the project channel, and primarily focuses on measures of natural channel stability (aggradation, degradation, and lateral migration). Riparian vegetation is assessed but only for the purpose of bank stability. The stream and floodplain assessment includes the same channel measures but also includes measures of floodplain connection and extent of riparian vegetation.
- Regression to the Known – The stream type is appropriate for the valley type.
- Roll-Up Approach – An overall score is provided for the reach that represents an overall function or condition score.

Specific assessment methods used to inform stream compensatory mitigation accounting were not used in the scenarios.

Evaluation Criteria and Results

The evaluation criteria are provided below in Table A2. Results are provided in the ensuing evaluation matrices, representing the twelve evaluation scenarios.

Table A3. Scenario Evaluation Criteria.

Criterion ID	Evaluation Criterion
C-1 - = +	Does it apply equally on debit and credit side?
C-2	Does it incentivize debit and credit determination that supports ecological benefits?
C-3	Does it support in-kind mitigation?
C-4	Does it incentivize restoration that is appropriate for the landscape?
C-5	Is it repeatable?
C-6	Is it straightforward to measure?

Scenario A: Channel Length UoM Applied to each Stream Archetype in the Absence of an Assessment Method.

Criteria	Stream archetypes [Scenario A]					
	1	2	3	4	5	6
Does it apply equally on debit and credit side? - = +	Yes (all agree)	No (all agree)	Yes (most agree); One "it depends" response, regarding how channel size is factored in.	No (all agree)	Yes (all agree)	Yes (all agree)
Does it incentivize debit and credit determination that supports ecological benefits?	No (all agree)	No (all agree)	No (all agree)	No (all agree)	No (all agree)	No (all agree)
Does it support in-kind mitigation?	No (most agree); One "yes" response, based on likely economic considerations.	No (all agree)	No (all agree)	No (all agree)	No (most agree); One "yes" response, based on likely economic considerations.	No (all agree)
Does it incentivize restoration that is appropriate for the landscape?	No (all agree)	No (all agree)	No (all agree)	No (all agree)	No (all agree)	No (all agree)
Is it repeatable?	Yes (all agree)	No (all agree)	Yes (all agree)	No (all agree)	Yes (all agree)	Yes (all agree)
Is it straightforward to measure?	Yes (all agree)	No (all agree)	Yes (all agree)	No (all agree)	Yes (all agree)	Yes (all agree)

Scenario B: **Channel Length UoM Applied to each Stream Archetype with Stream Assessment.**

Criteria	Stream archetypes [Scenario B]					
	1	2	3	4	5	6
Does it apply equally on debit and credit side? **- = +**	Yes (all agree)—depends on whether all debits are from channel impacts, and the same assessment method is applied to both impact and offset site.	Yes (all agree)—depends on whether a primary thread can be defined.	Yes (most agree)—depends on whether all debits are from channel impacts; one "It depends" response based on how the size of the channel is being factored in.	Yes (all agree)—depends on whether a primary thread can be defined.	Yes (all agree)—depends on whether all debits are from channel impacts.	Yes (all agree)—depends on whether all debits are from channel impacts.
Does it incentivize debit and credit determination that supports ecological benefits?	Mixed—Some said it depends on the type of assessment used and its ability to assess stream function and/or condition; others said no because it incentivizes in-channel benefits only.	No (all agree)—incentivizes work on single channel only as well as in-channel benefits only.	Mixed—Some said it depends on whether larger channel impacts and mitigation may be focused in-channel; some said it depends on if impacts are wholly in-channel and metric stratification is used.	No (all agree)—incentivizes work on single channel only as well as in-channel benefits only.	Yes (all agree)—depends on whether assessment method includes stratification.	Yes (all agree)—depends on whether assessment method includes stratification.

Criteria	Stream archetypes [Scenario B]					
	1	2	3	4	5	6
Does it support in-kind mitigation?	Yes (all agree)—Depends on eligibility criteria for the proposed mitigation site (could be in a different watershed setting).	Mixed—Some said yes, depending on eligibility criteria and whether metric stratification is used; others said no because it doesn't account for floodplain functions and/or conditions that may be lost or gained.	Yes (most agree)—Depends on whether eligibility criteria are applied; one "no" response due to channel size limitations.	Mixed—Some said yes, depending on eligibility criteria and whether metric stratification is used; others said no because it doesn't account for floodplain functions and/or conditions that may be lost or gained	Yes (all agree)—Depends on whether stratification of assessment metrics and eligibility criteria are applied.	Yes (all agree)—Depends on whether stratification of assessment metrics and eligibility criteria are applied.
Does it incentivize restoration that is appropriate for the landscape?	No (all agree)—Ignores the valley setting.	No (all agree)—Doesn't account for multiple channels or floodplain function/condition.	Mixed—May depend on assessment method used, but economics likely discourages restoration of large channels.	No (all agree)—Doesn't account for multiple channels or floodplain function/condition.	Mixed	Yes (most agree)
Is it repeatable?	Yes (all agree)	No (all agree)—Could select different channels, then apply assessment outputs to entire braided system.	Yes (all agree)	No (all agree)—Could select different channels, then apply assessment outputs to entire braided system.	Yes (all agree)	Yes (all agree)
Is it straightforward to measure?	Yes (all agree)	No (all agree)—Could select different channels.	Yes (all agree)	No (all agree)—Could select different channels.	Yes (all agree)	Yes (all agree)

Scenario C: Channel Length UoM Applied to each Stream Archetype Using an Assessment Method of the Stream and Floodplain.

Criteria	Stream archetypes [Scenario C]					
	1	2	3	4	5	6
Does it apply equally on debit and credit side? **- = +**	Yes (all agree)	Yes (all agree)—Depends on if a primary thread can be defined.	Yes (most agree)—One "it depends" response, regarding how channel size is factored in.	Yes (all agree)—Depends on if a primary thread can be defined.	Yes (all agree)	Yes (all agree)
Does it incentivize debit and credit determination that supports ecological benefits?	Yes (most agree)—Depends on whether floodplain assessment results can be effectively length-weighted.	Yes (most agree)—Depends on whether floodplain assessment results can be effectively length-weighted.	Yes (most agree)—Depends on whether floodplain assessment results can be effectively length-weighted and if stratification of assessment metrics is applied; one "it depends" response due to economic factors that may discourage restoration in larger channels.	Yes (most agree)—Depends on whether floodplain assessment results can be effectively length-weighted and if stratification of assessment metrics is applied; one "it depends" response based on whether assessment method incentivizes multi-thread channels.	Yes (all agree)—Depends on if stratification of assessment metrics is applied.	Yes (all agree)—Depends on if stratification of assessment metrics is applied.

Criteria	Stream archetypes [Scenario C]					
	1	2	3	4	5	6
Does it support in-kind mitigation?	Yes (all agree)—Depends on eligibility criteria for the proposed mitigation site (could be in a different watershed setting).	Yes (all agree)—Depends on eligibility criteria and whether stratification (of metrics) is used.	Yes (most agree)—Depends on eligibility criteria and whether stratification of assessment metrics is applied; one "no" response due to channel size limitations.	Yes (all agree)—Depends on eligibility criteria and whether stratification of assessment metrics is applied.	Yes (all agree)—Depends on if eligibility criteria are applied.	Yes (all agree)—Depends on if eligibility criteria are applied.
Does it incentivize restoration that is appropriate for the landscape?	Yes (most agree)—Depends on whether floodplain elements can be captured in length metric; one "no" response because scenario ignores valley setting.	Yes (most agree)—Depends on whether floodplain elements and multi-thread aspects can be captured in length.	Yes (most agree)—Depends on whether floodplain elements can be captured in length metric; one "it depends" response based on economic factors that may discourage restoration in larger channels.	Yes (most agree)—Depends on whether floodplain elements and multi-thread aspects can be captured in length.	Yes (most agree)	Yes (most agree)
Is it repeatable?	Yes (all agree)	No (all agree)—Requires single length to measure, floodplain hard to define.	Yes (all agree)	No (all agree)—Requires single length to measure, floodplain hard to define.	Yes (all agree)	Yes (all agree)

Criteria	Stream archetypes [Scenario C]					
	1	2	3	4	5	6
Is it straightforward to measure?	Yes (all agree)	No (all agree)—Multiple channels, floodplain is hard to define.	Yes (all agree)	No (all agree)—Multiple channels, floodplain is hard to define.	Yes (all agree)	Yes (all agree)

Scenario D: Valley Length UoM Applied to each Stream Archetype in the Absence of an Assessment Method.

Criteria	Stream archetypes [Scenario D]					
	1	2	3	4	5	6
Does it apply equally on debit and credit side? - = +	Mixed—Some said no because channel length is not factored in.	Yes (most agree)	Mixed— How is size of channel being factored in?	Yes (most agree)	Yes (most agree)	Yes (most agree)
Does it incentivize debit and credit determination that supports ecological benefits?	No (all agree)	No (all agree)	No (all agree)	No (all agree)	No (all agree)	No (all agree)
Does it support in-kind mitigation?	No (all agree)	No (all agree)	No (all agree)	No (all agree)	No (all agree)	No (all agree)
Does it incentivize restoration that is appropriate for the landscape?	No (all agree)—Ignores valley setting.	No (all agree)- —Doesn't account for multiple channels or floodplain function/condition.	No (most agree)—One "it depends" response due to economic factors that may discourage restoration in larger channels.	No (all agree) —Doesn't account for multiple channels or floodplain function/condition.	No (most agree)	No (most agree)
Is it repeatable?	Yes (all agree)	Yes (all agree)	Yes (all agree)	Yes (all agree)	Yes (all agree)	Yes (all agree)
Is it straightforward to measure?	Yes (all agree)	Yes (all agree)	Yes (all agree)	Yes (all agree)	Yes (all agree)	Yes (all agree)

Scenario E: Valley Length UoM Applied to each Stream Archetype with Stream Assessment.

Criteria	Stream archetypes [Scenario E]					
	 1	 2	 3	 4	 5	 6
Does it apply equally on debit and credit side? **- = +**	Yes (most agree)	Yes (most agree)	Yes (most agree) — One “it depends” response, regarding how channel size is factored in.	Yes (most agree)	Yes (all agree)	Yes (all agree)
Does it incentivize debit and credit determination that supports ecological benefits?	Mixed—Yes, only if impacts are wholly in-channel and on ability of assessment method to fully assess stream function.	No (all agree) — Incentivizes working on shortest channel and ignores floodplain functions.	Mixed—Some said yes, only if impacts and restoration are limited to the channel, and channel lengths do not change; others said it depends on ability of assessment method to fully assess stream function.	No (all agree) — Incentivizes working on shortest channel and ignores floodplain functions.	Yes (most agree)—One “no” response due to concerns it would incentivize benefits in the channel only.	Yes (most agree)—One “no” response due to concerns it would incentivize benefits in the channel only.

Criteria	Stream archetypes [Scenario E]					
	1	2	3	4	5	6
Does it support in-kind mitigation?	Mixed—Some said yes, only if eligibility criteria are used such that watershed context matters; others said no because it ignores floodplain function/condition.	No (all agree)—Ignores floodplain function/condition	Mixed—Some said yes, assuming impacts and restoration are limited to the channel, channel lengths do not change, and if eligibility criteria are used such that watershed context matters; others said no because it doesn't account for floodplain functions or channel size.	No (all agree)—Ignores floodplain function/condition	Yes (all agree)—Depends on if eligibility criteria are used such that watershed context matters.	Yes (all agree)—Depends on if eligibility criteria are used such that watershed context matters.
Does it incentivize restoration that is appropriate for the landscape?	No (all agree)	No (most agree)	No (all agree)	No (most agree)	Yes (all agree)	Yes (all agree)
Is it repeatable?	Yes (all agree)	Yes (most agree)	Yes (all agree)	Yes (most agree)	Yes (all agree)	Yes (all agree)
Is it straightforward to measure?	Yes (all agree)	Yes (most agree)	Yes (all agree)	Yes (most agree)	Yes (all agree)	Yes (all agree)

Scenario F: Valley Length UoM Applied to each Stream Archetype with Stream and Floodplain Assessment

Criteria	Stream archetypes [Scenario F]					
	1	2	3	4	5	6
Does it apply equally on debit and credit side? - = +	Yes (most agree	Yes (all agree)	Yes (most agree) — One “it depends” response, regarding how channel size is factored in.	Yes (all agree)	Yes (all agree)	Yes (all agree)
Does it incentivize debit and credit determination that supports ecological benefits?	Mixed—Some said no because it could incentivize straight channels or out-of-channel functions over in-channel ones, depending on assessment method used.	Mixed—could require an assessment approach that goes beyond what is assumed for the current evaluation.	Mixed—Some said no because it could incentivize straight channels or out-of-channel functions over in-channel ones, depending on assessment method used.	Mixed—Some said no because it incentivizes working on shortest channel.	Yes (all agree)	Yes (all agree)
Does it support in-kind mitigation?	Mixed	Yes (most agree)	Mixed—Depends on how channel size is factored in.	Yes (most agree)	Yes (most agree)—if site selection eligibility criteria are used such that watershed context is taken into account.	Yes (most agree)—if site selection eligibility criteria are used such that watershed context is taken into account.
Does it incentivize restoration that is appropriate for the landscape?	Mixed—Some said yes, but only for floodplain, not channel; others said no because it could disincentivize single-thread channels.	Mixed—Some said no, or it depends because it disincentivizes working on longer channels, or even in-channel work.	Mixed—Some said yes, but only for floodplain, not channel; others said no because of concerns over how channel size is factored in.	Mixed—some said no because it could incentivize working on shortest channel.	Yes (all agree)	Yes (all agree)

Criteria	Stream archetypes [Scenario F]					
	 **1**	 **2**	 **3**	 **4**	 **5**	 **6**
Is it repeatable? 	Yes (all agree)	Yes (all agree)	Yes (all agree)	Yes (all agree)	Yes (all agree)	Yes (all agree)
Is it straightforward to measure? 	Yes (all agree)	Yes (all agree)	Yes (all agree)	Yes (all agree)	Yes (all agree)	Yes (all agree)

Scenario G: Channel Area UoM Applied to each Stream Archetype in the Absence of an Assessment Method.

Criteria	Stream archetypes [Scenario G]					
	1	2	3	4	5	6
Does it apply equally on debit and credit side? - = +	Mixed	Mixed— Depends on whether there is a consistent, primary channel.	Mixed	Mixed— Depends on whether there is a consistent, primary channel.	Mixed	Mixed
Does it incentivize debit and credit determination that supports ecological benefits?	No (all agree)	No (all agree)	No (all agree)	No (all agree)	No (all agree)	No (all agree)
Does it support in-kind mitigation?	No (all agree)	No (all agree)	No (all agree)	No (all agree)	No (all agree)	No (all agree)
Does it incentivize restoration that is appropriate for the landscape?	No (all agree)	No (all agree)	No (all agree)	No (all agree)	No (all agree)	No (all agree)
Is it repeatable?	Mixed—Some said no because there may be changes in stream width over time.	No (most agree)	Mixed—Some said no because there may be changes in stream width over time.	No (most agree)	No (most agree)	Mixed
Is it straightforward to measure?	Mixed	No (most agree)	Mixed	No (most agree)	No (most agree)	Mixed

Scenario H: Channel Area UoM Applied to each Stream Archetype with Stream Assessment.

Criteria	Stream archetypes [Scenario H]					
	1	2	3	4	5	6
Does it apply equally on debit and credit side? - = +	Mixed	Mixed—It depends whether there is a consistent, primary channel.	Mixed	Mixed—It depends whether there is a consistent, primary channel.	Yes (most agree)	Yes (most agree)
Does it incentivize debit and credit determination that supports ecological benefits?	Mixed—Some said yes if impacts are contained in the channel; others said no because it ignores floodplain function/condition.	Mixed—Some said yes if area accounts for multiple threads, could incentivize streams/wetlands; others said no because it ignores floodplain function.	Mixed-—Some said yes if impacts and restoration are within the channel; others said no, or it depends on the assessment method.	Mixed—Some said yes if impacts are contained in the channels; others said no because it ignores floodplain function/condition.	Yes (most agree) — if impacts and restoration are all within the channel.	Yes (most agree) — if impacts and restoration are all within the channel.
Does it support in-kind mitigation?	Mixed—Some said yes if impacts are all in-channel and depending on eligibility criteria for proposed mitigation site (watershed setting); others said no because it ignores floodplain function/condition.	Mixed—Some said yes if impacts are all in-channel and depending on eligibility criteria for proposed mitigation site (watershed setting); others said no because it ignores floodplain function/condition.	Mixed—Some said yes if impacts are all in-channel and depending on eligibility criteria for proposed mitigation site (watershed setting); others said no because it ignores floodplain function/condition.	Mixed—Some said yes if impacts are all in-channel and depending on eligibility criteria for proposed mitigation site (watershed setting); others said no because it ignores floodplain function/condition.	Yes (most agree) — If impacts and restoration are only in the channel and if eligibility criteria are used such that watershed context is accounted for.	Yes (most agree)- — If impacts and restoration are only in the channel and if eligibility criteria are used such that watershed context is accounted for.
Does it incentivize restoration that is appropriate for the landscape?	No (most agree)	Mixed—Only yes if area accounts for multiple threads.	No (most agree)	No (most agree)	Mixed	Mixed

Criteria	Stream archetypes [Scenario H]					
	1	2	3	4	5	6
Is it repeatable?	Mixed	No (most agree)	Mixed	No (most agree)	No (most agree)	Mixed
Is it straightforward to measure?	Mixed	No (most agree)	Mixed	No (most agree)	No (most agree)	Mixed

Scenario I: Channel Area UoM Applied to each Stream Archetype with Stream and Floodplain Assessment.

Criteria	Stream archetypes [Scenario I]					
	1	2	3	4	5	6
Does it apply equally on debit and credit side? - = +	Mixed	Mixed—Yes, only if area includes all channels.	Mixed	Mixed— Yes, only if area includes all channels.	Mixed	Mixed
Does it incentivize debit and credit determination that supports ecological benefits?	Mixed—Some said yes, if floodplain assessment results can be effectively area-weighted; others said no because it incentivizes large channels.	Mixed—Yes, only if floodplain assessment results can be effectively area-weighted.	Mixed—Some said yes, if floodplain assessment results can be effectively area-weighted; others said no because it incentivizes large channels.	Mixed—Yes, only if floodplain assessment results can be effectively area-weighted.	Mixed—Some said yes, if floodplain assessment results can be effectively area-weighted; others said no because it incentivizes large channels.	Mixed—Some said yes, if floodplain assessment results can be effectively area-weighted; others said no because it incentivizes large channels.
Does it support in-kind mitigation?	No (most agree)	No (most agree)	No (most agree)	No (most agree)	No (most agree)	No (most agree)
Does it incentivize restoration that is appropriate for the landscape?	No (most agree)	No (most agree)	No (most agree)	No (most agree)	Mixed	Mixed
Is it repeatable?	Mixed—Some said no because of changes in stream width over time.	Mixed	Mixed	No (most agree)	Mixed	Mixed
Is it straightforward to measure?	Mixed	No (most agree)	Mixed	No (most agree)	Mixed	Mixed

Scenario J: Valley Area UoM Applied to each Stream Archetype in the Absence of an Assessment Method.

Criteria	Stream archetypes [Scenario J]					
	1	2	3	4	5	6
Does it apply equally on debit and credit side? - = +	Mixed	Mixed	Mixed	Mixed	Mixed	Mixed
Does it incentivize debit and credit determination that supports ecological benefits?	No (all agree)	No (all agree)	No (all agree)	No (all agree)	No (all agree)	No (all agree)
Does it support in-kind mitigation?	No (all agree)	No (all agree)	No (all agree)	No (all agree)	No (all agree)	No (all agree)
Does it incentivize restoration that is appropriate for the landscape?	No (all agree)	No (all agree)	No (all agree)	No (all agree)	No (all agree)	No (all agree)
Is it repeatable?	Mixed	Mixed	Mixed	Mixed	Mixed	Mixed
Is it straightforward to measure?	Mixed	Mixed	Mixed	Mixed	Mixed	Mixed

Scenario K: Valley Area UoM Applied to each Stream Archetype with Stream Assessment.

Criteria	Stream archetypes [Scenario K]					
	1	2	3	4	5	6
Does it apply equally on debit and credit side? - = +	Mixed	No (all agree)	No (most agree)	No (all agree)	Yes (most agree)—One "no" response because it could emphasize restoration of the floodplain over restoration of the channel.	Yes (most agree)—One "no" response because it could emphasize restoration of the floodplain over restoration the channel.
Does it incentivize debit and credit determination that supports ecological benefits?	Mixed	Mixed—Some said yes because it incentivizes Stage 0; others said no because it ignores the floodplain.	Mixed	Mixed—Some said no because it ignores the floodplain.	Yes (most agree)	Yes (most agree)
Does it support in-kind mitigation?	No (most agree)	Mixed	No (most agree)	Mixed	Yes (most agree)—One "no" response because it could emphasize restoration of the floodplain over restoring the channel.	Yes (most agree)—One "no" response because it could emphasize restoration of the floodplain over restoring the channel.
Does it incentivize restoration that is appropriate for the landscape?	No (most agree); Ignores floodplain	Mixed—Some said no because it ignores the floodplain.	No (most agree)	Mixed—Some said no because it ignores the floodplain.	Mixed	Mixed
Is it repeatable?	Yes (most agree)—May be yes for some valley types and not for others.	Yes (most agree)—May be yes for some valley types and not for others.	Yes (most agree)—May be yes for some valley types and not for others.	Mixed	Mixed	Mixed

Criteria	Stream archetypes [Scenario K]					
	 1	 2	 3	 4	 5	 6
Is it straightforward to measure? 	Mixed	Mixed	Mixed	Mixed	Mixed	Mixed

Scenario L: Valley Area UoM Applied to each Stream Archetype with Stream and Floodplain Assessment.

Criteria	Stream archetypes [Scenario L]					
	1	2	3	4	5	6
Does it apply equally on debit and credit side? - = +	Yes (most agree)—One "no" response due to concerns that it could emphasize restoration of the floodplain over restoration of the channel.	Yes (most agree)—One "no" response due to concerns that it could emphasize restoration of the floodplain over restoration of the channel.	Yes (most agree)—One "no" response due to concerns that it could emphasize restoration of the floodplain over restoration of the channel.	Yes (most agree)—One "no" response due to concerns that it could emphasize restoration of the floodplain over restoration of the channel.	Yes (most agree)—One "no" response due to concerns that it could emphasize restoration of the floodplain over restoration of the channel.	Yes (most agree)—One "no" response due to concerns that it could emphasize restoration of the floodplain over restoration of the channel.
Does it incentivize debit and credit determination that supports ecological benefits?	Yes (most agree)—Unless projects focus on valleys or portions of valleys that have minimal fluvial engagement.	Yes (most agree)	Yes (most agree)—Unless projects focus on valleys or portions of valleys that have minimal fluvial engagement.	Yes (most agree)	Yes (most agree)	Yes (most agree)
Does it support in-kind mitigation?	Yes (most agree)—One "no" response due to concerns that it could emphasize restoration of the floodplain over restoration of the channel.	Yes (most agree)—One "no" response due to concerns that it could emphasize restoration of the floodplain over restoration of the channel.	Yes (most agree)—One "no" response due to concerns that it could emphasize restoration of the floodplain over restoration of the channel.	Yes (most agree)—One "no" response due to concerns that it could emphasize restoration of the floodplain over restoration of the channel.	Yes (most agree)—One "no" response due to concerns that it could emphasize restoration of the floodplain over restoration of the channel.	Yes (most agree)—One "no" response due to concerns that it could emphasize restoration of the floodplain over restoration of the channel.

Criteria	Stream archetypes [Scenario L]					
	1	2	3	4	5	6
Does it incentivize restoration that is appropriate for the landscape?	Yes (most agree)—One "no" response due to concerns that it could emphasize restoration of the floodplain over restoration of the channel.	Yes (most agree)—One "no" response due to concerns that it could emphasize restoration of the floodplain over restoration of the channel.	Yes (most agree)—One "no" response due to concerns that it could emphasize restoration of the floodplain over restoration of the channel.	Yes (most agree)—One "no" response due to concerns that it could emphasize restoration of the floodplain over restoration of the channel.	Yes (most agree)—One "no" response due to concerns that it could emphasize restoration of the floodplain over restoration of the channel.	Yes (most agree)—One "no" response due to concerns that it could emphasize restoration of the floodplain over restoration of the channel.
Is it repeatable?	Mixed—Could depend on valley type.	Mixed	Mixed—Could depend on valley type.	Mixed	Mixed	Mixed
Is it straightforward to measure?	Mixed—Could depend on valley type.	Mixed	Mixed—Could depend on valley type.	Mixed	Mixed	Mixed

APPENDIX B: Photographic Examples of Stream Archetypes Considered in Evaluation of Units of Measure

1. Wadeable, single-thread, perennial stream located in an alluvial valley.

Stream restoration project in North Carolina.

1. Wadeable, single-thread, perennial stream located in an alluvial valley.

Stream impacted by cattle in North Carolina

1. Wadeable, single-thread, perennial stream located in an alluvial valley.

Stream in Wyoming

1. Wadeable, single-thread, perennial stream located in an alluvial valley.

Muir Woods, California

2. Wadeable, multi-thread (anastomosed), perennial stream located in an alluvial valley with low stream power.

Stream in Colorado

2. Wadeable, multi-thread (anastomosed), perennial stream located in an alluvial valley with low stream power.

Stream in Alaska

2. Wadeable, multi-thread (anastomosed), perennial stream located in an alluvial valley with low stream power.

Stream in Mississippi

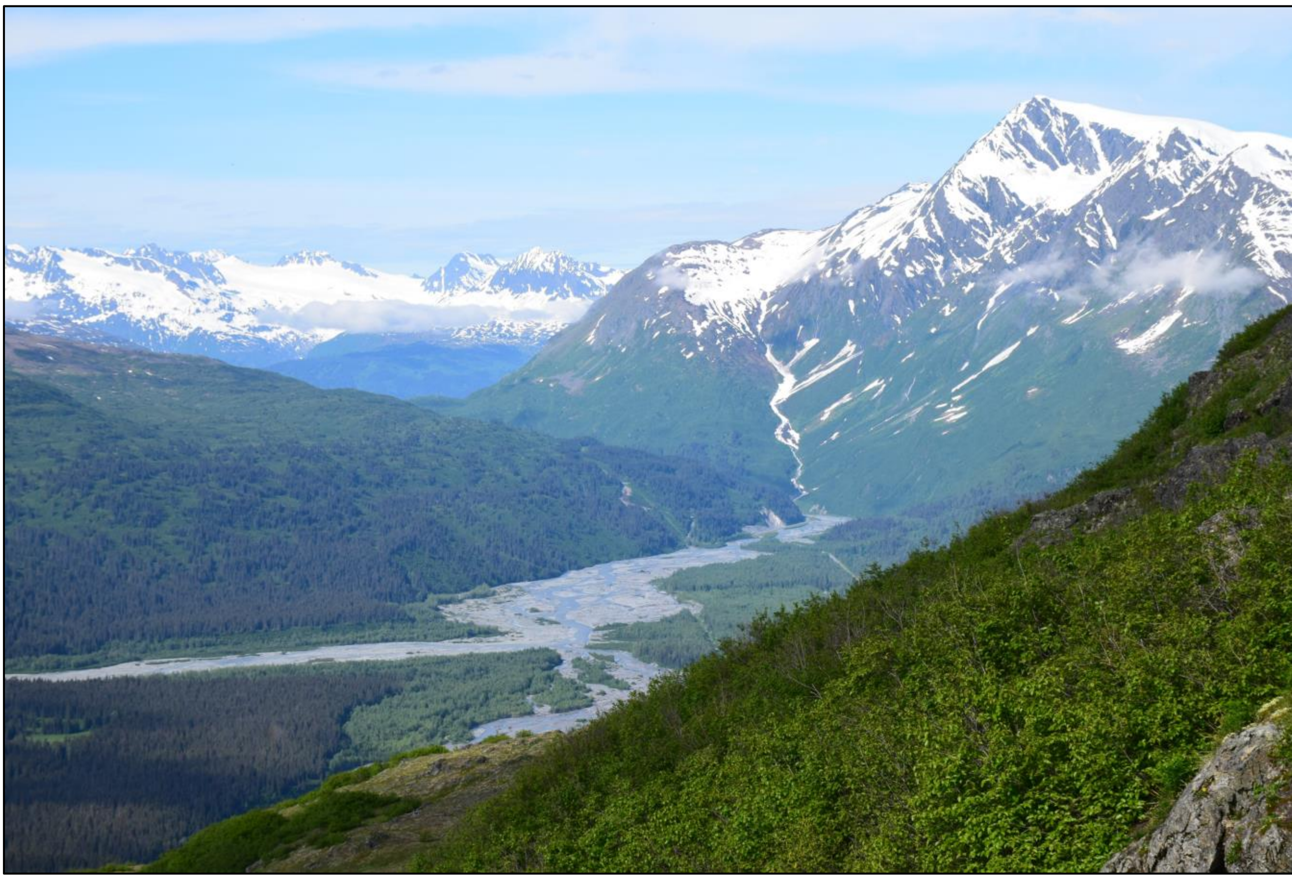
3. Non-wadeable, single-thread, perennial stream located in an alluvial valley.

Stream restoration project in Wyoming

3. Non-wadeable, single-thread, perennial stream located in an alluvial valley.

River in the Alaska Interior

4. Perennial or intermittent multi-thread (braided) channel.



Braided stream in a glacial valley in Alaska

4. Perennial or intermittent multi-thread (braided) channel.

Braided stream in Southwest Texas, there are more channels than shown in photo

5. Single-thread, ephemeral channel in a confined alluvial valley.

Ephemeral channel in Texas

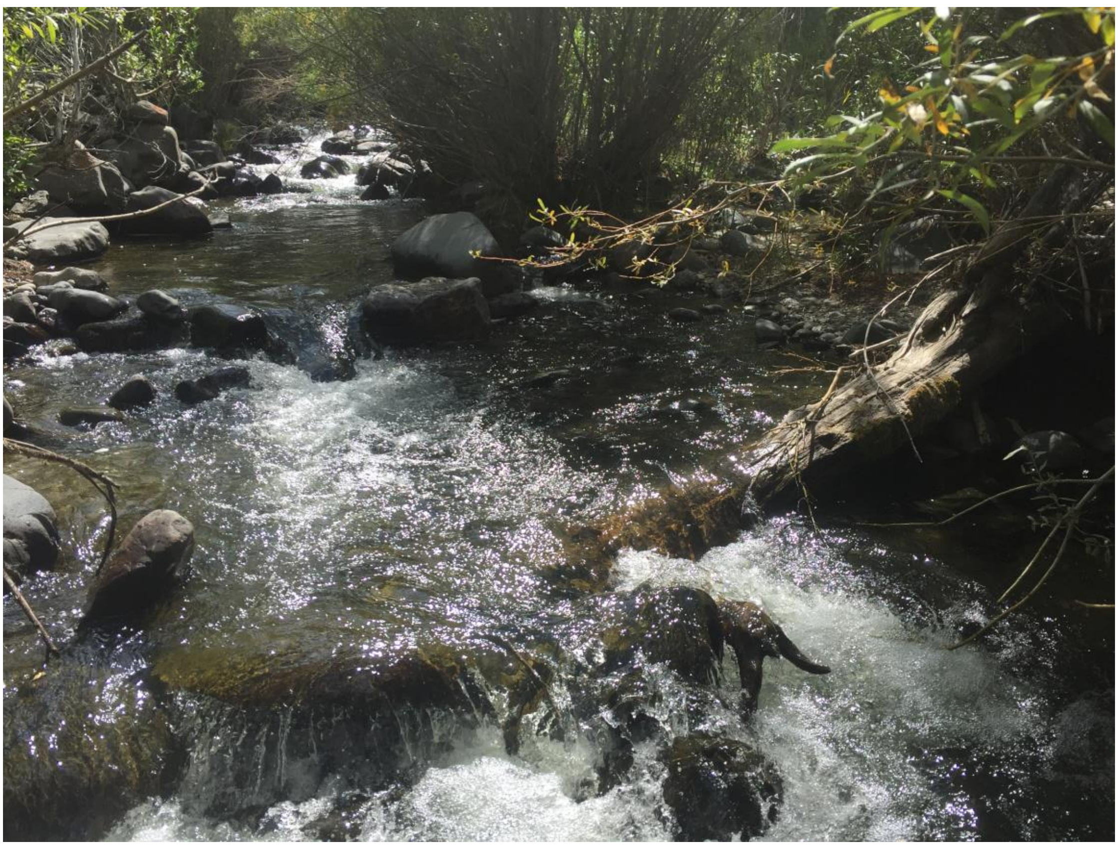
5. Single-thread, ephemeral channel in a confined alluvial valley.

Ephemeral channel in eastern Oregon

6. Wadeable, perennial, colluvial valley (step-pool) system.

Headwater mountain streams in the Appalachian Mountains (West Virginia and North Carolina)

6. Wadeable, perennial, colluvial valley (step-pool) system.

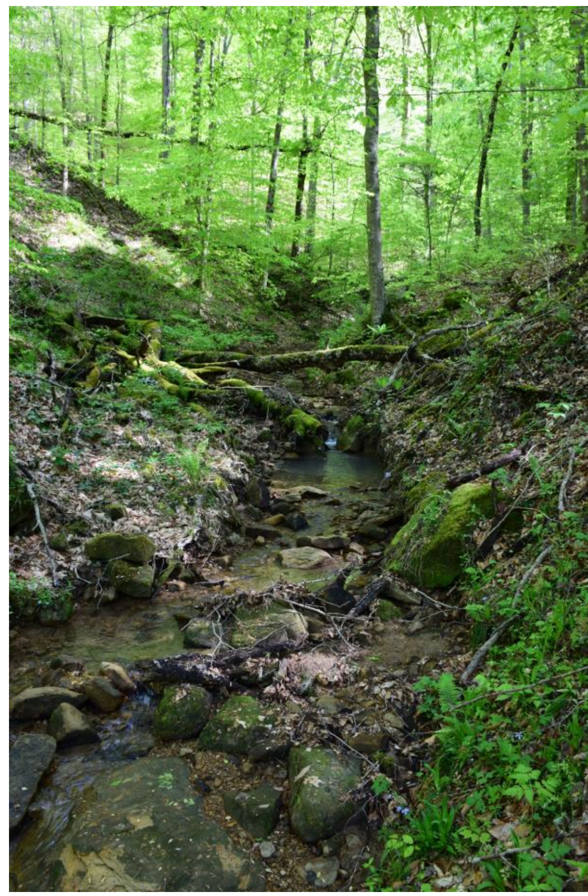


Step-pool channel in Wyoming

6. Wadeable, perennial, colluvial valley (step-pool) system.

Placer-mine site in Alaska

6. Single-thread perennial in a colluvial or v-shaped valley (step-pool) channel.



Stream in Kentucky