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A Scientific Rationale in Support of the Stream Function Assessment Method for Oregon

Version 1.1

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1.0 Introduction

This Scientific Rationale, a companion to the Stream Function Assessment Method for Oregon (SFAM) (Nadeau *et al.,* 2020), documents the development and scientific underpinning of the method. SFAM has been developed to provide a standardized, rapid, more function-based method for assessing stream function statewide. It is intended to further federal and state regulatory objectives by informing mitigation planning. It includes updates to maintain consistency with revisions made to other SFAM components (i.e., User Manual, Excel Workbook, SFAM Map Viewer) to produce SFAM Version 1.1: a section has been added to the User Manual on the use of SFAM to inform restoration design and predict stream function, the SFAM Workbook has been coded to automatically link data entered into Field Forms with other Workbook tabs to reduce effort and the potential for transcription errors, and new and updated data layers were added to the SFAM Map Viewer. The current document replaces the Version 1.0 document.

The federal Final Compensatory Mitigation Rule (2008), under Clean Water Act (CWA) Section 404, promotes the use of function assessment to determine the appropriate amount of compensatory mitigation to replace the loss of functions due to unavoidable impacts to aquatic resources. The Oregon Removal-Fill Law requires the replacement of the functions and values of water resources lost due to permitted impacts. Both state (Oregon Removal-Fill Law[1]) and federal (CWA Section 404[2]) policies require mitigation for impacts to waters of the state and waters of the U.S. This includes impacts to streams. SFAM provides a predictable, transparent, consistent, and scientifically robust approach to assessing the ecological processes affected by unavoidable impacts to streams in Oregon. While SFAM has been collaboratively developed by the agencies for mitigation application, it has broader application where a rapid function-based stream assessment could inform management, conservation, and restoration decision-making and monitoring efforts.

The intent of this document is to support a deeper critical understanding of the method, provide transparency and avoid "black box" calculations, facilitate the transfer and adaptation of SFAM, and promote method improvements as new data and information become available. The development process, from conception through measure development, iterative field testing and statistical method (model) analysis, and the relationship of measures to assessed functions and values is described. A scientific rationale for individual function and value measures is provided, including a detailed description of the standard performance index for each function measure and establishment of a standard index scale to give ecological meaning to measure scores. Development of a web-based tool, the SFAM Map Viewer[3], which provides data and information supporting SFAM application is also described. Finally, the Scientific Rationale closes with a brief discussion of measures that were considered but not included, or were removed after field testing, and the reasoning behind their exclusion from the current version of SFAM.

In Oregon, the north-south running Cascade Mountain Range creates a strong demarcation between the wet western and the dry eastern sides of the state (Loy *et al.,* 2001; Jackson and Kimerling, 2003). Elevation ranges from sea level along the Pacific coast to greater than 11,000 feet in the Cascade Mountain Range. Average annual precipitation west of the Cascades ranges from the moderately wet Willamette Valley to the wetter coastal areas (70–90 inches) and the very wet rain forests of the Oregon Coast Range (100–200 inches). In contrast, areas east of the Cascades are generally dry (7–11 inches) except at high mountain elevations. The delivery of precipitation in the Pacific Northwest is generally greatest during the winter months, resulting in fairly distinct wet winter/spring and dry summer seasons. The dominance of seasonal winter precipitation, as rain or snow, overlays a variety of regional climates (Jackson and Kimerling, 2003).

1 ORS 196.795-990

2 "Compensatory Mitigation for Losses of Aquatic Resources; Final Rule" Department of Defense 33 CFR Parts 325 and 332. Environmental Protection Agency 40 CFR Part 230 73(70) (10 April 2008), pp 19594-19705.

3 The SFAM Map Viewer is available on a shared platform with the Oregon Rapid Wetlands Assessment Protocol Map Viewer as an integrated web-based tool.

Oregon's extremely varied climate, hydrology, and geology results in a broad range of streams and rivers. Given this extensive variety of streams, and our aim to develop an assessment method that supports the state and federal compensatory mitigation programs, our objective in developing this first version of SFAM is that it would apply to 80% of the permit applications received for impacts to streams. SFAM is primarily applicable to wadeable streams. We are exploring scientifically-supported modifications for non-wadeable streams and large rivers, and tidally- influenced streams, which may be addressed in future versions of the method.

1.1 References

Jackson, P.L., Kimerling, A.J. (2003) Atlas of the Pacific Northwest, Ninth ed. Oregon State University Press, Corvallis, OR

Loy W.G., Allan S., Buckley A.R., Meacham J.E. (2001) Atlas of Oregon. Second ed. University of Oregon Press, Eugene, OR

Nadeau, T-L., D. Hicks, C. Trowbridge, N. Maness, R. Coulombe, N. Czarnomski. (2020) Stream Function Assessment Method for Oregon (SFAM, Version 1.1) Oregon Dept. of State Lands, Salem, OR, EPA 910-R-20-002, U.S. Environmental Protection Agency, Region 10, Seattle, WA

2.0 Development Process

A summary overview of the SFAM development process is provided, following the chronological timeframe (**Figure 2.1**). In some instances, readers are referred to other sections of this document where more in-depth information is provided on aspects of the SFAM development process.

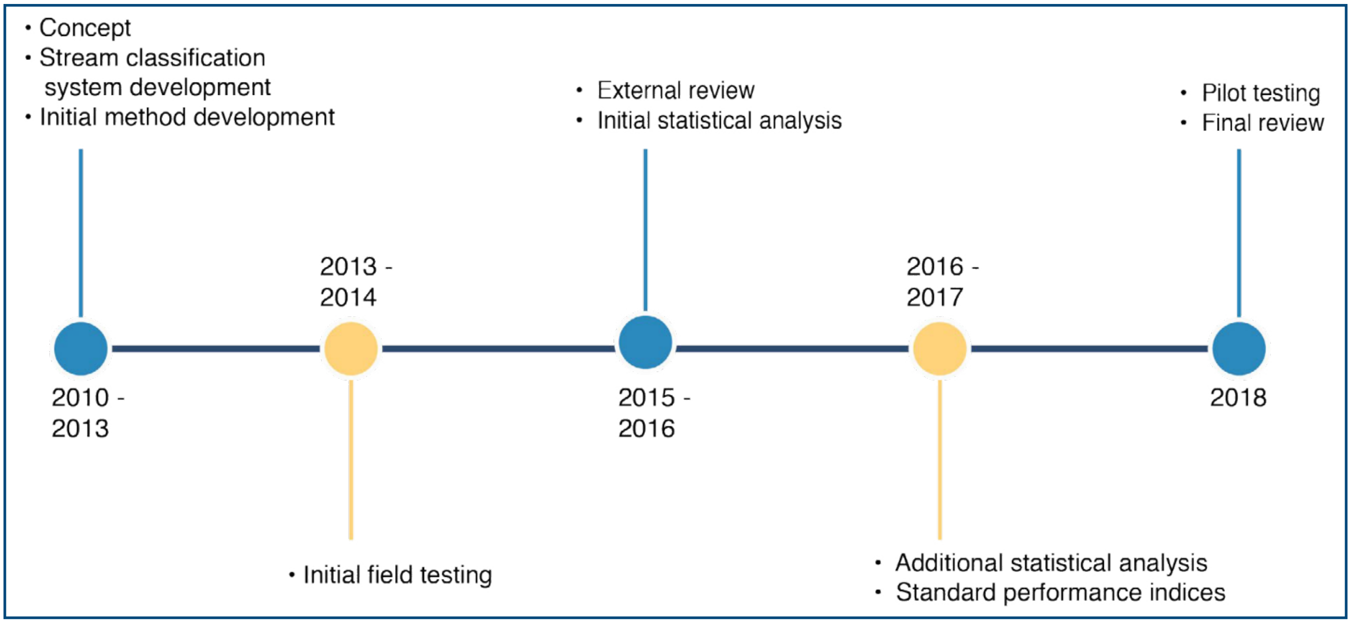


Figure 2.1 SFAM Development Process

2.1 Conception to Draft

Several stream mitigation programs existed nationally when we began SFAM development in 2009, and these programs were evaluated to see if they could be adapted for use in Oregon. In addition, a catalog of assessment protocols that have relevance to assessment of stream function and riparian/floodplain systems and were in active use in the Pacific Northwest (Washington, Oregon, Montana, Idaho, California) was created. Several key issues with these existing protocols and programs were identified:

Lack of a stream functional assessment tool- Existing tools are based largely on qualitative assessment of stream biological or physical conditions, which many scientists feel do not adequately assess stream functions.

Lack of a watershed approach- Existing approaches limit assessments to the reach-scale without consideration of the watershed context.

Lack of tools to evaluate out-of-kind mitigation- Existing stream mitigation facilitates the restoration or enhancement of out-of-channel components of the ecosystem for impacts to in-stream functions.

Narrow recognition of values- Existing approaches value and promote restoration of certain stream types rather than valuing the full range of functions and variability provided by natural stream types.

Reliance on condition assessments- Existing tools rely largely on subjective assessment of stream conditions rather than qualitative assessment of functions. This can devalue partially degraded streams and discourage restoration.

To address these issues, and to achieve other objectives for the state and federal mitigation programs in Oregon in implementing the federal Final Compensatory Mitigation Rule (2008), the agencies sought to develop a new stream assessment method. The method aims to provide for a site level assessment, but also consider that site in the context of its larger watershed. To meet regulatory program needs, the method also must be science-based, yield credible results, and be relatively rapid, easy to use, repeatable and applicable across most of Oregon's streams. We defined these development objectives as follows:

Science-based- Integrating the best available science using ecological functions applied in a watershed context;

Rapid- Two trained professional field scientists should be able to complete the field assessment at any time of year for a 1000-foot reach in one day. Total time for completing all work (including all office work, data entry and score calculations) could take two days;

Credible- Sensitive to year-over-year changes within a site and to differences among sites, and repeatable, so that any two assessment teams would arrive at a similar answer for the same site;

Transparent- Where all measures, calculation formulas, etc., can be easily accessed and understood by a variety of stakeholders, not just the trained professionals applying the assessment methodology; and

User-friendly- Manuals, documentation, and tools are available online and are easy to use.

An additional issue identified in many existing stream assessment protocols used in mitigation is that the assessment and credit/debit quantification protocols are often combined into a single methodology, leading to policy decisions affecting the numerical or 'quantitative' outputs of such methods. While this can lead to efficiencies for rapid assessment methods, it can also reduce transparency and project a scientific rigor for all method outputs that rightly ascribes to only partial aspects of the method. This can reduce method credibility and defensibility. To avoid this, an additional development objective is that SFAM be a stand-alone function assessment method, with an associated mitigation accounting protocol developed separately. This allows SFAM to evolve independently as scientific understanding, data availability, and collection techniques advance, and promotes transparency in clearly explaining program policy decisions and their implementation through the separate mitigation accounting protocol. Furthermore, separate assessment and accounting protocols facilitate the transfer and adaptation of SFAM for use in other programs and where different mitigation policies are in place.

In January 2010, we convened a workshop including technical experts representing 18 federal, state, and local agencies, universities, and the private and non-profit sectors (**Appendix A**).

Participants explored the current state of the science and technical considerations regarding stream mitigation and restoration, and identified elements essential to the assessment of stream function. Advance materials included a summary of the functions that streams provide based on an extensive literature review and the current state of scientific understanding. Participants identified the key ecological characteristics and processes of streams that ideally should be evaluated for a robust assessment of Oregon's streams; *key* because they met the criteria of realistic, practical, and scientifically legitimate in the mitigation context. The group identified knowledge gaps and research needs related to:

- A stream classification system that could inform expectations for functions provided by streams in Oregon;
- gaps in our understanding of specific functions;
- unknown or limited accuracy and precision of measures to assess stream functions; and
- unknown or limited data to design a function assessment scheme such as baseline and reference sites, thresholds enabling change detection related to an action, and the ability to predict ecological processes over time.

Direct measure of stream function is the optimal approach to evaluating function; however, such measurements present two significant challenges for use in mitigation. Direct measurement of function requires that data be collected and evaluated over longer time frames and larger spatial scales than are within the practical scope of individual permitted actions. While longer- term (> 7 years) and intensive monitoring may enable assessment of changes in function associated with many permitted actions or mitigation actions, calculating debits and credits for regulatory purposes requires a narrower timeframe. Additionally, changes in stream function may only be detectable after some lag-time following permitted impacts or mitigation restoration or when the combined effects of multiple projects are taken into account (Sudduth *et al.,* 2011; Moreno-Mateos *et al.,* 2012). In the current method we propose that, by identifying attributes that indicate function and directly measuring those attributes, we can assess stream function within program constraints. As a result, we describe the method as "functionally based."

Function & Value as Defined in SFAM

Function - the processes that create and support a stream ecosystem

Value - the ecological and societal benefits that riverine systems provide

Recognizing the varied interpretations and contexts for which *function* has been defined (NRC, 2002; Fischenich, 2006; Sandin and Solimini, 2009), we define *function* as the processes that create and support a stream ecosystem. 'Function' is often characterized as providing societal services, such as clean water, food resources, or recreation. However, such characterizations are inherently subjective and value-based, as 'service' implies a beneficiary (e.g., humans or preferred fish species). In the assessment method presented here, *values* (i.e. ecosystem services) are assessed separately from function, and are defined as the ecological and societal benefits that riverine systems provide. The definition of function used for SFAM focuses solely on ecological processes.

The foundational documents (U.S. Environmental Protection Agency [USEPA], 2012) and initial technical workshop led to a conceptual model for SFAM, and informed the 11 stream functions and associated values SFAM assesses (see **Section 3**: Ecological Functions and Values). Using the conceptual model, SFAM was drafted in two stages – identification of measures and construction of the excel-based tool. To support moving SFAM from concept to a working method (model), we convened a standing Stream Technical Working Group (**Appendix A**) – an expert advisory team that included scientists and practitioners representing a breadth of experience working in stream systems across Oregon and the Pacific Northwest, whom we periodically engaged at significant junctures of method development and initial field testing.

Because direct measurement of stream processes is a challenge, we developed a comprehensive list of attributes which create a link to the measurable characteristics that represent a particular function and the extent to which that function is active on a given stream reach. Attributes describe specific components of that function and may connect to multiple functions. For example, overbank flow is an attribute of surface water storage and sub/surface transfer. The peer-reviewed and vetted list of functions and attributes provided the foundation for measure development (see **Section 4.2, Table 4.2** for revised final list).

Next, we identified possible measures for each attribute—information or data that is collected to indicate the extent to which an attribute is expressed (**Figure 2.2**). In some instances, more than one measure was available to assess a given attribute and its link to a given function. Possible measures were then vetted against established criteria—rapidly assessed, repeatable, relevant, and science-based.

A similar process was followed to develop measures of value for each function (see **Section 4.3, Table 4.41** for revised final list). Measures of value assess the opportunity to provide a particular function and the local significance of that function. The majority of these measures are assessed in the office, using a web-based mapping tool. While SFAM assesses both functions and values ('services'), as required by Oregon's Removal-Fill Law and the CWA Section 404, the scoring for stream reach function and value are separate by design.

This process resulted in the suite of function and value measures that were incorporated into the initial draft SFAM: 20 measures of function (**Table 2.1**) and 14 measures of value. The function and value measures were assigned to categories that meet one or several interpretive values for the measures. For some measures a simple binary ("meets" or "does not meet") categorization was used, and for others intermediate levels of meeting the measure were assigned. Categorical bins ranged from 0 for not meeting a minimal value to 1 for reaching a full expectation; intermediate categorical bins were assigned proportions between 0 and 1 to indicate various levels of partially meeting expectations. The relevant function and value measures were grouped and averaged to form 11 function and 11 value subscores (subscore groups are averaged over 3 to 9 measures per subscore). The function and value subscores were then grouped and averaged to form function and value grouped scores (Hydrologic; Geomorphic; Biologic; Water Quality); the subscores and grouped scores form the outputs of the method (**Table 2.2**).

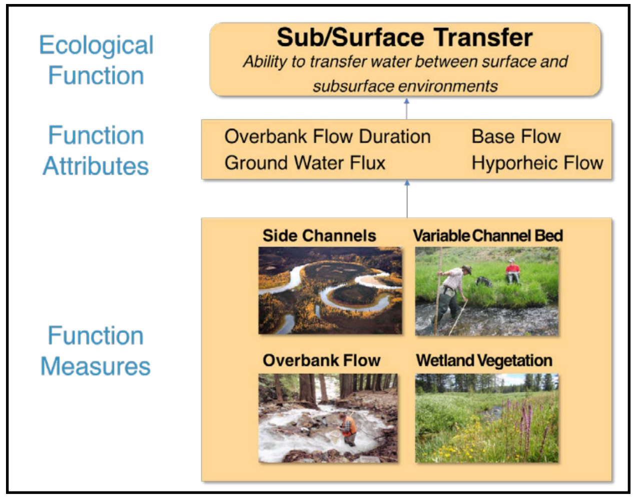


Figure 2.2 Relationship of Function Measures to Attributes of Function, Using the Sub/Surface Transfer Function as an Example

Based on the SFAM conceptual model**,** in addition to the function and value measures, several other attributes were recorded to provide context for scoring. These context factors were used in some instances to adjust subscores (outputs) based on differing functional expectations (e.g., intermittent vs. perennial stream; xeric versus mountain wet ecoregion; presence or absence of a floodplain).

Concurrent with method construction we developed a User Manual and a web-based mapping tool, the SFAM Map Viewer that provides access to relevant data layers in a user-friendly platform, to facilitate efficient and consistent method application. Thus, SFAM has four components including the current document:

1. Excel Workbook
2. User Manual
3. SFAM Map Viewer
4. Scientific Rationale

2.2 Stream Classification System

As part of the effort to improve compensatory mitigation outcomes in Oregon, and more function-based assessment of streams, we developed a stream/watershed classification system for streams and rivers (Nadeau *et al.,* 2012). Informed by an expert workshop (**Appendix A**) convened in 2011, the stream classification system is based in part on a hydrologic landscape classification system, addressing local assessment units, previously developed for Oregon (Wigington *et al.,* 2013). The current stream classification system, available through the SFAM Map Viewer, reflects recent revisions to the hydrologic landscape classification system that informs several of the included classification parameters. Specific changes from that initial classification system (Nadeau *et al.,* 2012) include the use of local assessment units based on National Hydrography Dataset (NHD) Plus Version 2 to promote compatibility with geospatial data that are more broadly available with the United States, and aquifer and soil permeability classes based on uniform criteria (Comeleo *et al.,* 2014; Leibowitz *et al.,* 2016).

The stream classification system is hierarchical, expandable, and dualistic—providing information at both the local and watershed (integrative) scales. It recognizes the hydrologic and geologic drivers of stream functions, and meets several *a priori* criteria established to assure statewide applicability: (1) the same variables are applied regardless of geography to assure consistency across regions, (2) classification is accomplished through an automated GIS process, (3) classes do not require field verification, and (4) data used are at appropriate resolution.

Each class is defined by basic hydrologic and physical characteristics and determinants of flow regime, using 11 local scale and nine watershed scale parameters, and reflects broad functional expectations. Local-scale parameters are calculated for each local unit. As the local units are based on NHD catchments, there are usually several stream segments within each local unit. Because stream processes are highly influenced by watershed scale parameters, we developed watershed scale data layers to address such questions as annual water surplus availability, seasonality of surplus release, and floodplain influence. Adding a watershed component to the classification promotes consideration of watershed processes. Watershed- scale parameters are calculated for the area composed of each local-scale unit and all upstream units. There are 4,048 local units in Oregon, and the designated class, indicating both local and watershed scale parameters, applies to the entire local unit and the streams within that unit.

To provide a limited number of classes for easier comparison, we developed an exclusionary rule set for 17 (local assessment unit) types using classification parameter values that the local units have in common. These types describe 17 subsets of local unit groupings that have similar landscape position, water budget, and seasonal hydrology. Detailed information on the stream classification system, describing the local and watershed scale parameters, associated metadata, and the rule set used to establish the 17 statewide stream types, is provided in **Appendix B**.

2.3 Field Testing, Statistical Analysis & Peer Review (Phase I)

We took a two-pronged approach to meet our objectives in evaluating the performance of the initial SFAM model; field testing and external peer-review. Together these provided for a comprehensive evaluation.

Field Testing (2013-2014)

Field testing of the draft SFAM included application on 39 streams ranging across the hydrologic landscape settings of Oregon in both the summer-dry and winter-wet seasons. Study sites represented a range of stream 'classes' (e.g., climate, stream type, flow permanence, gradient, land use, and stream order). The data collection/sampling design was developed by a team that included experienced stream scientists and field ecologists, who worked to maximize the diversity of streams included within the practical funding constraints. Testing design and parameters were further reviewed and refined by the Stream Technical Working Group before field work commenced. Supplementary data were collected at each site, including Streamflow Duration Assessment Method (Nadeau, 2015) application: Wetland Plants, Macroinvertebrate Presence, Percent Slope, and Number of EPT [Ephemeroptera, Plecoptera, and Trichoptera] Taxa.

Field Testing Objectives

Testing objectives included evaluating the draft tool for accuracy, usability, and applicability across stream types to assure a robust method.

Accuracy means that the assessment method produces scores that correspond to actual stream functioning. To evaluate accuracy, a stream function assessment method ideally should be compared against actual function, determined using independently and objectively defined field criteria (Stauffer and Goldstein, 1997). Determining actual (quantitative) function for each of the 11 stream functions at 39 sites was well beyond the scope and resources of this study. As a surrogate, the scores for each study site, in each season, were tested against expert opinion and, where possible, explicit knowledge of sites by experts working in study stream systems. To produce this surrogate to support accuracy evaluation of the method, at each of the 39 test sites, in the wet and dry seasons, evaluators conducted a best professional judgment (BPJ) assessment of the 11 stream functions as defined (**Section 3.2**), assigning a score of 0-10. BPJ scoring of how well study streams performed each function as defined, was relative to stream size (discharge). The same trained field team of two conducted the BPJ and subsequent field assessments at all study sites, reducing evaluator variability in BPJ and SFAM assessment outputs.

Usability means that the assessment method can be applied by a person familiar with stream systems and field measurements, with SFAM training, effectively and efficiently (e.g. hours rather than days per site), and that the provided instructions are easy to understand and carry out correctly.

Applicability across stream types means that the assessment method can be used in the range of different stream types and hydrologic settings commonly found in Oregon. Test sites were selected to represent hydrological and geographic diversity of Oregon stream types. To evaluate this objective, the method was tested at sites that displayed varying stream characteristics. A variety of stream type parameters were used as selection criteria for inclusion in the study, such as hydrogeology (e.g. east vs. west of Cascade mountain range), flow permanence (perennial, intermittent, ephemeral), stream order, gradient, and surrounding land use (forest, agriculture, urban).

Statistical Analysis (2015)

SFAM has multiple, potentially correlated inputs ("measures") and outputs ("scores"). To evaluate model performance, our analytical approach had two objectives (**Figure 2.3**):

Objective 1: Evaluate response variability for six stream categories (flow duration, wet/ dry season, slope (high/medium/low), east/west of Cascade Mountains, ecoregion) and measures, and identify potential value-added parameters (i.e. measures that best explain response variability), and

Objective 2: Evaluate relationships between measures and identify redundancies.

To address Objective 1, response variability for stream function subscores, individual stream measures, and supplementary measures were evaluated. To address Objective 2, correlations among the input measures for each stream function were evaluated using polychoric correlation and pairwise heatmaps.

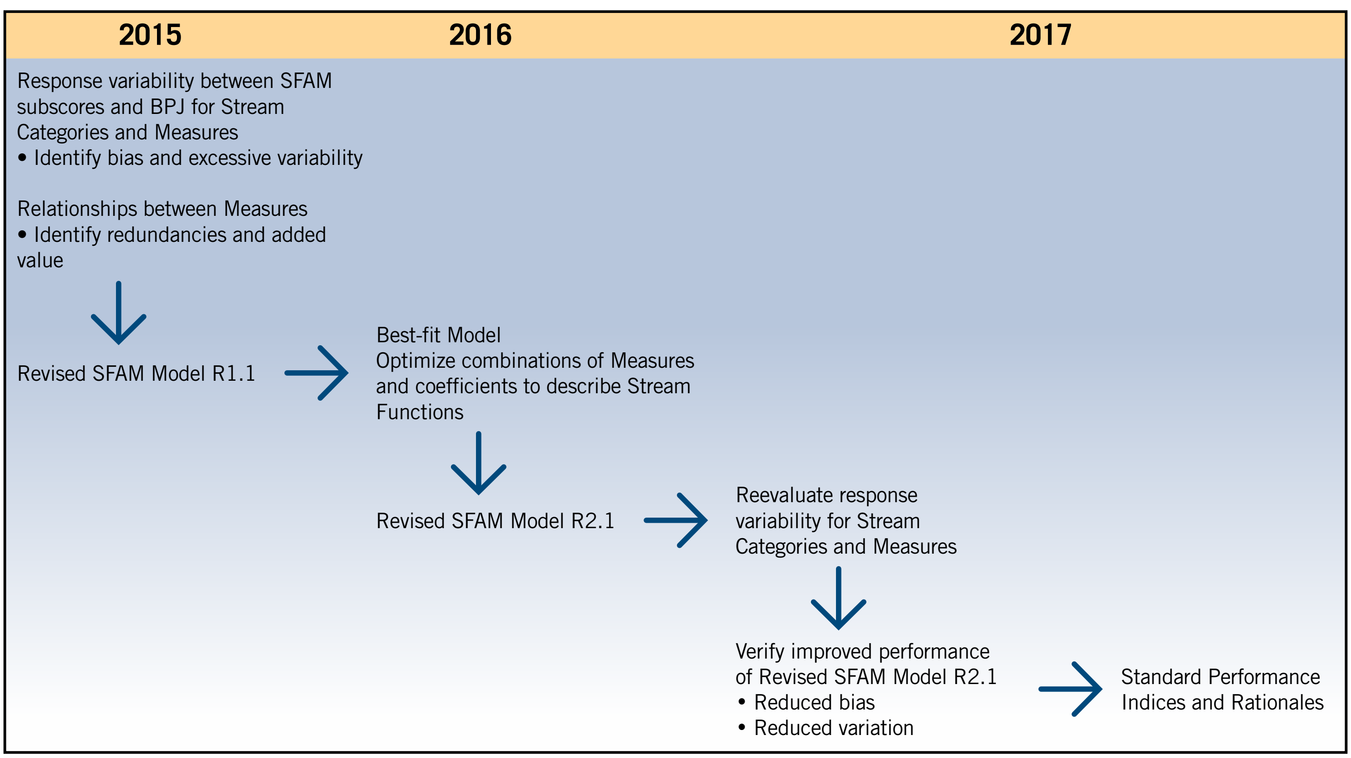


Figure 2.3 Procedure for Statistical Analysis

Objective 1 – Response Variability and Value-added Parameters

Method

Three separate evaluations were conducted to identify which stream measures are most predictive, or best explain, response variability, as tested against BPJ of stream function, and to identify value added parameters. First, response variability was broadly evaluated for each function subscore according to stream categories (e.g., flow duration (perennial/intermittent/ ephemeral); season (fall/spring); slope (high/medium/low); region of the state (east/west); and floodplain status (present/absent)). Second, response variability was assessed more narrowly for each individual stream measure for each function subscore (e.g. overbank flow for Surface Water Storage). Third, response variability was assessed against supplementary measures–evaluated in the field but not included in the initial model—and existing measures associated with the corresponding function subscore to identify potential value-added parameters. These evaluations were conducted on the actual function outputs (subscores), and on subscores which were adjusted using characteristics of streams that contextualized functional expectations (e.g., flow duration class, ecoregion, presence or absence of a floodplain). Respectively, “without context” and “with context.”

For all components of this objective, response variability was evaluated using residuals. Residuals were calculated as the difference between the BPJ score and the modeled (SFAM) score for each stream function subscore (residual = BPJ score – SFAM score). Positive residuals indicate the model is underpredicting BPJ (i.e. the model score is too low), and negative residuals indicate the model is overpredicting (i.e. the model score is too high). We considered function subscores with residuals greater than 2 or less than -2 as indicators of a poor fit between the model and BPJ.

Results

Response Variability for Stream Classifications

Most function subscores displayed some degree of overprediction or underprediction. For most stream categories, there was not obvious evidence of bias or excessive variation. However, floodplain presence or absence and flow duration class did show clear signs of bias for several stream functions. The appearance of bias and excessive variation differed between the model without context, or raw function score, and the model with context for several stream functions. The results of the model evaluation regarding overprediction or underprediction of the BPJ score for each function subscore are summarized in **Table 2.3**.

Response Variability for Stream Measures

The model scores were positively correlated with BPJ scores, indicating some degree of agreement between the SFAM model and BPJ for all stream functions. However, for several stream functions there was a linear relationship between model scores and residuals, indicating that model fit could be improved. For most stream functions, at least one measure was overemphasized or underemphasized. The measures that were overemphasized or underemphasized differed between the model score without context and the model scores with context for at least some stream functions. A summary of the measures that contribute to an ideal fit, and the measures that were overemphasized or underemphasized for each subscore, is provided in **Table 2.4**.

Response Variability for Value-added Parameters

For most stream functions, at least one measure was identified as value-added. Supplementary variables evaluated during field testing, especially wetland plants, were often identified as value- added parameters. Measures identified as possible value-added parameters for each stream function subscore are summarized in **Table 2.5**.

Objective 2 – Correlation Analysis

Method

Two variables with strong polychoric correlation can be interpreted as providing overlapping or redundant information. Polychoric correlations greater than 0.75 or less than -0.75 were considered strong correlations. A strong positive polychoric correlation indicates that when one variable takes on higher values, the other variable also tends to take on higher values. A strong negative polychoric correlation indicates that when one variable takes on higher values, the other variable tends to take on lower values. A polychoric correlation of 1 or -1 indicates perfect correlation and complete redundancy between values.

Results

For most stream function measures, there were no strong correlations. Only a few strong correlations were identified. A summary of measures that showed a strong correlation is provided in **Table 2.6**.

Recommendations from diagnostic statistical analysis

Results from statistical analysis indicated that agreement between BPJ and model scores (outputs) could be improved by eliminating bias, reducing variation, and improving overall model fit. Recommended approaches included:

- Modifying coefficients for existing model inputs. In the initial SFAM model, function subscores are calculated by averaging all model inputs (measures) and multiplying them by a constant; thus, each input measure has equal weight and coefficients.
- Including an “interaction” in calculating function subscores. An interaction means that the influence of one variable changes depending on the value of another input (e.g., floodplain presence; flow duration).
- Eliminating redundant or non-value-added measures.
- Including additional parameters (measures).

External Peer-review (2015-2016)

Several people with expertise in stream science, restoration practice, and mitigation conducted an extensive peer-review of SFAM (**Appendix A**), including field application in Oregon by a subset of reviewers. Supported primarily through contracts to ensure comprehensive evaluation, review objectives were similar to those for field testing, but with a particular focus on usability, applicability, credibility, and relevance of measures. Reviewers were provided with an overview of SFAM purpose, development history, and components, and asked to review drafts of the Workbook, User Manual, and Map Viewer. Specific evaluation questions in each focus area guided their review, and facilitated analysis and subsequent revision stemming from the reviews.

Field Testing, Statistical Analysis, and Peer-review Outcomes

- Removed four function measures: Richards-Baker Flashiness Index, Non-native Aquatic Animal Species, Benthic Index of Biotic Integrity, and Beaver (**Table 2.1**).
- Replaced function measure Dominant Vegetation with Wetland Vegetation (supplementary measure) protocol.

- Revised categorical bins for the Riparian Buffer and Wood function measures.
- Identified several measures that could be improved to better meet criteria.
- Considered modifying coefficients for model inputs (measures), by weighting measures that result in function subscores, rather than averaging them equally as in initial model.
- Reconsidered, conceptually, how to account for context (characteristics of streams adjusting functional expectations), which led to the removal of “with context” calculations.
- Provided a clean, quality-assured data set from the field study, as well as established statistical evaluation protocols.
- Identified significant areas to improve method usability, including method documents (i.e., User Manual, Workbook) and data availability through the SFAM Map Viewer.
- Recognized that the method contains an inconsistent mix of effort and precision in measure data collection, presenting opportunities to streamline the level of effort to better fit the precision needed, and/or to make better use of the precise data collected.
- Corroborated that scaling the assessment area on project length and bankfull width represented the appropriate “reach” for method application.
- Corroborated the identified critical need for standard performance indices and standardized thresholds to support meaningful SFAM outputs.

Further details on the development history of measures and significant revisions can be found in **Sections 4** and **5**, respectively.

2.4 Statistical Analysis (Phase II)

Following the removal, replacement and revision of SFAM measures resulting from Phase I efforts, further statistical analyses were initiated (2016-2017) (**Figure 2.3**). Although the initial SFAM model used categorical scoring for most function measure outputs, actual data were collected for all function and supplementary measures during the field study. Thus, revisions to the model could be tested statistically using the existing data as inputs and recalculating outputs for various model revisions.

Method

We undertook iterative data analysis of revised models with the following objectives:

Objective 1: Develop best-fit models using regression techniques for each stream function output in comparison to BPJ with combinations of measures.

Objective 2: Evaluate response variability between the revised SFAM models and BPJ.

Iterations of best-fit modeling were carried out using different combinations of measures and presence or absence of a floodplain, for each function subscore (e.g., Surface Water Storage, Maintain Biodiversity, etc.). Response variability was evaluated using residuals, as previously described (**Section 2.3**). For each function subscore residuals were plotted for five stream classifications: flow duration; season of data collection, slope, east/west of the Cascade Mountains, and presence or absence of floodplain. The data were evaluated with outputs from the SFAM model “without context” (i.e. not adjusted for functional expectation).

Plot and summary statistics of the residuals were used to evaluate biases and excessive variation in the model. A bias means a tendency for the average residual to be greater than or less than 0, reflecting poor accuracy of the model (underprediction or overprediction). Excessive variation occurs when a large proportion of residuals are more than 2 units away from the average residual, reflecting poor precision of the model. The summary statistics tables were used to inform modifications to the model.

A limitation of this evaluation is that bias and excessive variation, as estimated by the average residual and standard deviation, may not be very precise, especially for stream categories with a small number of observations. Additionally, the interpretation of residuals relies on the assumption that the BPJ score is “true.” There is uncertainty associated with any qualitative BPJ score; however, BPJ is considered to provide the most accurate assessment of stream function, as defined by SFAM, available.

Results

For the ‘best-fit’ revised model, for most stream categories, there was no obvious evidence of bias, indicated by average residuals within +/- 2 (**Table 2.7**). These results suggest the desired level of accuracy has been achieved for the majority of stream categories. In comparison to the initial draft SFAM, bias was reduced for many stream categories in the revised SFAM, and the model no longer tends to underpredict BPJ for any stream functions (**Table 2.8**). The variation of residuals, estimated by standard deviation, ranged between 1.5 and 2.5 for all stream categories and did not change substantially from the initial SFAM model evaluation, suggesting the precision of the model is unchanged.

Iterative model revisions

To evaluate modifying coefficients for model inputs (measures), rather than calculating function subscores by averaging model inputs equally, we conducted iterative analysis on all function subscore (“no context”) calculations. These were based on the evaluation of residual analysis and best-fit modeling, input from reviewers, and clarification of the objective and definitions of the function subscores that these calculations (formulas for each function subscore calculation) represent. This model improvement was achieved by recalculating the outputs from the field study data iteratively to seek the best fit with BPJ of all study sites, using the residuals as described. This is how we arrived at the best-fit model.

Statistical analysis outcomes

- Removed three function measures: Temperature Exceedance, Geomorphic Successional Stage, and Conifers (Plant Composition submeasure) (**Table 2.1**).
- Revised categorical bins for the function measure Cover.
- Modified coefficients for model inputs (measures) for several of the function subscores, rather than averaging them equally.
- Recognized that some remaining revisions and improvements would be achieved through developing the standard performance indices for function measures.
- Recognized that it was more scientifically appropriate to account for some aspects of stream context (characteristics of streams that affect functional expectation) at the function measure level where possible, rather than at the function subscore level per our original concept.

2.5 Standard Performance Indices for Function Measures

To provide ecological meaning to scoring the function measures included in the SFAM model, standard performance indices (range of expected performance) were developed (2017). Such performance indices facilitate standardization of individual measure—and thus function—scores to a common scale, which is important for calculating function subscores, as the measures are used additively in the function formulas (Independent Multidisciplinary Science Team [IMST], 2007, 2009). Measure standardization also allows comparison of SFAM scores.

Because the primary sensitivity of SFAM lies in the cutoffs, or thresholds used to score each of the function measures, we extended extensive effort in developing scientifically-based standard performance indices and thresholds. These are the basis of SFAM output interpretation and the power of the method.

Context is important to interpreting many of the measures and thresholds. To assure that function measure scores are evaluated against appropriate standard performance indices where factors such as stream size or ecoregion may affect expected performance, standard performance indices of some function measures are stratified on these attributes, where there is data-driven support to do so. For example, when assessing natural cover over a stream, differences would be expected based upon stream width and geographic location (i.e. east/west of the Cascades). This was supported in the data and literature used to develop the standard performance index for natural cover, which is stratified by both stream width and geographic location of the subject stream.

A detailed development description and rationale for each measure, including standard performance index development, threshold establishment, and stratification is provided in **Section 4**, and forms the bulk of this document.

Standard Performance Indices Development Outcomes

- Removed one function measure: Vegetation on Bars (**Table 2.1**)
- Added one function measure: Embeddedness
- Improved data collection protocols for many measures, to coincide where possible with the data collection protocols used to generate standard performance indices
- Replaced categorical scoring of function measures with continuous data for all but three measures (Floodplain Exclusion, Overbank Flow, Wetland Vegetation), optimizing use of the data collected and sensitivity of the method
- Developed transparent standard performance indices for all function measures

2.6 Pilot Testing & Final Peer Review

Based on the above described input and efforts, extensive changes were made to improve usability of the method, which is reflected in each of the SFAM components. This includes improved descriptions of both field- and office-based measures, addition of operational definitions for specific stream features, expanded guidance on the data collection protocols and use of the web-based mapping tool, and development of a field work "order of operations" to improve field application efficiency. Additionally, many improvements were made to the SFAM Map Viewer tool, and the organization of the Workbook and User Manual to maximize efficiency of application.

Having an extensively revised and improved method and having completed standard performance indices which are foundational to the scientific underpinning of the method, we initiated a final phase of input through pilot testing and external peer-review.

Pilot Testing (2018)

Conducted collaboratively with field staff from the Oregon Departments of Transportation, Fish and Wildlife, and State Lands, and the U.S. Army Corps of Engineers – Portland District (**Appendix A**), there were two aspects to the pilot project. The first, focused on method usability, sought to answer the question "Are you able to apply SFAM using the draft User Manual, Workbook, and Map Viewer with no training?" The second, focused on credibility of SFAM outputs, addressed the question "With training, do you believe that when the method is applied accurately that the outputs for the functions and values make sense?"

Key objectives for pilot testing by agency staff included:

- Providing feedback regarding the feasibility, time, cost, benefits and drawbacks of the draft method to meet both administrative and environmental objectives, and
- Recommendations for improvements.

To familiarize testers with SFAM prior to application, we provided an overview presentation on SFAM components. Method application was then conducted by teams of testers, on different streams, over a period of several weeks. Following this, we provided a presentation on SFAM development history and scientific underpinning in preparation for in-person training. In-person training comprised a half day in the field and a half day in the office, and covered both field and office components of SFAM. For both aspects of the pilot, testers were provided with specific evaluation questions that guided their review, and facilitated analysis and subsequent revision stemming from the reviews.

External Peer-review (2018)

Several people having expertise in stream science, restoration practice, and mitigation peer- reviewed the revised SFAM (**Appendix A**). Review objectives were again focused on usability, applicability, credibility and relevance of measures. Consideration of method improvements was an additional objective for those who had provided Phase I review. Reviewers were provided with revised drafts of the Workbook, User Manual, and Map Viewer. Specific evaluation questions in each focus area guided their review, and facilitated analysis and subsequent revision stemming from the reviews.

Pilot Testing and Peer-review Outcomes

- Identified specific areas where additional clarity was needed to improve method usability, efficiency, and applicability.
- Added one function measure: Fish Passage Barriers.
- Revised Unique Habitat Features value measure and scoring.
- Determined additional revisions would be necessary for application in tidal channels.
- Illustrated the importance of training to promote efficient and appropriate application.
- Indicated that the method has been greatly improved.

2.7 SFAM Map Viewer

The Oregon Rapid Wetland Assessment Protocol (ORWAP) and SFAM Map Viewer (Map Viewer) is an online, publicly-accessible data viewing tool created to facilitate collection of necessary data for an ORWAP or an SFAM assessment. The tool is hosted on the Oregon State University Library's Oregon Explorer website and is maintained by the Institute for Natural Resources and the Oregon Department of State Lands (DSL), and was developed with grant support from the USEPA, Region 10. An ORWAP Map Viewer was originally created in 2007, but since SFAM uses many of the same data layers and features, the combined tool was created to minimize ongoing maintenance costs while allowing the user to filter data layers depending on the type of assessment being conducted. The Map Viewer can be used for viewing and overlaying statewide spatial data sets, generating a report of summary information for a particular site, and creating basic site maps. The Map Viewer has proved helpful in minimizing the amount of time a user spends searching various data sources to answer assessment questions and improving the repeatability of ORWAP, and we anticipate the same benefits for SFAM.

The primary functions of the Map Viewer are to (1) provide a publicly-accessible one-stop-shop for relevant data, (2) ensure that users are evaluating consistent, verified data sets to answer questions, and (3) to provide users who do not have the software or skills to perform Geographic Information System

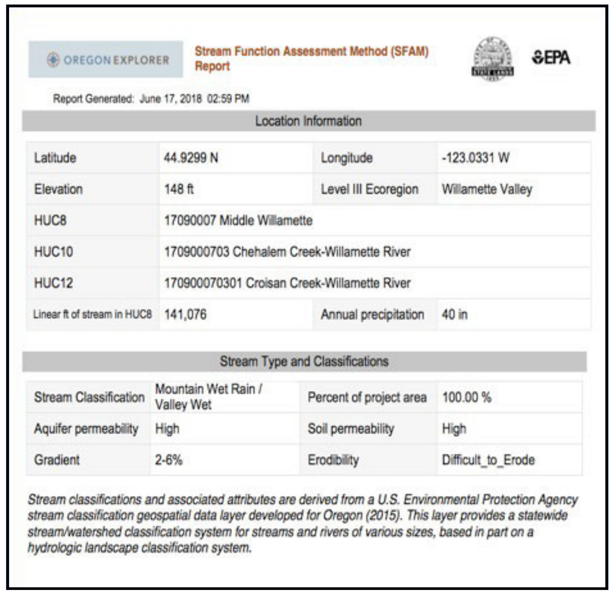
(GIS) queries on their own with online GIS capabilities. There are some assessment questions in SFAM for which additional data sources can be considered, but the Map Viewer provides all layers that are minimally required for determining answers to the value measures and describing site context.

Several criteria were established prior to determining which spatial data layers were appropriate to display within the Map Viewer for SFAM. Each data layer was evaluated against the following criteria:

- **Appropriate spatial extent:** The data layer provides information for the entire state.
- **Transparent/verifiable:** The data generation methods are clear and the data is gathered by an objective source using sound (replicable) scientific methods.
- **Relevant:** Data have a clear and direct connection to informing the assessment of functions and values of a stream system.
- **Reliable:** Data were generated by an organization that uses a clear quality assurance and quality control process including periodic updates.

Some of the available layers are intended to help the user understand the landscape context of their project area (e.g., hydrography, precipitation, soils, etc.), while others are required for answering assessment questions (e.g., water quality data, zoning, Essential Salmonid Habitat, etc.).

The Map Viewer generates a site-specific report (SFAM Report) providing important summary information about the project area, which is used to complete some SFAM assessment questions. An example SFAM Report is shown in **Figure 2.4**. There are two different methods used to query information for the SFAM Report: a polygon-based query and a centroid-based query. The polygon-based query pulls data from within a polygon that is drawn around a specific site or study area. The purpose of polygon-based data queries is to retrieve data that describes characteristics of that area (i.e. spatial data features that are contained within, or intersected by, the drawn polygon). Information in the SFAM Report that results from the polygon-based query includes stream classification information, soil characteristics, and water quality impairments. The centroid-based query pulls data from a specific radial distance from the center of the drawn polygon. The purpose of the centroid-based data query is to retrieve data that describes contextual characteristics of the area surrounding the site (i.e. spatial data features that are present within a certain distance from a site). Information in the SFAM Report that is centroid-based includes the location details, rare species scores (occurrences are queried at the project location up to the HUC 6), Essential Salmonid Habitat (queried within the HUC 12), Important Bird Area (queried within 2 miles), and special protected areas (within 300 ft).



OREGON EXPLORER | Stream Function Assessment Method (SFAM) Report | EPA

Report Generated: June 17, 2018 02:59 PM

Location Information

Latitude	44.9299 N	Longitude	-123.0331 W
Elevation	148 ft	Level III Ecoregion	Willamette Valley
HUC8	17090007 Middle Willamette		
HUC10	1709000703 Chehalem Creek-Willamette River		
HUC12	170900070301 Croisan Creek-Willamette River		
Linear ft of stream in HUC8	141,076	Annual precipitation	40 in

Stream Type and Classifications

Stream Classification	Mountain Wet Rain / Valley Wet	Percent of project area	100.00 %
Aquifer permeability	High	Soil permeability	High
Gradient	2-6%	Erodibility	Difficult_to_Erode

Stream classifications and associated attributes are derived from a U.S. Environmental Protection Agency stream classification geospatial data layer developed for Oregon (2015). This layer provides a statewide stream/watershed classification system for streams and rivers of various sizes, based in part on a hydrologic landscape classification system.

Figure 2.4 Example SFAM Report

A description of all SFAM-relevant data layers included in the Map Viewer is provided in ***Appendix C***.

2.8 Tables

Table 2.1 Displaying Initial SFAM Function Measures and Revisions for the Current Function Measures

<table>
<tr><th colspan="2">SFAM Initial</th><th>SFAM Current</th></tr>
<tr><td colspan="2">Floodplain Exclusion</td><td>Floodplain Exclusion</td></tr>
<tr><td colspan="2">R-B Flashiness Index</td><td>-removed-</td></tr>
<tr><td colspan="2">Non-Native Aquatic Species</td><td>-removed-</td></tr>
<tr><td colspan="2">Side Channels</td><td>Side Channels</td></tr>
<tr><td colspan="2">Benthic Index of Biotic Integrity (BIBI)</td><td>-removed-</td></tr>
<tr><td colspan="2">Temperature Exceedance</td><td>-removed-</td></tr>
<tr><td colspan="2">Entrenchment</td><td>Incision</td></tr>
<tr><td colspan="2">Cover</td><td>Cover</td></tr>
<tr><td rowspan="4">Plant Composition</td><td rowspan="4">noxious weeds
native woody vegetation large trees
native coniferous trees</td><td>Invasive Vegetation</td></tr>
<tr><td>Native Woody Vegetation</td></tr>
<tr><td>Large Trees</td></tr>
<tr><td>-removed-</td></tr>
<tr><td colspan="2">Dominant Vegetation</td><td>Wetland Vegetation</td></tr>
<tr><td colspan="2">Geomorphic Successional Stage</td><td>-removed-</td></tr>
<tr><td colspan="2">Overbank Flow</td><td>Overbank Flow</td></tr>
<tr><td colspan="2">Lateral Migration</td><td>Lateral Migration</td></tr>
<tr><td colspan="2">Riparian Buffer</td><td>Vegetated Riparian Corridor Width</td></tr>
<tr><td colspan="2">Wood</td><td>Wood</td></tr>
<tr><td colspan="2">Vegetation on Bars</td><td>-removed-</td></tr>
<tr><td colspan="2">Bank Armoring</td><td>Bank Armoring</td></tr>
<tr><td colspan="2">Bank Stability</td><td>Bank Erosion</td></tr>
<tr><td colspan="2">Channel Bed Variability</td><td>Channel Bed Variability
wetted width
thalweg depth
-added-</td></tr>
<tr><td colspan="2">Beavers</td><td>-removed-</td></tr>
<tr><td colspan="2"></td><td>Embeddedness
-added-</td></tr>
<tr><td colspan="2"></td><td>Fish Passage Barriers
-added-</td></tr>
</table>

** Measures in blue font replaced initial measures.*

Table 2.2 SFAM Grouped Functions and Eleven Specific Functions/Values

Function Group	Specific Functions/Values
Hydrologic	Surface Water Storage Sub/Surface Transfer Flow Variation
Geomorphic	Sediment Continuity Substrate Mobility
Biologic	Maintain Biodiversity Create and Maintain Habitat Sustain Trophic Structure
Water Quality	Nutrient Cycling Chemical Regulation Thermal Regulation

Table 2.3 Summary of Model Fit to BPJ by Stream Categories

Context	SFAM Subscore	Model Overpredicts BPJ	Model Underpredicts BPJ	Model Results are Inconsistent
No context	Surface water storage	--	Floodplain absent	--
	Sub-surface transfer	--	Floodplain absent	--
	Flow variation	All categories	--	--
	Sediment continuity	All categories	--	--
	Sediment mobility	--	--	All categories
	Maintain biodiversity	Intermittent and perennial	Ephemeral	--
	Create and maintain habitat	Intermittent and perennial	Ephemeral	--
	Sustain trophic structure	--	Ephemeral	Intermittent and perennial
	Nutrient cycling	All categories	--	--
	Chemical regulation	All categories	--	--
	Thermal regulation	All categories	--	--
With context	Surface water storage	--	Floodplain absent	--
	Sub-surface transfer	--	All categories	--
	Flow variation	--	--	All categories
	Sediment continuity	All categories	--	--
	Sediment mobility	--	--	All categories
	Maintain biodiversity	--	Ephemeral	Intermittent and perennial
	Create and maintain habitat	--	Ephemeral	Intermittent and perennial
	Sustain trophic structure	--	Ephemeral	Intermittent and perennial
	Nutrient cycling	All categories	--	--
	Chemical regulation	All categories	--	--
	Thermal regulation	All categories	--	--

Notes:
-- = not applicable
BPJ = best professional judgment

Table 2.4 Summary of Model Performance by Stream Measure

Context	SFAM Subscore	Overemphasized Measures (Negative Trend)	Underemphasized Measures (Positive Trend)	Measures Contributing to an Ideal Fit (No Significant Trend)
No context	Surface water storage	OBFlow, Entrench, Exclusion, SideChan	--	Beaver
	Sub-surface transfer	DomVeg (with FloodPlain), OBFlow, Beaver (with FloodPlain), Flow Duration	--	BedVar, SideChan
	Flow variation	--	--	BedVar, Impound, Flow Duration
	Sediment continuity	Entrench, LatMigr	--	BankStab, GeoSuc, Armor
	Sediment mobility	BarVeg	--	Flow Duration, BedVar
	Maintain biodiversity	BedVar, Wood, NoxWeed, MatTree, Conifer	DomVeg	SideChan, NNAquSpp, WoodyVeg
	Create and maintain habitat	Conifer, MatTree, WoodyVeg	Beaver	Exclusion, BarVeg, BedVar, SideChan, Wood
	Sustain trophic structure	Conifer, NoxWeed, Cover, WoodyVeg	DomVeg	OBFlow
	Nutrient cycling	BedVar, Cover	--	RipBuff, DomVeg, OBFlow
	Chemical regulation	OBFlow, RipBuff	--	BedVar, DomVeg
	Thermal regulation	TempEx	Cover	Flow Duration
With context	Surface water storage	OBFlow, Entrench, Exclusion, SideChan	--	Beaver
	Sub-surface Transfer	Flow Duration	--	DomVeg, OBFlow, Beaver, BedVar, SideChan
	Flow variation	--	--	BedVar, Impound, Flow Duration
	Sediment continuity	Entrench, LatMigr	--	BankStab, GeoSuc, Armor
	Sediment mobility	BarVeg	--	Flow Duration, BedVar
	Maintain biodiversity	Conifer	--	BedVar, Wood, SideChan, NNAquSpp, NoxWeed, WoodyVeg, MatTree, DomVeg
	Create and maintain habitat		Beaver	Conifer, MatTree, WoodyVeg, Wood, Exclusion, BarVeg, BedVar, SideChan
	Sustain trophic structure	Conifer, NoxWeed	--	OBFlow, DomVeg, Cover, WoodyVeg
	Nutrient cycling	BedVar, OBFlow	--	RipBuff, Cover, DomVeg
	Chemical regulation	OBFlow, RipBuff	--	BedVar, DomVeg
	Thermal regulation	TempEx	Cover	Flow Duration+A2:E23

Note:

-- = not applicable

Table 2.5 Summary of Possible Value-added Parameters

Subscore	Possible Value-added Parameters
Surface water storage	Wetl_plnt when floodplain is absent
	Macros present when floodplain is absent
	DwnFP when floodplain is present
Sub-surface transfer	Macros present when floodplain is absent,
	Soil Permeability when floodplain absent
Flow variation	DwnFP when floodplain is present
Sediment continuity	Wetl_plnt, Macros, EPT_taxa
Substrate mobility	--
Maintain biodiversity	Wetl_plnt, % Slope, Macros, NonAFish
Create and maintain habitat	Wetl_plnt, % Slope, Macros
Sustain trophic structure	Wetl_plnt, % Slope, Macros, EPT_taxa, Temp_Imp
Nutrient cycling	Wetl_plnt, % Slope
Chemical regulation	Wetl_plnt, Macros
Temperature regulation	TempImp

Note:

-- = not applicable

Table 2.6 Summary of Measures with Strong Correlations

Subscore	Strong Correlations
Surface water storage	--
Sub-surface transfer	Beaver and Flow Duration (0.82)
Flow variation	--
Sediment continuity	LatMigr and GeoSuc (-0.83), Armor and GeoSuc (-0.82)
Substrate mobility	--
Maintain biodiversity	WoodyVeg and Wood (0.89), Conifer and NoxWeed (0.81)
Create and maintain habitat	WoodyVeg and Wood (0.89)
Sustain trophic structure	Conifer and NoxWeed (0.81), Cover and WoodyVeg (0.79)
Nutrient cycling	--
Chemical regulation	--
Temperature regulation	--

Note:

-- = not applicable

Table 2.7 Summary of Change in SFAM Model Fit to BPJ

Context	SFAM Subscore	2016 SFAM R1.2		Change from 2015 SFAM	
		Overall Residual Average	Overall Residual Standard Deviation	Change in Distance of Overall Residual Average from Zero	Change in Overall Residual Standard Deviation
Without context	Surface water storage	0.71	2	-0.33	-0.30
	Sub-surface transfer	0.63	2.16	0.02	0.34
	Flow variation	-0.51	2.29	-1.38	0.62
	Sediment continuity	-2.66	1.96	0.00	0.00
	Sediment mobility	-0.15	2.31	-0.04	0.23
	Maintain biodiversity	0.28	2.02	-0.19	-0.10
	Create and maintain habitat	-0.19	2.1	-0.41	0.01
	Sustain trophic structure	0.29	1.82	-0.30	-0.59
	Nutrient cycling	-1.23	2.07	0.20	0.01
	Chemical regulation	-1.28	2.17	-0.16	0.01
	Temperature regulation	-0.5	1.86	-0.97	-0.04

Table 2.8 Summary of Change in SFAM Bias Compared to BPJ by Stream Categories with Revised Model

Context	SFAM Subscore	2015 SFAM Model Overpredicts BPJ	2016 SFAM R1.2 Model Overpredicts BPJ	2015 SFAM Model Underpredicts BPJ	2016 SFA<R1.2 Model Underpredicts BPJ
Without context	Surface water storage	N/A	N/A	Floodplain absent	N/A
	Sub-surface transfer	N/A	N/A	Floodplain absent	N/A
	Flow variation	All classifications	Ephemeral	N/A	N/A
	Sediment continuity	All classifications	All classifications	N/A	N/A
	Sediment mobility	N/A	Ephemeral	N/A	N/A
	Maintain biodiversity	Intermittent and perennial	Ephemeral	Ephemeral	N/A
	Create and maintain habitat	Intermittent and perennial	Ephemeral	Ephemeral	N/A
	Sustain trophic structure	N/A	Ephemeral	Ephemeral	N/A
	Nutrient cycling	All classifications	Ephemeral, High Slope, and West Region	N/A	N/A
	Chemical regulation	All classifications	Ephemeral, High Slope, and Floodplain Absent	N/A	N/A
	Temperature regulation	All classifications	High Slope	N/A	N/A

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3.0 Ecological Functions & Values

Stream functions are the dynamic and interrelated physical, chemical and biological processes that create and maintain the character of a stream and the associated riparian system, and determine the flux of energy, materials and organisms through or within a stream system. Functions are distinct from conditions, which are the qualities and structure of a stream ecosystem at a given point in time. A naturally functioning stream ecosystem is inherently stable and resilient to disturbance because the functions at play are generally interrelated, responsive, and unconstrained. Stream values are the ecological and societal benefits that the stream functions provide.

3.1 Thematic Groups & Specific Functions

Four functional groups provide the basis for the function-based assessment for streams:

1. **Hydrologic functions**: Include movement of water through the watershed and the variable transfer and storage of water among the stream channel, its floodplain, and associated alluvial aquifer.
2. **Geomorphic functions**: Encompass hydraulic and sediment transport processes that generate variable forces within the channel and the variable input, transfer and storage of sediment within the channel and adjacent environs that are generally responsible for channel form at multiple scales.
3. **Biologic functions**: Include processes that result in maintenance and change in biodiversity, trophic structure, and habitat within the stream channel.
4. **Water quality functions**: Encompass processes that govern the cycling, transfer, and regulation of energy, nutrients, chemicals, and temperature in surface and groundwater, and between the stream channel and associated riparian system.

Within these broad groups, a suite of 11 stream functions are identified (**Table 3.1**). The 11 functions were modified from a suite of functions identified through an expert workshop and extensive literature review, using the work of Fischenich (2006) as a foundation. To ensure that functions were categorized and described sufficiently for application to compensatory mitigation, criteria were developed to guide the selection and definition of functions. Stream functions were evaluated against the following criteria:

1. **Relevance:** function assessed is relevant to impacts resulting from proposed actions and is relevant to a broad spectrum of native species across varying stream types and spatial scales.
2. **Utility:** function assessed is practical for mitigation accounting because it is practically measurable and quantifiable, responsive to actions, and predictable.
3. **Multi-functionality:** function assessed represents the interrelated character of stream functions and is likely to contribute to positive change in other functions and influence overall stream system health.

Table 3.1 Eleven Stream Functions

Function Group	Specific Functions/Values
Hydrologic	Surface Water Storage Sub/Surface Transfer Flow Variation
Geomorphic	Sediment Continuity Substrate Mobility
Biologic	Maintain Biodiversity Create and Maintain Habitat Sustain Trophic Structure
Water Quality	Nutrient Cycling Chemical Regulation Thermal Regulation

Although values differ from functions, the values identified through this process correspond to the same 11 categories used for functions (**Figure 3.1**). The difference between the functions and values lies in how they are expressed. While a function is a description of process, values are determined by (a) the opportunity to provide a particular function, and (b) the local significance of that function (Adamus, 1983). In a practical manner, a function can either be expressed or not expressed at a given site, while a value is the context of that function in the broader landscape. Assessment of values often differs between physical/chemical functions and biological functions. A higher value is often assigned to hydrologic and water quality functions when natural processes have been altered upstream, such that the given site has greater opportunity to moderate their delivery or expression downstream. In contrast, a higher value is assigned for biological functions when hydrology, geomorphology, and water quality is not impaired since the health of biota is ultimately dependent on these underlying processes.

3.2 Function & Value Definitions

a) Surface Water Storage

The surface water storage (SWS) function reflects the ability of a site to temporarily store surface water in a relatively static state, generally during high flow. This function is important for regulating discharge, replenishing soil moisture, providing pathways for fish and invertebrate movement, creating low velocity habitat and refugia, and extending the hydrologic contact time necessary for certain biogeochemical processes.

Opportunity would be higher if water from the contributing watershed is running off quickly and there are no upstream impoundments. Significance would be higher if there is infrastructure or crops downstream that are or could be damaged by flooding.

b) Sub/Surface Transfer

The sub/surface transfer (SST) function represents the ability of a site to transfer water between surface and subsurface environments, often through the hyporheic zone. This function provides aquifer recharge, maintains base-flow, allows hyporheic exchange of nutrients and chemicals, moderates in-channel flows, and maintains soil moisture.

Opportunity would be higher if the contributing watershed otherwise lacks capacity for water transfer between surface and subsurface environments. Significance would be higher if groundwater recharge is important in or near the project area.

c) Flow Variation

The flow variation (FV) function represents daily, seasonal and/or inter-annual variation in flow, which provides variability in the stream energy driving channel dynamics. Such variability provides environmental cues for life history transitions and provides temporal habitat variability. It also drives redistribution and sorting of sediment and causes differential deposition.

Opportunity would be higher if water comes into the project area during limited time frames, and upstream flow variation is low. Significance would be higher if there are species in the riparian area or downstream that are dependent on the benefits that flow variation provides and there are habitat limitations downstream. Significance would be lower if there are impoundments downstream.

d) Sediment Continuity

The sediment continuity (SC) function represents a balance between transport and deposition of sediment such that there is no net erosion (degradation) or deposition (aggradation) within the channel. Continuity of sediment maintains channel character and the associated habitat diversity, provides sediment source and storage for riparian and aquatic habitat succession, and maintains channel equilibrium.

Opportunity would be higher if sediment is not in balance upstream or upslope. This could mean that the stream reach is receiving too much sediment or not enough sediment. Significance of balanced sediment through the project area would be higher if the downstream floodplain area lacks infrastructure, the reach is not easily erodible, and there are no impoundments downstream.

e) Substrate Mobility

The substrate mobility (SM) function represents regular movement of the channel bed substrate. Movement of substrate provides sorting of sediments, mobilizes/flushes fine sediment, creates and maintains hydraulic diversity, and creates and maintains habitat.

Opportunity would be higher if there is either unsorted or uniform substrate being delivered into the project area. Sorting within the project reach would benefit downstream habitats, increasing significance, if there are habitat designations, rare species, or unique habitat features nearby dependent on certain substrate characteristics.

f) Maintain Biodiversity

The maintain biodiversity (MB) function represents the maintenance of a variety of species, life forms of a species, community compositions, and genetics. Biodiversity provides species and community resilience in the face of disturbance and disease as well as a full spectrum of trophic resources and balance of resource use (through interspecies competition).

Opportunity would be higher if a diverse array of species can access and utilize the site from surrounding habitats upstream, downstream, and adjacent to the project area. Significance would be higher if the area/ surrounding area contains habitat designations, rare species, or unique habitat features.

g) Create and Maintain Habitat

The create and maintain habitat (CMH) function represents the ability of the site to provide the suite of physical, chemical, thermal, and nutritional resources necessary to sustain organisms. Habitat includes both in-channel habitat, defined largely by depth, velocity, and substrates, and riparian habitat, defined largely by vegetative structure.

Opportunity would be higher if the project area receives the suite of physical, chemical, thermal, and nutritional resources needed to sustain organisms. Significance would be higher if processes in the project area are able to reach and benefit downstream and adjacent habitats.

h) Sustain Trophic Structure

The sustain trophic structure (STS) function represents the production of food resources necessary to sustain all trophic levels including primary producers, consumers, prey species, and predators. Trophic structure provides basic nutritional resources for aquatic resources, regulates the diversity of species and communities, and promotes growth and reproduction of biotic communities across trophic levels.

Opportunity would be higher if the project area is connected to natural habitats. Significance would be higher if nutritional resources produced or flowing through the project area are able to reach and benefit downstream and adjacent habitats.

i) Nutrient Cycling

The nutrient cycling (NC) function represents the transfer and storage of nutrients from environment to organisms and back to environment. This function provides basic resources for primary production, regulates excess nutrients, and provides sink and source areas for nutrients.

Opportunity would be higher if waters are impaired or if conditions in the contributing basin result in increased transport of nutrients to the project area. Significance is higher if waters flow to areas used as drinking water sources or those that provide important habitat to fish, invertebrate, amphibian, and reptile species.

j) Chemical Regulation

The chemical regulation (CR) function represents the ability to moderate chemicals in the water. Moderation of chemicals limits the concentration of beneficial and detrimental chemicals in the water.

Opportunity would be higher if waters are impaired or if conditions in the contributing basin result in increased transport of chemicals to the project area. Significance is higher if waters flow to areas used as drinking water sources or those that provide important habitat to fish, wildlife, or plant species.

k) Thermal Regulation

The thermal regulation (TR) function represents the ability to moderate water temperature. It limits the transfer and storage of thermal energy to and from streamflow and the hyporheic zone.

Opportunity would be higher if the water temperature coming from upstream can be maintained through the project area. This is more likely to occur when the riparian area upstream is more natural and continuous, and the contributing watershed has less impervious surfaces. Significance is higher if there are species downstream that benefit from cooler water.

3.3 Function & Value Scoring Formulas

Table 3.2 Formulas for Each of the Eleven Functions

The formula narrative provides a very brief description of the various factors that inform the overall function measure.

Function	Function Score Formula[4]	Formula Narrative
SWS	=AVERAGE(SideChan, BedVar, OBFlow, Exclusion)*6 + AVERAGE(Incision, Wood)*4	The score for this function is the weighted sum of (a) the average of the measure scores that represent the proportion of side channels, the variability of the channel bed, the existence of overbank flow, and the degree of floodplain exclusion, and (b) the average of the measure scores that represent the degree of streambank incision and the frequency of wood.
SST	=AVERAGE(BedVar, WetVeg, SideChan, OBFlow)*10	The score for this function is an average of the measure scores that represent the variability of the channel bed, the presence and distribution of wetland vegetation, the proportion of side channels, and the existence of overbank flow.
FV	=AVERAGE(BedVar, Embed,(ImpoundUS))*10	The score for this function is an average of the measure scores that represent the variability of the channel bed, the degree of substrate embeddedness, and the absence of upstream impoundments.
SC	=AVERAGE(Incision, Erosion, LatMigr)*10	The score for this function is an average of the measure scores that represent the degree of streambank incision, bank erosion, and the ability of the channel to migrate laterally.
SM	=Armor*3 + Embed*3 + BedVar*4	The score for this function is the weighted sum of (a) the degree of bank armoring, (b) the degree of substrate embeddedness, and (c) the variability of the channel bed.
MB	=(Barriers * AVERAGE(BedVar, Wood, SideChan))*5 + AVERAGE(InvVeg, WoodyVeg, LgTree, WetVeg)*5	The score for this function is the sum of (a) the average of the measure scores that represent the variability of the channel bed, the frequency of wood, and the proportion of side channels, with the average modified by the presence of any fish passage barriers, and (b) the average of the measure scores that represent the abundance of invasive plants, the abundance of native woody plants, the abundance of large trees, and the presence and distribution of wetland vegetation.

4 Key to function measure abbreviations: SideChan = Side Channels; BedVar = Channel Bed Variability; OBFlow = Overbank Flow; Exclusion = Floodplain Exclusion; Incision = Incision; Wood = Wood; WetVeg = Wetland Vegetation; Embed = Embeddedness; ImpoundUS = Impoundments Upstream; Armor = Bank Armoring; Erosion = Bank Erosion; LatMigr = Lateral Migration; Barriers = Fish Passage Barriers; InvVeg = Invasive Vegetation; WoodyVeg = Native Woody Vegetation; LgTree = Large Trees; Cover = Natural Cover; RipWidth = Vegetated Riparian Corridor Width.

Table 3.2 Formulas for Each of the Eleven Functions (continued)
The formula narrative provides a very brief description of the various factors that inform the overall function.

Function	Function Score Formula	Formula Narrative
CMH	=AVERAGE(Exclusion, WoodyVeg, LgTree)*5 + (Barriers * AVERAGE(Incision, Wood, Embed, BedVar, SideChan))*5	The score for this function is the sum of (a) the average of the measure scores that represent the variability of the channel bed, the frequency of wood, and the proportion of side channels, with the average modified by the presence of any fish passage barriers, and (b) the average of the measure scores that represent the abundance of invasive plants, the abundance of native woody plants, the abundance of large trees, and the presence and distribution of wetland vegetation.
STS	=AVERAGE(OBFlow, Cover, InvVeg, WoodyVeg)*7 + WetVeg*3	The score for this function is the weighted sum of (a) the average of the measure scores that represent the existence of overbank flow, the degree of natural cover overhanging the stream, the abundance of invasive plants, and the abundance of native woody plants, and (b) the presence and distribution of wetland vegetation.
NC	=AVERAGE(OBFlow, BedVar, RipWidth, Cover, WetVeg)*10	The score for this function is the average of the measure scores that represent the existence of overbank flow, the variability of the channel bed, the width of the riparian corridor, the degree of natural cover overhanging the stream, and the presence and abundance of wetland vegetation.
CR	=AVERAGE(RipWidth, BedVar, WetVeg, OBFlow)*10	The score for this function is the average of the measure scores that represent the width of the riparian corridor, the variability of the channel bed, the presence and abundance of wetland vegetation, and the existence of overbank flows.
TR	=Cover*10	The score for this function is based on the degree of natural cover overhanging the stream.

Table 3.3 Formulas for Each of the Values Associated with the Eleven Functions

Scores are made up of two components: the opportunity subscore and the significance subscore. The opportunity subscore represents the set of circumstances that makes it favorable for the project area to be able to provide a specific set of functions, predicted in part by what is upslope and upstream of the project area. The significance subscore represents the importance of a specific function (or set of functions) being provided at the particular location of the project area, predicted by what is adjacent to (floodplains) and downstream of the project area (that may be affected by the function being provided in the assessment area), and by how unique or rare the function or the aquatic resource type is in the landscape. The formula narrative provides a very brief description of the various factors that inform the overall value.

Value	Value Score Components[5]			Formula Narrative
	Opportunity Subscore	Significance Subscore	Final Score	
Water Storage (SWS)	=AVERAGE(ImpArea, Runoff, ImpoundUS)*5	=AVERAGE(MAX (DwnFP,Zoning), DwnFld,Fish)*5	Opportunity + significance	The score for this value is the sum of (a) the average of the measure scores that represent the prevalence of impervious area in the contributing basin, the abundance of surface water runoff, and the absence of impoundments upstream, and (b) the average of the measure scores that represent the existing or potential infrastructure in the downstream floodplain, the frequency of downstream flooding, and the presence of rare fish species or a designation of Essential Salmonid Habitat
Sub/Surface Transfer (SST)	=AVERAGE (AquaPerm, SoilPerm)	=Source	=IF (Source=1,10, AVERAGE (AquaPerm, SoilPerm)*10	This value is assigned the maximum score if the site is within close proximity to a water source or designated groundwater management area. Otherwise, the score for this value is the average of measure scores representing the soil and aquifer permeability of the local area.
Flow Variation (FV)	=AVERAGE (ImpArea, MAX(FlowMod, FlowRest, 1- ImpoundUS), AquaPerm, SoilPerm)*5	=AVERAGE (ImpoundDS, MAX(RarInvert, RarAmRep,Fish)*5	Opportunity + significance	The score for this value is the sum of (a) the average of the measure scores that represent the prevalence of impervious area in the contributing basin, known streamflow issues, and local soil and aquifer permeability, and (b) the average of the absence of impoundments downstream and the nearby occurrences of rare species that might depend on hydrologic cues.

5 Key to Value Measure Abbreviations: ImpArea = Impervious Area; Runoff = Surface Water Runoff; ImpoundUS = Impoundments Upstream; DwnFP = Extent of Downstream Floodplain Infrastructure; Zoning = Zoning; DwnFld = Frequency of Downstream Flooding; Fish = Essential Salmonid Habitat or Rare Non-anadromous Fish; AquaPerm = Aquifer Permeability; SoilPerm = Soil Permeability; Source = Designated Water Source; FlowMod = Flow Modification; FlowRest = Streamflow Restoration Need; SurrLand = Surrounding Land Type; RarInvert = Rare Invertebrates; RarAmRep = Rare Amphibians and Reptiles; SedList = Sediment Impairment; Position = Watershed Position; Erode = Erodibility; ImpoundDS = Impoundments Downstream; HabFeat = Unique Habitat Features; RarPlant = Rare Plants; Passage = Fish Passage Barriers; RipCon = Riparian Continuity; Protect = Protected Areas; Waterbird = Important Bird Areas or Rare Waterbirds; RarBdMm = Rare Songbirds and Mammals; RipArea = Riparian Area; NutrImp = Nutrient Impairment; TempImp = Temperature Impairment; ToxImp = Toxics Impairment.

Table 3.3 Formulas for Each of the Values Associated with the Eleven Functions (continued)

Value	Value Score Components[5]			Formula Narrative
	Opportunity Subscore	Significance Subscore	Final Score	
Sediment Continuity (SC)	= SedList*4 + AVERAGE (ImpArea, Im poundUS, Position)*5	=AVERAGE (1-DwnFP, Erode, ImpoundDS)*5	Opportunity + significance	The score for this value heavily weights the presence of known sediment impairment and sums it with (a) the average of the measure scores that represent the prevalence of impervious area in the contributing basin, the absence of impoundments upstream, and the site's relative position in the watershed and (b) the average of the measure scores that represent infrastructure in the downstream floodplain, the erodibility rating of the local basin, and the absence of impoundments downstream.
Substrate Mobility (SM)	=AVERAGE (ImpArea, ImpoundUS)*5	=AVERAGE (SubFeat, MAX(Fish, RarPlant, RarAmRep, RarInvert))*5	Opportunity + significance	The score for this value is the sum of (a) the average of the measure scores that represent the prevalence of impervious area in the contributing basin and the absence of impoundments upstream and (b) the average of the measure scores that represent the presence of unique habitat features and nearby occurrences of rare species.
Maintain Biodiversity (MB)	=AVERAGE (Passage, SurrLand, RipCon)*5	=AVERAGE (HabFeat, Protect, MAX(Fish, RarInvert, RarAmRep, Waterbird, RarBdMm, Rar Plant))*5	Opportunity + significance	The score for this value is the sum of (a) the average of the measure scores that represent the presence of fish passage barriers upstream and downstream, the surrounding land cover types, and the extent of the contiguous riparian corridor and (b) the average of the measure scores that represent the presence of unique habitat features, the proximity of protected natural areas, and nearby occurrences of rare species.
Create and Maintain Habitat (CMH)	=AVERAGE(1-ImpArea, ImpoundUS, RipArea, RipCon, MAX(1-NutrImp, 1-FlowMod,1-FlowRest)*5	=AVERAGE (MAX(1-DwnFP, 1-Zoning), ImpoundDS, HabFeat)*5	Opportunity + significance	The score for this value is the sum of (a) the average of the measure scores that represent the prevalence of impervious area in the contributing basin, the absence of impoundments upstream, the extent and connectivity of intact riparian area in the contributing basin, and the absence of known flow and nutrient impairments and (b) the average of the measure scores that represent the existing or potential infrastructure in the downstream floodplain, the presence of unique habitat features, and the absence of impoundments downstream.

Table 3.3 Formulas for Each of the Values Associated with the Eleven Functions (continued)

Value	Value Score Components[5]			Formula Narrative
	Opportunity Subscore	Significance Subscore	Final Score	
Sustain Trophic Structure (STS)	=AVERAGE (SurrLand, 1-ImpArea, Passage, RipArea, RipCon, 1-NutrImp, 1- TempImp)*5	=AVERAGE (Protect, MAX(1-DwnFP,1-Zoning), MAX (Fish, RarInvert, RarAmRep, Waterbird, RarBdMm, RarPlant), Hab Feat)*5	Opportunity + significance	The score for this value is the sum of (a) the average of the measure scores that represent the surrounding land cover types, the prevalence of impervious area in the contributing basin, the presence of fish passage barriers upstream and downstream, the extent and connectivity of intact riparian area in the contributing basin, and the absence of known flow and nutrient impairments and (b) the average of the measure scores that represent the site's proximity to protected areas, the existing or potential infrastructure in the downstream floodplain, documented rare species occurrences, and presence of unique habitat features.
Nutrient Cycling (NC)	=NutrImp*4+ AVERAGE (ImpArea, 1- RipArea, 1-RipCon, SedList, Position)*1	=AVERAGE (MAX(Fish, RarInvert, RarAmRep), Source)*5	Opportunity + significance	The score for this value heavily weights the presence of known nutrient impairment and sums it with (a) the average of the measure scores that represent the prevalence of impervious area in the contributing basin, the extent and connectivity of intact riparian area, known sediment impairment, and the site's relative position in the watershed, and (b) the average of the measure scores that represent documented rare species occurrences and proximity to important water sources.
Chemical Regulation (CR)	=ToxImp*4+ AVERAGE (ImpArea, 1- RipArea, 1-RipCon, SedList, Position)*1	=AVERAGE(MAX (Fish, RarInvert, RarAmRep, Waterbird, RarBdMm, RarPlant), Source)*5	Opportunity + significance	The score for this value heavily weights the presence of known toxics impairment and sums it with (a) the average of the measure scores that represent the prevalence of impervious area in the contributing basin, the extent and connectivity of intact riparian area, known sediment impairment, and the site's relative position in the watershed, and (b) the average of the measure scores that represent documented rare species occurrences and proximity to important water sources.
Thermal Regulation (TR)	=(1-TempImp)*4 +AVERAGE (RipArea, RipCon, ImpArea)*1	=AVERAGE (ThermFeat, MAX(Fish, RarInvert, RarAmRep)*5	Opportunity + significance	The score for this value heavily weights the absence of a known temperature impairment and sums it with (a) the average of the measure scores that represent the prevalence of impervious area in the contributing basin, and the extent and connectivity of intact riparian area, and (b) the average of the measure scores that represent unique habitat features and documented rare species occurrences.

3.4 Assessment Outputs

The formulas for each specific function and value produce a numerical score between 0.0 and 172B10.0. For ecological functions, a score of 0.0 indicates that negligible function is being provided by the stream whereas a score of 10.0 indicates that the stream is providing maximum function (as defined) given certain contextual factors (e.g., ecoregion, size). For values, a score of 0.0 indicates that even if a specific ecological function can be provided within the project area, there is negligible opportunity for the site to provide that function, or even if it does, it is not particularly significant given the context of the site. Conversely, a value score of 10.0 indicates 173Bthat a site has the opportunity to provide a specific function and that it is highly significant in that particular location. For all function and value formulas, both extents of the scoring range (0.0 and 10.0) are mathematically possible.

To facilitate conceptual understanding and communication of outputs, numerical *scores* are translated into *ratings* of Lower, Moderate, or Higher. The numerical thresholds for each of these rating categories are consistent across all functions and values such that scores of <3.0 are rated "Lower," scores ≥3.0 but ≤7.0 are rated "Moderate," and scores that are >7.0 are rated "Higher." These thresholds are consistent with the standard scoring scheme applied to all individual function measures.

Each specific function, and its associated value, is included in one of the four thematic groups described in **Section 3.1**: hydrologic, geomorphic, biologic, and water quality functions. Function groups provide an indication of the degree to which each group of processes is present at a site. Groups are represented by the highest function with the highest associated value among the two to three functions that comprise each group. This hierarchical selection system ensures that thematic functional groups are represented by the highest performing and highest valued ecological function. If multiple specific functions are equally ranked in the selection hierarchy, the function with the highest numerical function score is selected.

SFAM was designed as a standalone function assessment; it is not, in and of itself, a credit quantification tool. Any associated mitigation policy and accounting protocols are structured around the method, with the understanding that individual scores can be directly compared across sites and across functions and that group scores represent a roll-up of the information from individual scores.

3.5 References

Adamus, P.R. (1983) FHWA Assessment Method, v. 2 of Method for wetland functional assessment. FHWA-IP-82-24, U.S. Department of Transportation, Federal Highway Administration, Washington, DC

Fischenich, J.C. (2006) Functional Objectives for Stream Restoration. ERDC TN-EMRPP SR- 55, USACE Research and Development Center, Vicksburg, MS

4.0 Measures of Function & Value

Stream functions are expressed in varied and complex ways; therefore, they are difficult, costly, and time-consuming to measure directly. To enable the assessment of functions and values within the constraints of a rapid method, measures were identified for each function.

Measures are metrics that allow a quantitative or qualitative assessment of specific attributes that may indicate the extent to which a particular function is active. Measures can be continuous or discrete variables and may be assessed in the field (e.g., streambank incision, substrate embeddedness, bankfull width), in the office (e.g. GIS analysis of land use or impervious areas), or collected from existing sources (e.g., 303d listing, USEPA stream classification dataset). SFAM measures are primarily quantitative; however, where no practical quantitative approach exists to assess an attribute, measures consisting of observations and scores that represent a defined range (rather than a continuous set of measures) are used.

An initial list of measures was compiled for this project from multiple data sources, including the scientific literature, existing stream assessment protocols, spatial data sources, state-wide databases, and office-based analysis techniques. Selection criteria were then applied to assure the scientific validity of each measure and its practicality for use in a rapid assessment tool. SFAM measures (**Table 4.1**) meet the following inclusion criteria:

- **Rapid:** Attribute can be measured within the anticipated timeframe of a rapid assessment method.
- **Repeatable:** Multiple trained assessment teams would likely come up with the same value for this metric for a site at a given point in time.
- **Science-based:** A panel of scientists with relevant expertise would agree that the measure is either a direct measure or highly correlated indicator of a particular stream function attribute; it is likely that the relationship between the measure and the function could be substantiated through peer-reviewed literature or through rigorous scientific evaluation.

Table 4.1 SFAM Function and Value Measures

Function Measures		Value Measures	
F1	Natural Cover	**V1**	Rare Species Occurrence & Special Habitat Designations
F2	Invasive Vegetation	**V2**	Water Quality Impairments
F3	Native Woody Vegetation	**V3**	Protected Areas
F4	Large Trees	**V4**	Impervious Area
F5	Vegetated Riparian Corridor Width	**V5**	Riparian Area
F6	Fish Passage Barriers	**V6**	Extent of Downstream Floodplain Infrastructure
F7	Floodplain Exclusion	**V7**	Zoning
F8	Bank Armoring	**V8**	Frequency of Downstream Flooding
F9	Bank Erosion	**V9**	Impoundments
F10	Overbank Flow	**V10**	Fish Passage Barriers
F11	Wetland Vegetation	**V11**	Water Source
F12	Side Channels	**V12**	Surrounding Land Cover
F13	Lateral Migration	**V13**	Riparian Continuity
F14	Wood	**V14**	Watershed Position
F15	Incision	**V15**	Flow Restoration Needs
F16	Embeddedness	**V16**	Unique Habitat Features
F17	Channel Bed Variability		

4.1 Measure Development & Scientific Rationales

The following sections provide in-depth descriptions of each function and value measure included in the Stream Function Assessment Method, including the models, scientific rationale, and a brief history of the evolution of each measure. The synopsis of each measure is structured as follows:

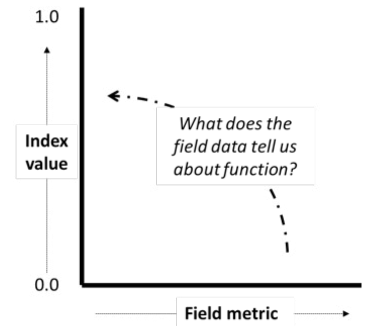
- **Measure text:** Provides the exact wording of the question, identical to that found in the SFAM User Manual and the SFAM Workbook.
- **Measure description:** Provides a conceptual overview of what the measure represents and assesses, as well as a quick-reference outline of the functions or values informed by the measure and the model(s) used to quantify the measure. For function measures, this includes tabular and graphical representations of performance indices.
- **Standard performance index (functions only):** Provides a description of how the standard performance index was developed, including the level of information available to develop the index, the method for determining thresholds, and the rationale behind stratification (if applicable). Standard performance indices were developed using different 185Bapproaches based on the quantity, quality, and type of relevant data and literature available.
- **Scientific support for ecological functions (functions only):** Provides an explanation of the state of scientific understanding relating measures to the performance of functions, highlighting any key studies that were assessed to develop standard performance indices.
- **Measure development (functions only):** Provides a description of how the measure was explored and developed, including alternatives considered and input from technical reviewers.
- **Rationale for inclusion (values only):** Provides an explanation of the scientific support for a value measure to inform both the opportunity for a stream site to provide specific ecological functions and the significance of those functions given the context of the site.

Creating Standard Performance Indices

Standard performance indices (range of expected performance) for each function measure included in the SFAM model provide ecological meaning to scoring the measures. Such performance indices are also needed to facilitate standardization of individual measure – and thus function – scores to a common scale, which is important for calculating and comparing assessment scores. The 17 function measures included in the method result in a variety of field metrics, including percentages, ratios, absolute values, coefficients of variance, and qualitative responses. These metrics must be converted into a common, calibrated unit before they can be incorporated into function formulas. The performance index for each function measure is set to a standardized scale that results in a measure score ranging from 0.0 to 1.0. Standard performance indices were developed using the following steps:

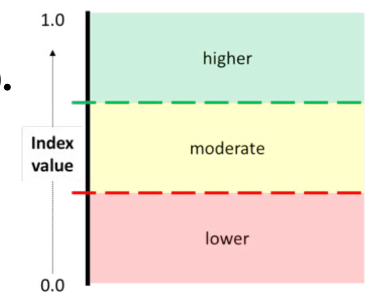
1. Establish index scales (axes).

For each index, the x-axis represents the field metric, and the range varies depending on the metric type (e.g. 0-100 for percentages). The y-axis represents possible index values, ranging from 0.0 to 1.0. Linear models are needed to translate field metrics to numeric index values.



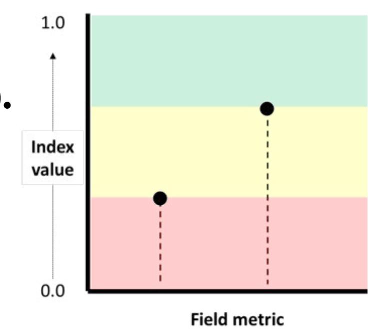
2. Identify index value thresholds (calibrate y-axis).

Standard function thresholds were applied to the index value scale in order to ensure that all measures are assigned scores that have consistent ecological meaning. The threshold indicating a shift from lower to moderate functioning is set at 0.3. The threshold indicating the difference between moderate and higher functioning is set at 0.7.



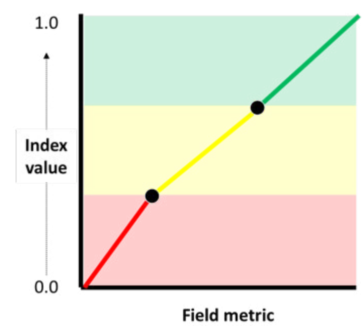
3. Identify field metric thresholds (calibrate x-axis).

Regional ecological literature and data sets were evaluated to identify field metric values that correspond with a change in functioning. These ecological thresholds indicate the point at which the functional rate of return may shift. See the following section for further description of the methods used to determine field metric thresholds.



4. Create linear models between thresholds.

The models describe the rate of functional return expected for increases (or, for inverse scales, decreases) in the field metric value. The use of linear (continuous) models allows the measure score to reflect incremental changes.



To assure that function measure scores are evaluated against appropriate standard performance indices where factors such as stream size or ecoregion may influence expected performance, standard performance indices of some function measures are stratified on these attributes. For example, when assessing natural cover over a stream, differences would be expected based upon stream width and geographic location and, therefore, cover measurements should be evaluated against appropriate standard performance indices. Stratified standard performance indices were developed when there was sufficient scientific support to do so.

Data Availability for Generating Standard Performance Indices

Given the diversity of function measures used in SFAM, we took different approaches to developing standard performance indices based on the availability of data. The three categories of data availability are as follows:

1. Substantial literature exists linking measures to ecological functioning. Indices are based on trends and thresholds expressed in research results reported in the literature.
2. In the absence of substantial literature, we relied on an abundance of raw data provided by the USEPA National Aquatic Resource Survey (NARS). Indices are based on data distributions and known reference site data that could be used to set expectations, supported by existing literature linking measures to ecological functioning.
3. In the absence of substantial literature or an abundance of raw data, we relied on the current scientific understanding of how measures relate to functioning.

Regardless of the level of data availability, scientific understanding from the current literature informed performance index thresholds. Thresholds, as illustrated above, are the break points between general levels of functioning (i.e. the point at which a function or value should be considered Moderate rather than Lower or Higher). The approaches used to develop standard performance indices and identify appropriate thresholds are detailed below.

1. Performance indices generated using available literature

For 6 of the 17 function measures (Invasive Vegetation, Native Woody Vegetation, Large Trees, Vegetated Riparian Corridor Width, Floodplain Exclusion, Side Channels), the standard performance indices and associated thresholds were developed based directly on analysis of research results reported in the scientific literature. The basic process for this was as follows:

a. Queried Pacific Northwest researchers who have conducted relevant studies, and agencies responsible for assessment, management, and monitoring of the stream resource, to assist in identifying existing data relevant to SFAM function and measures of function;
b. Conducted an extensive, systematic search of the scientific literature with a focus on studies conducted in the Pacific Northwest (Oregon, Washington, Idaho, British Columbia);
c. Selected studies that measured aspects of stream function, and described the degree of function, related to identified SFAM functions and using similar measures of function (i.e., percent cover of invasive vegetation, native woody vegetation, and large trees; width of vegetated riparian corridor; percent of floodplain connectivity; availability of side channels); and
d. Analyzed the data relevant to each measure to produce a standard performance index (0 – 1 scale) and thresholds of function (Low, Moderate, High).

A discussion of which studies were chosen and why, and how the thresholds were established for each standard performance index developed, is provided in the detailed description of each of these measures (**Section 4.2**).

2. Performance indices generated using USEPA NARS Rivers and Stream Assessment Data

For 5 of the 17 function measures (Natural Cover, Wood, Incision, Embeddedness, Channel Bed Variability), the standard performance indices were developed using raw data made available by the NARS, a program of the USEPA. As part of the NARS program, physical, chemical and biological data were collected from streams for the 2008–2009 and 2013–2014 National Rivers and Streams Assessment (NRSA) across the continental U.S. The assessments used a common methodology (USEPA, 2007) across all sites, with some slight deviations for wadeable versus non-wadeable streams. Sites ranged in size from small mountain headwater streams to large rivers like the Mississippi, reflecting the variety and types of rivers and streams across the United States.

To develop standard performance indices for SFAM measures, a subset of the NARS data was used. The subset was limited to those data collected from sites in the two ecoregions which occur in Oregon: Western Mountains (WMT) and Xeric (XER) (**Figure 4.1**). Ecoregions have been developed and identified through synthesis of data by similar soils, climate, and geography rather than geo-political boundaries. For this reason, our analysis uses all data from these two ecoregions applicable to these measures and is not limited to the data collected in Oregon. The larger dataset provides increased confidence in the data summaries through improved statistical power and reduced variance. It also allows the application of these measures and associated indices throughout the Western Mountains and Xeric ecoregions.

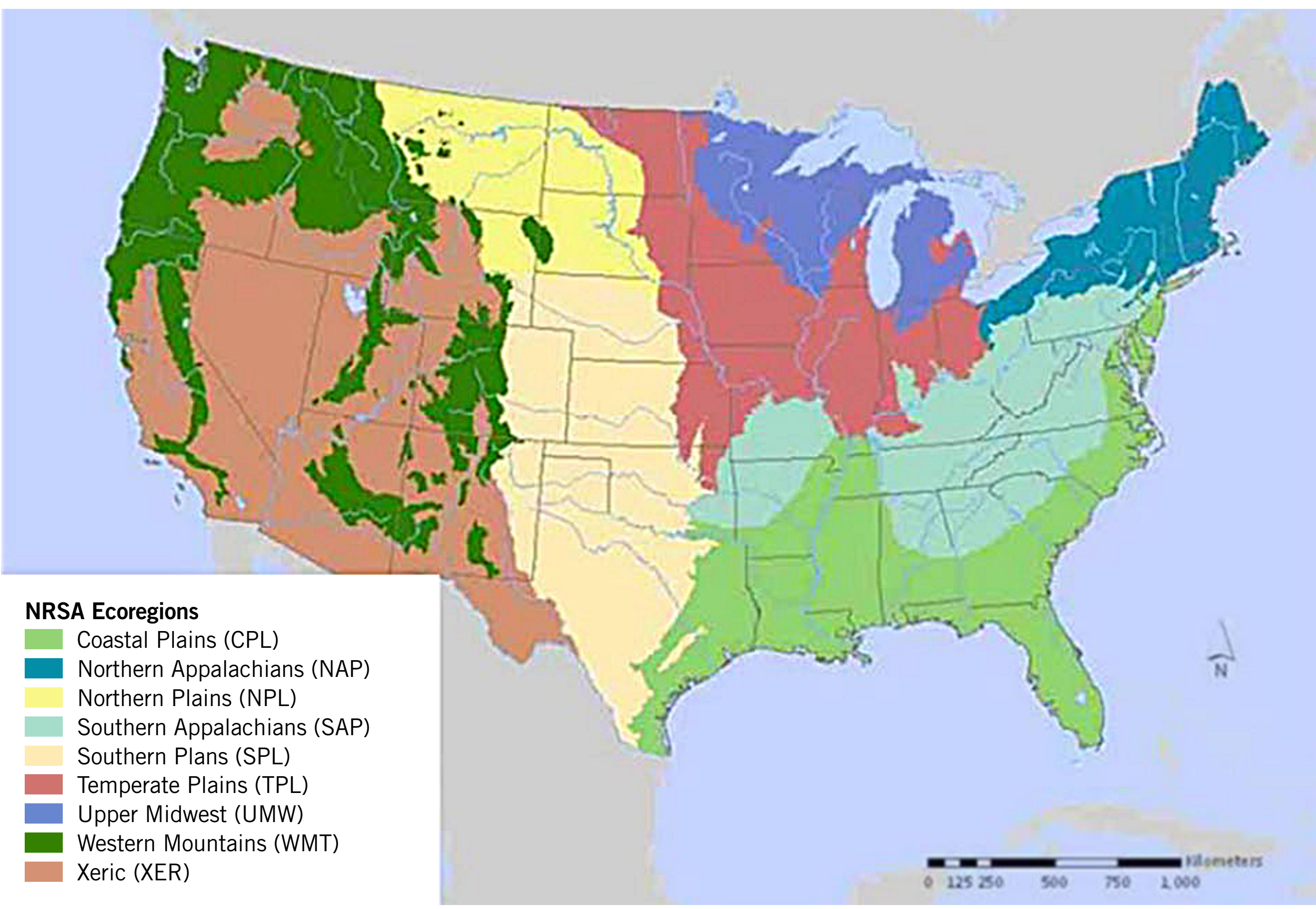


Figure 4.1 The Nine Ecoregions Used in the National Rivers and Streams Assessments (NRSA)
These are aggregations of the Level III ecoregions delineated by USEPA for the continental U.S. (https://www.epa.gov/national-aquatic-resource-surveys/ecoregion-descriptions-national-aquatic-resource-surveys). Survey data from the Western Mountains (green) and the Xeric (orange) ecoregions were used to inform standard performance index development.

Objectives for using the NARS data to inform the development of the standard performance indices for select measures included (a) identify the range and distribution of data values across a representative population of streams and rivers, (b) explore values across stream attributes to identify potential stratifiers for expectation of performance, and (c) use probabilistic site data to inform index thresholds (Low, Moderate, High). To address these objectives, frequency distributions of the corresponding data were evaluated for each relevant measure. Interpretations of the data are discussed in the *Standard Performance Index* section for each of the five measures.

A standard set of rules was applied to translate percentile values from the NARS data distributions into index thresholds upon which to base standard performance models (**Figure 4.2**):

- **the threshold for "low"** functioning was determined using the 25th percentile value of the survey site data, thus asserting that sites with a metric value as low as, or lower than, the bottom 25% of all NRSA sites are providing a "low" level of function to the stream;
- **the threshold for "high"** functioning was determined using the 75th percentile value of the survey site data, thus asserting that sites with a metric value as high as, or higher than, the top 75% of all NRSA sites are providing a "high" level of function to the stream;
- **the maximum metric value,** when needed, was determined using the 90th percentile value of the survey site data, thus asserting that a metric value as high, or higher than, the top 10% of all NRSA sites would be assigned the maximum index value (1.0). Maximum metric values were needed for metrics whose scales are not fixed.

For metrics that operate on an inverse scale (i.e. lower values correspond with higher functioning), the inverse of this rule set was applied.

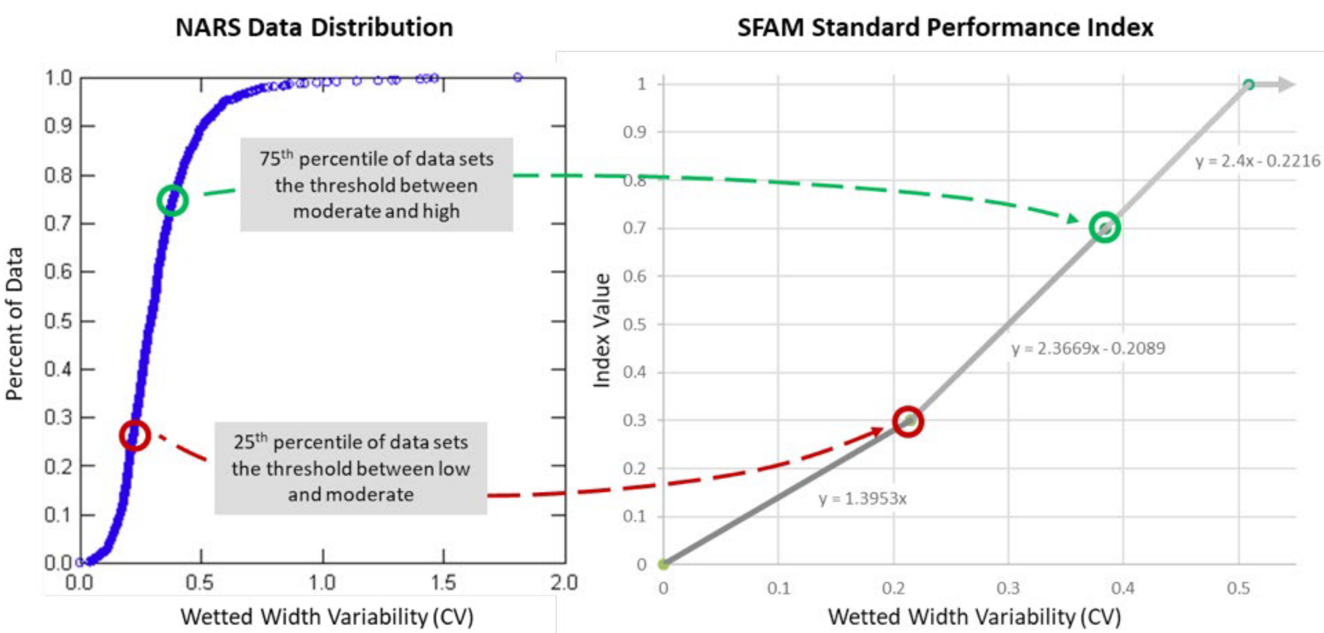


Figure 4.2 Raw Data Distributions from USEPA NARS Surveys are Used to Set Performance Expectations

3. Performance indices generated based on current scientific understanding

For 6 of the 17 function measures (Fish Passage Barriers, Bank Armoring, Bank Erosion, Overbank Flow, Wetland Vegetation, Lateral Migration), neither existing studies, NARS data, nor other sources of data were identified that could inform data driven standard performance indices. Thus, indices for these measures were developed based on current scientific understanding and expert review. The basic process for this was as follows:

a. Queried Pacific Northwest researchers who have conducted relevant studies, and agencies responsible for assessment, management, and monitoring of the stream resource, to assist in identifying existing data relevant to SFAM function and measures of function;

b. Conducted an extensive, systematic search of the scientific literature with a focus on studies conducted in the Pacific Northwest (Oregon, Washington, Idaho, British Columbia); and

c. Identifying no studies or applicable data sources providing the level of data necessary to support standard performance index development, indices and associated thresholds for these measures are based on current scientific understanding of these processes and their linkages to the stream functions they support.

A discussion of the literature supporting these standard performance indices is provided in the detailed description of these measures (**Section 4.2**).

4.2 Function Measures

Detailed descriptions of the scientific basis for each of the 17 function measures are included in the following section. These measures are primarily field-based and often require collection of quantitative data. There are several measures that can be estimated before conducting field work, but it is expected that any estimated answers be confirmed in the field. Data collection instructions for each measure are included in the SFAM User Manual.

Table 4.2 Measures Informing Each Function Formula

Function	Function Measures																
	Natural Cover	Invasive Vegetation	Native Woody Vegetation	Large Trees	Vegetated Riparian Corridor Width	Fish Passage Barriers	Floodplain Exclusion	Bank Armoring	Bank Erosion	Overbank Flow	Wetland Vegetation	Side Channels	Lateral Migration	Wood	Incision	Embeddedness	Channel Bed Variability
Surface water storage							X			X		X		X	X		X
Sub/surface transfer										X	X	X					X
Flow variation*																X	X
Sediment continuity									X				X		X		
Substrate mobility								X								X	X
Maintain biodiversity		X	X	X		X					X	X		X			X
Create & maintain habitat			X	X		X	X					X		X	X	X	X
Sustain trophic structure	X	X	X							X	X						
Nutrient cycling	X				X					X	X						X
Chemical regulation					X					X	X						X
Thermal regulation	X																

**Flow Variation is also informed by the value measure, Impoundments. See Section 4.3 for information on this measure*

a) Natural Cover

MEASURE TEXT

What is the percent natural cover above the stream within the Proximal Assessment Area (PAA)?

Measure the percentage of cover above the stream, including overstory and understory vegetation, and overhanging banks, by averaging spherical densiometer measurements taken at each transect within the PAA.

MEASURE DESCRIPTION

The presence of natural cover, including both vegetation and overhanging banks, is a major factor in water temperature maintenance and cooling which, in turn, regulates chemical fluctuations. Vegetative cover (including trees, shrubs, and other plants) that shade streams can provide important food and shelter resources for aquatic-dependent species by contributing leaf litter and wood to the stream habitat.

Function Groups: Biology, Water Quality
Functions Informed: Sustain Trophic Structure (STS), Nutrient Cycling (NC), Thermal Regulation (TR)
Stratification: This measure is stratified by both ecoregion (Western Mountains; Xeric) and stream size (small ≤ 50 ft width; large >50 ft width)
Metric: Percent cover

Model:

Western Mountains ecoregion; ≤ 50 ft wide:
IF Cover < 56, THEN = 0.0054*Cover
IF Cover = 56–92, THEN = 0.0111*Cover - 0.3222
IF Cover > 92–98, THEN = 0.05*Cover - 3.9
IF Cover > 98, THEN =1.0

Western Mountains ecoregion; > 50 ft wide:
IF Cover < 15, THEN = 0.02*Cover
IF Cover = 15–63, THEN = 0.0083*Cover + 0.175
IF Cover > 63–78, THEN = 0.02*Cover - 0.56
IF Cover > 78, THEN = 1.0

Xeric ecoregion; ≤ 50 ft wide:
IF Cover < 41, THEN = 0.0073*Cover
IF Cover = 41–87, THEN = 0.0087*Cover - 0.0565
IF Cover > 87–95, THEN = 0.0375*Cover - 2.5625
IF Cover > 95, THEN = 1.0

Xeric ecoregion; > 50 ft wide:
IF Cover < 13, THEN = 0.0231*Cover
IF Cover = 13–51, THEN = 0.0105*Cover + 0.1632
IF Cover > 51–71, THEN = 0.015*Cover - 0.065
IF Cover > 71, THEN = 1.0

Table 4.3 Natural Cover Scoring Index

Natural Cover as measured by percent of coverage over stream				
Function Value Ranges	**Low**	**Moderate**	**High**	
Western Mountains; ≤ 50 ft width	< 56	56–92	> 92–98	> 98
Western Mountains; > 50 ft width	< 15	15–63	> 63–78	> 78
Xeric East; ≤ 50 ft width	< 41	41–87	> 87–95	> 95
Xeric East; > 50 ft width	< 13	13–51	> 51–71	> 71
Index Value	0.0 – < 0.3	0.3–0.7	> 0.7–1.0	1.0

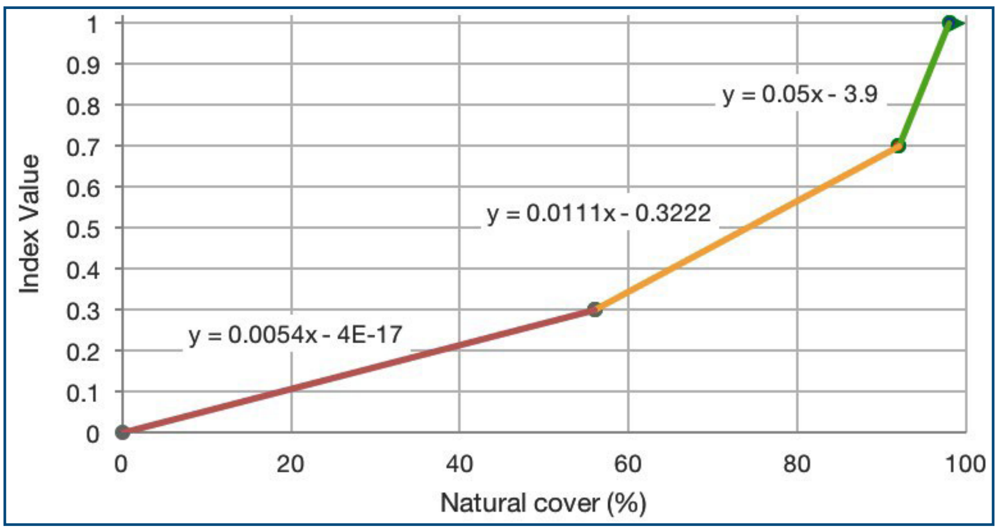


Figure 4.3 Natural Cover Standard Performance Index- Western Mountains Ecoregion; ≤50 ft width

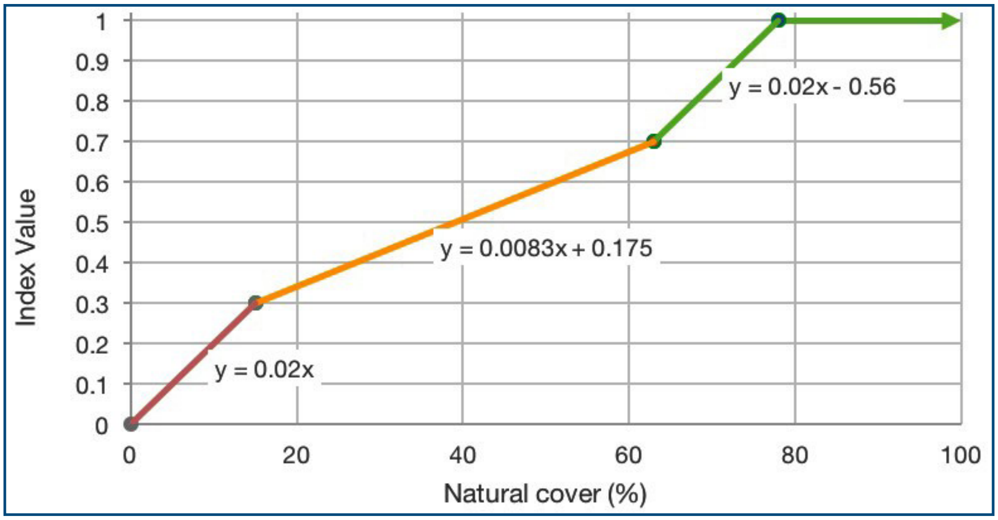


Figure 4.4 Natural Cover Standard Performance Index - Western Mountains Ecoregion; >50 ft width

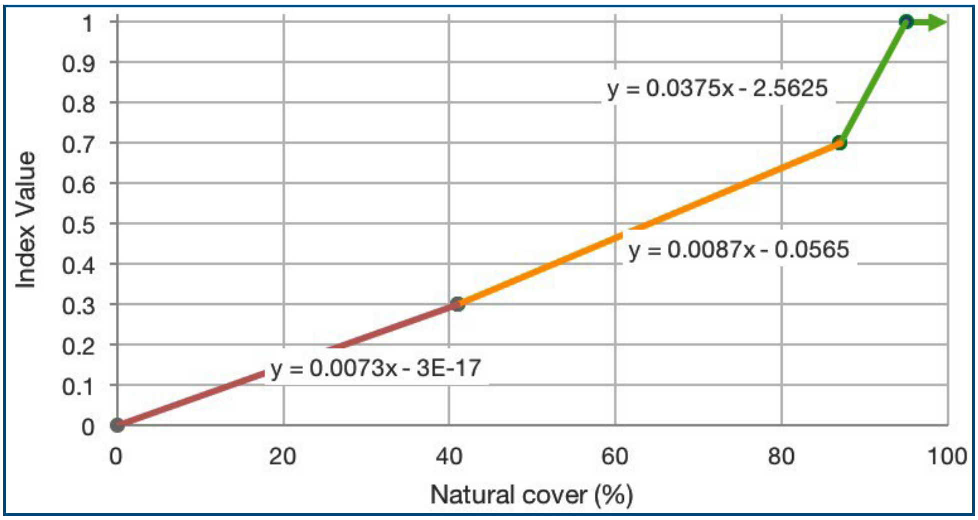


Figure 4.5 Natural Cover Standard Performance Index- Xeric Ecoregion; ≤50 ft width

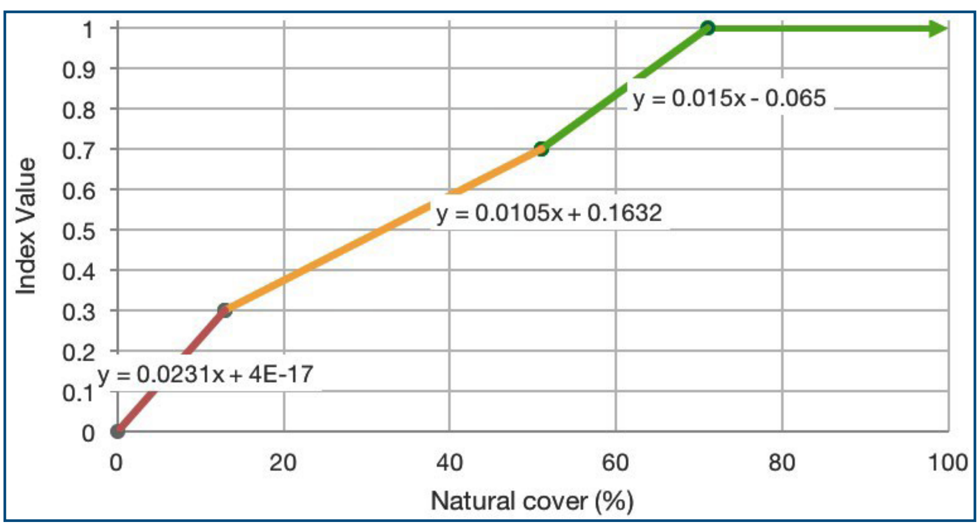


Figure 4.6 Natural Cover Standard Performance Index- Xeric Ecoregion; >50 ft width

STANDARD PERFORMANCE INDEX

Development Method

There is significant information in the literature to support that stream cover provided by riparian vegetation has a positive relationship with thermal and chemical regulation in streams. The range of specific function responses and the variety of methods used to quantify stream cover (percent cover, percent canopy closure, canopy height, shading, buffer width) in the literature make it difficult to quantify the resulting influence of cover on stream function and to develop a performance index based on this information. Therefore, the standard performance indices presented here were developed based on the distribution of field-collected data from the USEPA NRSA surveys (USEPA, 2007; 2016). The index thresholds were determined using the approach described in **Section 4.1**. Threshold values for this measure are presented in **Table 4.4**.

Stratification

It is expected that streams occurring in dry (xeric) climates, where riparian vegetation is likely to be less dense and shorter, have less canopy cover for stream shading and nutrient inputs compared to streams in wetter climates, even for streams in pristine condition. Additionally, one might expect larger streams to have lower percent stream cover because a larger proportion of the stream is farther away from where the riparian vegetation is rooted. Therefore, we evaluated using ecoregion (Western Mountains and Xeric) and two stream width categories small (width ≤ 50 ft) and large (width > 50 ft) to stratify the NARS stream cover data (**Figure 4.7**).

The results illustrated that percent of canopy cover tends to be greater for streams in the Western Mountains ecoregion than the Xeric ecoregion, and that small (width ≤ 50 ft) streams have greater percentage cover than larger streams in both ecoregions. Given the differences in percent cover by stream size and ecoregion in the NARS data, in addition to literature supporting different expectations of natural cover, this measure is stratified on both ecoregion and stream width. A standard performance index was developed for each combination of stratifiers.

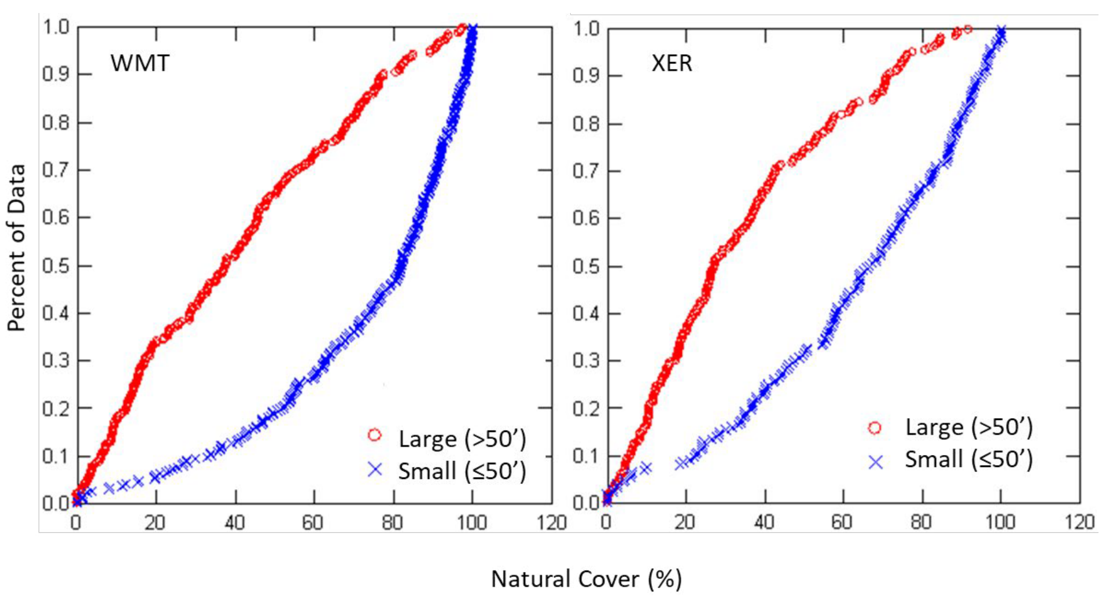


Figure 4.7 Frequency Distribution of Percent Natural Cover Values for 965 Stream Reaches by Ecoregion and Stream Width. *WMT Western Mountains; XER Xeric.*

Table 4.4 Frequency Distribution of NARS Stream Cover Data (Percent Shading), Stratified by Ecoregion and Stream Width
The 25th percentile of data, establishing the threshold between "lower" and "moderate" function index values, is highlighted in red. The 75th percentile of data, establishing the threshold between "moderate" and "higher" function index values, is highlighted in green. The 90th percentile of the data, establishing the threshold for the maximum index value (1.0), is highlighted in blue.

Natural Cover (%)				
Summary Statistics	**Western Mountains**		**Xeric**	
	Small (≤50')	**Large (>50')**	**Small (≤50')**	**Large (>50')**
Number of Sites	280	266	191	228
Minimum	0	0	0	0
Maximum	100	97.594	100	91.711
Arithmetic Mean	72.337	39.918	62.153	33.679
Standard Deviation	25.929	27.515	28.06	24.229
Distribution of Data				
1.00%	1.316	0	0	0.104
5.00%	17.513	2.754	4.358	3.182
25.00%	55.882	14.973	41.243	13.235
50.00%	81.952	37.567	66.578	27.206
75.00%	92.246	62.567	86.898	51.337
90.00%	98.262	77.54	94.887	71.136

SCIENTIFIC SUPPORT FOR ECOLOGICAL FUNCTIONS

Biologic Function

There is strong connectivity between terrestrial and aquatic ecosystems (Poff *et al.,* 2012) and riparian vegetation influences stream biota in several ways. Inputs of allochthonous material from riparian plants, including leaves, twigs, seeds, flowers, and terrestrial invertebrates and wood, provides food which helps sustain the productivity and biocomplexity of stream ecosystems (Wipfli *et al.,* 2007). In a synthesis paper describing the ecological linkages between upstream and downstream waters, and the transport of organic materials, Wipfli and co-authors (2007) note that allochthonous, nutrient rich inputs partially drive the energetics and structure of aquatic food web dynamics and production. Organic matter, once in the stream, can be processed through consumption by various organisms from microbes to invertebrates, and may be repackaged as feces for consumption by other organisms. These authors (Wipfli *et al.,* 2007) indicate that the conversion, retention, and transport of organic material is an important part of the ecological connectivity between terrestrial and aquatic systems. Terrestrial invertebrates, which are associated with both understory and overstory riparian plants, were found to be over half of the prey mass ingested by salmonids in southeastern Alaska streams (Wipfli, 1997).

Water Quality Functions

Individual studies (Sakamaki and Richardson, 2011) and literature reviews (Sweeney and Newbold, 2014) have found that canopy cover is one mechanism by which riparian buffers affect stream water quality measures and nutrient cycling. The effects of the riparian buffers on water quality are geographically specific and related to site and regional variables such as hillslope, upslope land management, evapotranspiration potential, stream gradient, and discharge. While riparian harvest clearly impacts stream ecosystems, in a meta-analysis of studies the direction and magnitude of change in water chemistry, primary production, and organic matter inputs was highly variable (Richardson and Béraud, 2014). Anderson *et al.* (2007) finds that effective riparian buffer width can be defined by topographic variation or vegetation community transition as it relates to nutrient cycling and temperature regulation.

Nutrient Cycling

Despite the variable influence of riparian vegetated corridor width, studies in the Pacific Northwest lead to some generalizations. For a summary of the relationship between riparian corridor width and nutrient cycling, which includes functions provided by the canopy such as allochthonous carbon input, see resources cited in the rationale for Vegetated Riparian Corridor Width (**Section 4.2(e)**).

Thermal Regulation

A review of multiple studies finds that the shading and temperature control that a riparian buffer provides depend in part on the width of the buffer since light may pass obliquely to the stream entirely through the understory. Sweeney and Newbold (2014) suggest a minimum buffer width of 20–30 m depending on length of buffer along stream, stream size, orientation, local topography, and the type, height, and density of streamside vegetation. In particular, Sweeney and Newbold (2014) note that streams oriented north-south may require wider buffers to promote thermal regulation function.

A collaborative study between the Bureau of Land Management, U.S. Department of Agriculture, U.S Geological Survey, and Oregon State University in western Oregon forests found that buffers ≥ 15 m width ensure daily maximum air temperature above stream center increased by ≤ 1°C, and that daily minimum relative humidity was ≤ 5% lower than for reaches with no upslope harvest (Anderson *et al.,* 2007). However, the authors caution that rather than define a constant buffer width, buffers of widths defined by the transition from riparian to upland vegetation or topographic slope breaks appear sufficient to mitigate the impacts of upslope harvest (Anderson *et al.,* 2007). Other studies have found light, irradiance, temperature, and photosynthetically active radiation (PAR) to be controlling factors in stream primary production, nutrient cycling, and chemical fate (Kiffney *et al*., 2003; Sakamaki and Richardson, 2011). Kiffney and co-authors (2003) found that in small streams periphyton biomass, PAR, and temperature increased as buffer width decreased from 30 m to 10 m to 0 m.

In a review comparing Coast Range forests (Western Oregon) and Blue Mountain forests (Eastern Oregon), Allen and Dent (2001) showed that total cover was approximately 17% less in unharvested Blue Mountain sites versus Coast Range sites, and 27% less in harvested sites. Unharvested stands had higher function in terms of shade provided to the stream, which is important to temperature regulation. In the Blue Mountains, areas of higher shading had a significant difference in basal area (large tree abundance) compared to areas of lower shading ($p=0.000$). The low and high shade categories began to differ) at 40 feet from bankfull ($p=0.076$). No difference between shade categories was observed in Coast Range riparian forest zones demonstrating a difference in relative contribution of large trees to shading. In summary, shade over streams in the Blue Mountains appears to be more sensitive to having additional trees farther away from the stream than the Coast Range. These authors (Allen and Dent, 2001) developed two separate models to relate forest cover to shade for the two regions, which supports the stratification of SFAM Natural Cover standard performance indices by ecoregion.

In a study of cumulative effects of riparian disturbance of grazing in Eastern Oregon (John Day River Basin), investigators found greater canopy cover was associated with lower daily maximum temperatures and rainbow trout abundance was negatively correlated with solar radiation and maximum temperature, particularly in streams with a north-south aspect that would have longer daily exposure to solar radiation

(Li *et al*., 1994). In this study, as in western Oregon streams, solar insolation causes an increase in algal and invertebrate biomass. However unlike in Western Mountains ecoregion streams, increases in invertebrate biomass were not related to trout uses, demonstrating that in xeric regions of Eastern Oregon where temperature nears lethal levels for salmon and trout, thermal regulation is a stronger driver of trout abundance than invertebrate abundance.

Table 4.5 Summary of Supporting Literature and Data for Natural Cover Standard Performance Indices

Reference	Metric	Function Response Variable	SFAM Functions Informed	Metric Classifications	Informative Conclusions
Data Sources					
USEPA NARS Rivers and Streams Assessment data	% canopy cover at stream banks using NARS metric XDENBNK	Stream condition	None	Many available; evaluated ecoregion and stream width (large vs small)	Evaluation of this large data set (n=965) from stream reaches representative of the Ecoregions which occur in Oregon provide the expected range and distribution of stream cover measures.
Decision Support for Biologic and Water Quality Functions					
Sweeney and Newbold, 2014	Review paper- buffer width to maintain stream health	Temperature	TR	Various	Buffers ≥ 30 m wide are needed to protect the physical, chemical, and biological integrity of small streams with watersheds 100 km2, or about fifth order or smaller in size.
Kiffney et al., 2003	Buffer width	Periphyton growth, Chlorophyll a, dissolved nutrients, temperature, PAR	TR, STS, NC	PNW, managed forest; headwaters	PAR, temperature increased as buffer decreased and this resulted in increased PP (Chlorophyll a and periphyton biomass). The authors note that light penetrates through sides of the buffer.
Sakamaki and Richardson, 2011	Buffer width; vegetation (conifer or conifer + deciduous mix)	Rock biofilm (stream-origin POM), fine sediment POM, and fine POM suspended in water, and benthic macroinvertebrates	TR, STS	PNW, managed forest; headwaters	A six-variable model explained 72.6% of total variance in biogeochemical properties of fine POM, but riparian buffer was not significant alone. Fine POM of sediment is a good indicator of local environment, while fine POM of water is not. Fine sediment POM was significantly related to irradiance and coarse POM.

Reference	Metric	Function Response Variable	SFAM Functions Informed	Metric Classifications	Informative Conclusions
Decision Support for Biologic and Water Quality Functions					
Anderson et al., 2007	Variable buffer width; upslope thinning treatments	Temperature (microclimate) changes	TR	Coastal Range, PNW, Western Oregon forests; headwaters	Buffers at least 15 m kept increase in max daily temp ≤1 °C and decrease in humidity ≤5%, regardless of upslope treatment. Buffer widths defined by topographic or vegetation transition are sufficient.
Allen and Dent, 2001	Trees per 1,000 feet	Shade	TR	Coastal Range, Blue Mountains, Oregon	Contribution of riparian trees to shade differs between East and West Regions; supports stratification by region
Li et al., 1994	Insolation	Temperature, algal biomass, invertebrate biomass, rainbow trout biomass, other stream habitat characteristics	TR, STS	John Day River Basin, Oregon	Effect of solar insolation due to lack of canopy cover is to increase temperature to levels that elevate primary and secondary productivity but reduce fish abundance. Response differs in Xeric vs Western Mountains rivers. Supports stratification by ecoregion.

Notes:
CPOM: Coarse particulate organic matter
PAR: Photosynthetically active radiation
POM: Particulate organic matter
STS: Sustain Trophic Structure
NC: Nutrient Cycling
PNW: Pacific Northwest
PP: Primary production
TR: Thermal Regulation

MEASURE DEVELOPMENT

This measure was added to SFAM prior to the field study, to obtain a more precise measurement of stream shading, for which vegetated riparian corridor width had previously been used as a surrogate. Initially, the measure used a line-intercept protocol, but technical reviewers suggested using a more robust protocol for capturing canopy cover. The protocol was revised to use densiometer measurements as they capture cover that contributes to stream shading even if it is not directly over the stream. This is particularly important for the shade (stream cooling) element that is needed for the Thermal Regulation function. The final data collection protocol is consistent with the protocol used in NARS; data from which standard performance indices for this measure were developed.

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b) Invasive Vegetation

MEASURE TEXT

What is the percent cover of invasive plants within the PAA?

Conduct a line-intercept survey along three transects in the PAA to evaluate riparian vegetation composition. This method is used to collect data for three functional groups of vegetation, including invasive vegetation. Consult the Oregon Department of Agriculture (2017) list of plant species considered invasive in Oregon (SFAM User Manual, Appendix 3). Additional information on invasive vegetation is available on the iMAPInvasives website (https://www.inaturalist.org/ lists/258254-Oregon-iMapInvasivess-Check-List?rank=species) and the iNaturalist web site (https://www.inaturalist.org/lists/258254-Oregon-iMapInvasivess-Check-List?rank=species).

MEASURE DESCRIPTION

This measure indicates the presence and relative abundance of non-native, invasive plant species. The biotic community is the most visible testament to the overall health of the river system. The vegetation community provides a spatially persistent and somewhat long-lived metric to evaluate habitat availability, diversity, and food resource availability on the floodplain or at the stream margin. The presence of invasive plants can create increased competition for native species and can alter habitat and food resources available for wildlife.

Function Group: Biology
Functions Informed: Maintain Biodiversity (MB), Sustain Trophic Structure (STS)
Stratification: This measure is not stratified
Metric: Percent cover

Model:
IF $InvVeg \geq 50$, THEN $= 0.0$
IF $InvVeg > 15 - < 50$, THEN$= -0.0086 * InvVeg + 0.4286$
IF $InvVeg = 1–15$, THEN$= -0.0286 * InvVeg + 0.7286$
IF $InvVeg < 1$, THEN$= -0.3 * InvVeg + 1$

Table 4.6 Invasive Vegetation Scoring Index

Invasive Vegetation as measured by percent cover				
Function Value Ranges	**Low**		**Moderate**	**High**
Field Value	≥ 50	> 15 – < 50	1–15	< 1
Index Value	0.0	> 0.0 – < 0.3	0.3–0.7	> 0.7–1.0

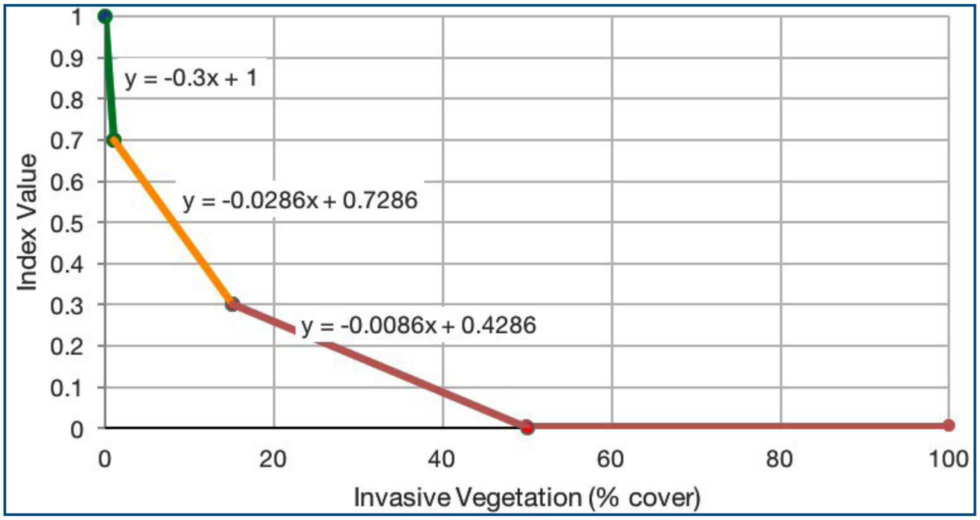

Figure 4.8 Invasive Vegetation Standard Performance Index

STANDARD PERFORMANCE INDEX

Development Method

Extensive information in the scientific literature indicates that when invasive plant species establish in place of native species, the altered successional trajectories can change the biological environment leading to changes in local and watershed scale riparian ecology (see papers cited in Schmitz and Jacobs, 2007). The development of the standard performance index for this measure was informed by data from studies conducted in the western U.S., and index thresholds are based on an assessment of these studies and current scientific understanding of the effects of invasive vegetation.

The model for this measure uses continuous data to make the best use of the data collection method.

SCIENTIFIC SUPPORT FOR ECOLOGICAL FUNCTIONS

Biologic Function

Studies of invasive vegetation suggest that relatively low levels of invasion may lead to monocultures of plant cover relatively rapidly both west and east of the Cascades (e.g. within a decade). It is hypothesized that monocultures of riparian vegetation would alter ecosystems by altering trophic structure and biodiversity compared to native and more diverse vegetation communities. Some authors have studied the effect of changes in allochthonous inputs, nutrients and decay rates by plant species in the Pacific Northwest, however it is challenging to relate the change in plant composition to change in biological function, and the effect of invasive vegetation differs depending on the invasive species (e.g., Braatne *et al*., 2007; Mineau *et al*., 2012). Using an approach to relate the most common invasive weeds in the Western U.S. to biological function, Ringold and coauthors (2008) observed that instream biotic integrity was lower when even a single invasive plant target taxon was present than when invasive plant species were absent. Taken together, these findings support best professional judgment that suggests that relatively low levels of cover by invasive vegetation (e.g. invasive vegetation < 1%) can reduce stream function to moderate levels.

Table 4.7 Summary of Supporting Literature for Invasive Vegetation Standard Performance Index

Reference	Metric	Function Response Variable	SFAM Functions Informed	Informative Conclusion
Ringold et al., 2008	Invasive weed presence	Instream Biotic Integrity indices	MB, STS	Lower IBI with presence of common invasive weeds
Mineau et al., 2012	Organic matter processing	Primary production, Ecosystem respiration	STS	Russian olive altered allochthonous inputs but not autochthonous organic material processing
Braatne et al., 2007	Allochthonous leaf litter organic matter input	Macroinvertebrate colonization	MB, STS	Allochthonous inputs from Japanese knotweed had no effect on leaf decomposition or macroinvertebrate dynamics

Notes:
CMH: Create and Maintain Habitat
IBI: Index of Biological Integrity
MB: Maintain Biodiversity
STS: Sustain Trophic Structure

MEASURE DEVELOPMENT

The Technical Working Group determined that this measure is easily evaluated in the field using standard protocols and that it is an important element of impacts to stream function and restoration projects. The original model used categorical bins to translate the cover data to index values, but it was revised to a continuous data model to better use the precise data collected and to improve sensitivity to action.

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c) Native Woody Vegetation

MEASURE TEXT

What is the percent cover of native woody vegetation within the PAA?

Conduct a line-intercept survey along three transects in the PAA to evaluate riparian vegetation composition for three functional groups of vegetation, including native woody vegetation.

MEASURE DESCRIPTION

This measure indicates the presence and relative abundance of native woody vegetation. The biotic community is the most visible testament to the overall health of the river system. The vegetation community provides a spatially persistent and somewhat long-lived metric to evaluate habitat availability, diversity, and food resource availability on the floodplain or at the stream margin. Increased cover of woody vegetation often indicates higher quality riparian areas as the vegetation can create microclimates, increase habitat complexity, facilitate terrestrial/aquatic interactions, and provide organic material to the stream system.

Function Group: Biology
Functions Informed: Maintain Biodiversity (MB), Create and Maintain Habitat (CMH)
Stratification: This measure is not stratified
Metric: Percent cover

Model:
IF WoodyVeg < 20, THEN=0.015*WoodyVeg;
IF WoodyVeg = 20–60, THEN= 0.01*WoodyVeg + 0.1;
IF WoodyVeg > 60, THEN=0.0075*WoodyVeg + 0.25

Table 4.8 Native Woody Vegetation Scoring Index

Native Woody Vegetation as measured by percent cover			
Function Value Ranges	**Low**	**Moderate**	**High**
Field Value	< 2 0	20–60	> 60
Index Value	0.0 – < 0.3	0.3–0.7	> 0.7–1.0

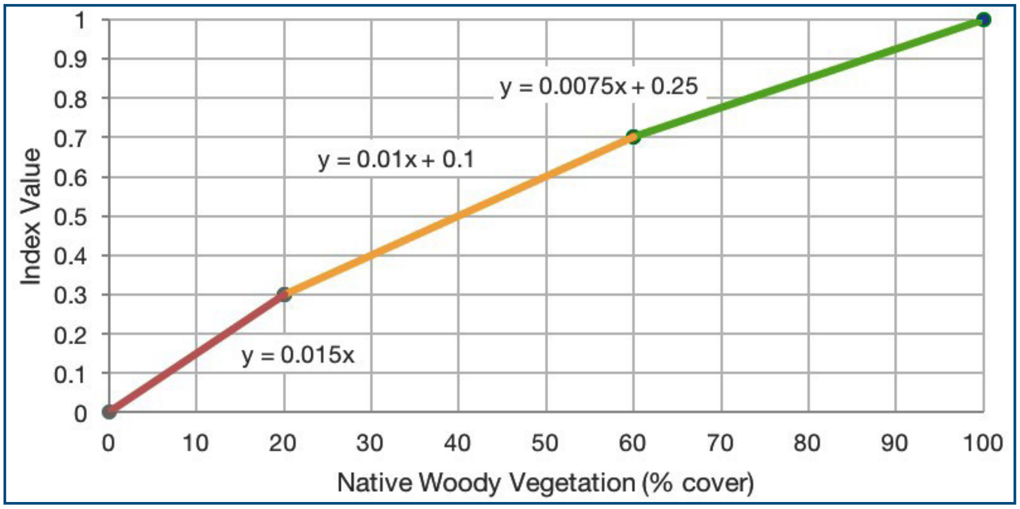

Figure 4.9 Woody Vegetation Standard Performance Index

STANDARD PERFORMANCE INDEX

Development Method

Riparian ecosystems provide essential ecological functions and are the focus of extensive research which indicates that while plant species may vary, native vegetation, including woody species, supports high functioning aquatic systems (see papers cited in Poff *et al.,* 2012). The development of the standard performance index for this measure was informed by data from studies conducted in the Western U.S., and index thresholds are based on an assessment of these studies and current scientific understanding.

The model for this measure uses continuous data to make the best use of the data collection method.

SCIENTIFIC SUPPORT FOR ECOLOGICAL FUNCTIONS

Biologic Function

In Western Oregon, riparian areas with shrub cover of approximately 60–85% occur naturally in mature forests (Pabst and Spies, 1998; Hibbs and Bower, 2001). In the John Day River Basin of Eastern Oregon, cover by shrubs ranged from 0–65% in reaches where grazing was prevented and with better riparian area function (e.g. association with higher mesic and wetland plant diversity) (Kauffman *et al.,* 2002). In a high mountain meadow (Stanley Basin, Idaho), light or medium grazing reduced willow cover 19% and 27% respectively, compared to no grazing over 10 years; however, all three treatments showed increases in willow cover suggesting sites represented some recovery of condition and are within the range of moderate to good function (Clary, 1999). Taken together, studies suggest that in more arid eastern regions, shrub cover (like tree cover) can range considerably in streams considered to be in relatively good condition, however the addition of shrubs and trees can improve function for species that depend on wetland-type environments and shade. High stream function is likely to occur where woody vegetation is greater than 60%, whereas reductions of approximately 20–40% of woody vegetation cover can still provide moderate stream function.

Table 4.9 Summary of Supporting Literature for Native Woody Vegetation Standard Performance Index

Reference	Metric	Function Response Variable	SFAM Functions Informed	Informative Conclusion
Hibbs and Bower, 2001	% cover by overstory canopy (conifer or hardwood), shrubs, herbs; seedlings per hectare	Managed riparian area or unlogged	MB, CMH,	High function streams may have large tree cover ≥50% and woody vegetation cover ≥85%
Pabst and Spies, 1998	% cover by species	Vegetation community	MB, CMH,	High function streams may have mean woody vegetation cover of 63%
Kauffman *et al.,* 2002	% cover for shrubs, trees	Indices of plant biodiversity, wetland indicator score	CMH	Woody vegetation cover above 65% indicates good condition with elevated function
Clary, 1999	% willow cover	Vegetation community	CMH	Light or medium grazing reduced woody vegetation recovery 19% and 27% respectively

Notes:
CMH: Create and Maintain Habitat
MB: Maintain Biodiversity

MEASURE DEVELOPMENT

The original model used categorical bins to translate the cover data to index values, but it was revised to a continuous data model to better use the precise data collected and to improve sensitivity to action.

REFERENCES CITED

Clary, W. (1999) Stream channel and vegetation responses to late spring cattle grazing. Journal of Range Management 52:218-227

Hibbs, D.E. and Bower, A.L. (2001) Riparian forests in the Coast Range. Forest Ecology and Management 154:201-213

Kauffman, J. B., Bayley, P., Li, H., McDowell, P., Beschta, R.L. (2002) Chapter 1 Riparian Vegetation Composition in Paired Grazed and Ungrazed Stream Reaches in Northeastern Oregon in Research/Evaluate Restoration of NE Oregon Streams: Effects of Livestock Exclosures (Corridor Fencing) on Riparian Vegetation, Stream Geomorphic Features, and Fish Populations. Final Report to the Bonneville Power Administration. Oregon State University and University of Oregon. September 17, 2002

Pabst, R.J. and Spies, T.A. (1998) Distribution of herbs and shrubs in relation to landform and canopy cover in riparian forests of coastal Oregon. Canadian Journal of Botany 76:298- 315

Poff, B., Koestner, K.A., Neary, D.G., Merritt, D. (2012) Threats to western United States riparian ecosystems: A bibliography. Gen. Tech. Rep. RMRS-GTR-269, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO 78 p

d) Large Trees

MEASURE TEXT

What is the percent cover of large trees (dbh>20 in) within the PAA?

Conduct a line-intercept survey along three transects in the PAA to evaluate riparian vegetation composition for three functional groups of vegetation, including large trees. Large trees are those trees with a diameter at breast height (DBH) greater than 20 inches. Note that cover from large, native trees will be counted twice; once as native woody vegetation and once as large trees.

MEASURE DESCRIPTION

This measure indicates the presence and relative abundance of large trees. The biotic community is the most visible testament to the overall health of the river system. The vegetation community provides a spatially persistent and somewhat long-lived metric to evaluate habitat availability, diversity, and food resource availability on the floodplain or at the stream margin. The presence of large trees is assessed independently from other types of woody vegetation as it indicates longevity of the riparian habitat.

Function Group: Biology
Functions Informed: Maintain Biodiversity (MB), Create and Maintain Habitat (CMH)
Stratification: This measure is stratified based on geographic regions of Oregon: West and East
Metric: Percent cover

Model:
West Region:
IF LgTree < 10, THEN = 0.03*LgTree
IF LgTree = 10–50, THEN = 0.01*LgTree + 0.2;
IF LgTree > 50, THEN = 0.006*LgTree + 0.4;

East Region:
IF LgTree < 10, THEN = 0.03*LgTree
IF LgTree = 10–20, THEN = 0.04*LgTree - 0.1;
IF LgTree > 20, THEN = 0.0038*LgTree + 0.625;

Table 4.10 Large Trees Scoring Index

Large Trees as measured by percent cover			
Function Value Ranges	**Low**	**Moderate**	**High**
West of Cascade Mountain range	< 10	10–50	> 50
East of Cascade Mountain range	< 10	10–20	> 20
Index Value	0.0 – < 0.3	0.3–0.7	> 0.7–1.0

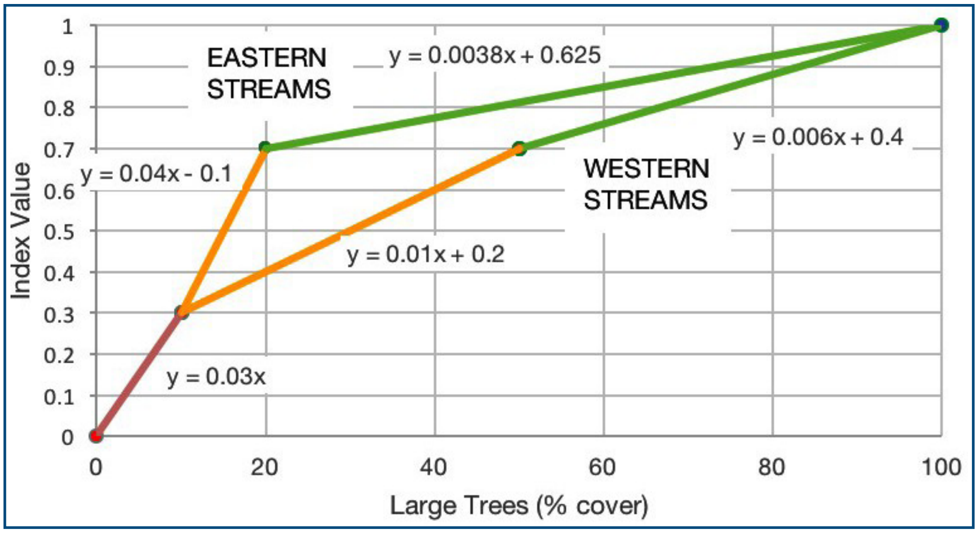

Figure 4.10 Large Trees Standard Performance Index

STANDARD PERFORMANCE INDEX

Development Method

The development of the standard performance index for this measure was informed by data from studies conducted in the Pacific Northwest, and index thresholds are based on an assessment of studies specific to Oregon.

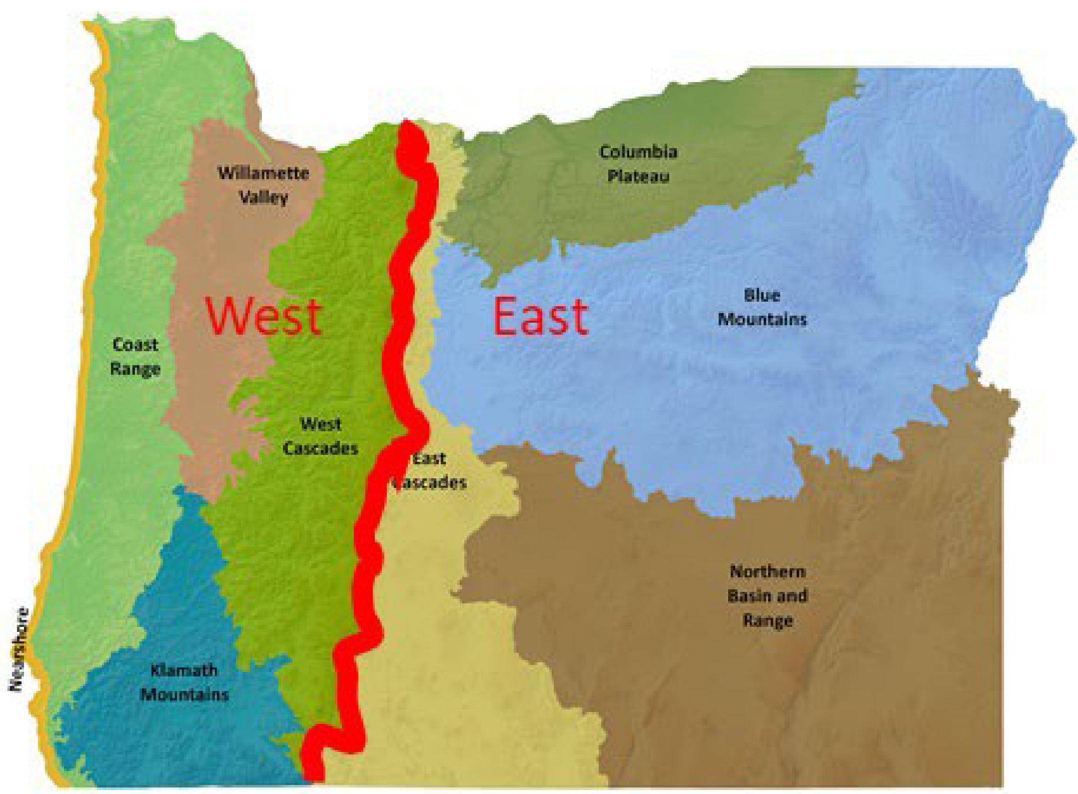

Figure 4.11 USEPA Level III Ecoregions in Oregon
Modified from original image (Oregon Department of Fish and Wildlife, Oregon Conservation Strategy: http://oregonconservationstrategy.org/ecoregions/)

Stratification

Trends presented in the literature supported stratifying expectations of large tree cover based on geographic position in the state. Specifically, Allen and Dent (2001) and Dent (2001) compared conditions at sites statewide and their data indicated that the cover of large trees around streams differs noticeably between west and east regions of the state. The west side of the state includes the following USEPA Level III ecoregions: Coast Range, Willamette Valley, Klamath Mountains, and West Cascades. The east side of the state includes the following USEPA Level III ecoregions: Eastern Cascades, Columbia Plateau, Blue Mountains, Northern Basin and Range, and Snake River Plain (**Figure 4.11**).

SCIENTIFIC SUPPORT FOR ECOLOGICAL FUNCTION

Biologic Function

In the western part of the state, plant composition in mature riparian areas, with no human disturbance or forest management, is patchy due to natural disturbance regimes, geology, or successional processes. Mature riparian forests may have alternating patches dominated by large mature trees and shrubs and herbs. Riparian areas with greater than 50% cover of large trees occur naturally in mature forests, and therefore are considered to represent high ecological function. In a study characterizing riparian ecosystems throughout Oregon's Coast Range, Nierenberg and Hibbs (2000) found that cover from large trees in mature coastal forests dominated 47–77% of study plots (depending on slope). In a similar study of Coast Range riparian forests, Hibbs and Bower (2001) found that canopy cover from large trees ranged from 52% in conifer-dominated areas to 74% in hardwood dominated areas. These studies suggest that in the western region of the state, high stream function is achieved with ≥ 50% cover provided by large trees.

Nierenberg and Hibbs (2000) found that hardwoods may outcompete conifers in coastal forests but conclude that hardwoods provide the same functions as conifers with the exception of the amount and quality of habitat-shaping large wood provided to the stream.

Differences in mature forest between eastern and western regions of the state appear to reflect natural processes in highly-functioning riparian areas. In the eastern region, woody vegetation cover may vary considerably across streams considered to be in good condition. Kauffman *et al.* (2002) found that total cover of woody vegetation (trees + shrubs) ranged from 1 to 129% across stream reaches in various conditions, with cover by trees ranging from 0 to 9%. Dent (2001) showed that on eastern region streams, the number of large trees (basal area of hardwoods + conifer) and the maximum canopy cover provided (which creates shading that contributes to habitat structure) is on average about half the number as on western region streams. Review of literature on mature forests (Dent, 2001) shows the basal area of mature trees in managed forest in the eastern region may be, on average, three quarters of that in the western region. Managed riparian stands in the eastern region tend to be dominated by conifers with little hardwood compared to western region riparian stands. Shade over streams in the eastern region appears to be more sensitive to the presence of additional mature trees than the Coast Range.

Allen and Dent (2001) developed two separate models to relate forest cover to shade for the two regions. In the Blue Mountains (eastern region), a difference in tree number (basal area) was observed for areas providing different levels of shade to a stream, especially in areas at least 40 feet away from bankfull width of the stream and greater. No differences in the number of trees providing shade were observed in Coast Range streams (Allen and Dent, 2001). In the eastern region, mature trees may not be present even in stream sections considered to be in good condition, however where mature trees are present, shading improves function by lowering temperatures, and the presence of large trees is associated with more salmonids and sculpins, and higher macroinvertebrate biomass (Tait *et al.,* 1994). The effect of the increase in biomass on trophic interactions may depend on the macroinvertebrate species composition. These studies provide evidence that, in the eastern region, expectations for high stream function are met with less large tree cover (≥ 20%) than in the western region.

Generally, canopy cover provided by large trees has been found to be similar between unlogged forests and managed riparian buffers adjacent to logged areas which supports the use of managed riparian buffers for maintaining stream function (Hibbs and Bower, 2001; Dent, 2001; Allen and Dent, 2001). A literature review showed cover values (as it relates to shade) ranged up to 75 to 82% in old growth stands, 89% in stands with no recent harvest, 71–90% in harvested areas with 30 to 50-foot buffers (Allen and Dent, 2001). However, the probability of trees becoming large wood is reduced in managed riparian stands compared to unlogged stands by as much as 60% (Dent, 2001), and unharvested stands tended to have greater average shade, live crown ratios, tree heights, basal area, and trees per acre in both the West and East Regions, but especially in the East (Allen and Dent, 2001). Total shade-producing cover was approximately 17% less in unharvested Blue Mountain sites compared to Coast Range sites, but approximately 27% less in harvested sites (Allen and Dent, 2001). For SFAM purposes, the assumption was made that managed riparian buffers, while affected by human disturbance, still contribute to a moderate to high stream function, with better function in the western region.

Table 4.11 Summary of Supporting Literature for Large Tree Standard Performance Indices

Reference	Metric	Function Response Variable	SFAM Functions Informed	Metric Classification	Informative Conclusion
Decision Support for Biologic Functions					
Nierenberg and Hibbs, 2000	Species, DBH, age, dominant overstory type, tree regeneration	Frequency of dominant cover type	MB, CMH	West	High function streams may have large tree cover ≥50%
Hibbs and Bower, 2001	Percent cover by overstory canopy (conifer or hardwood), shrubs, herbs; seedlings per hectare	Managed riparian area or unlogged	MB, CMH	West	High function streams may have large tree cover ≥50%
Dent, 2001	Trees per 1,000 feet	Large wood recruitment potential, shade	CMH	West, East	In western region, high function streams may have large tree cover ≥50%. In eastern region, high function streams may have large tree cover 25-40%; supports stratification by region
Allen and Dent, 2001	Trees per 1,000 feet	Shade	CMH	West, East	Contribution of riparian trees to shade differs between east and west regions; supports stratification by region
Kauffman et al., 2002	% cover for shrubs, trees	Indices of plant biodiversity, wetland indicator score	CMH	East	Woody vegetation cover above 65% indicates good condition with elevated function

Notes:
CMH: Create and Maintain Habitat
DBH: Diameter at Breast Height
MB: Maintain Biodiversity

MEASURE DEVELOPMENT

The original model used categorical bins to translate the cover data to index values, but it was revised to a continuous data model to better use the precise data collected and to improve sensitivity to action.

REFERENCES CITED

Allen, M. and Dent, L. (2001) Shade Conditions Over Forested Streams in the Blue Mountain and Coast Range Georegions of Oregon. Oregon Department of Forestry. ODF Technical Report 13, August 2001

Dent, L. (2001) Harvest effects on riparian function and structure under current Oregon forest practice rules. Oregon Department of Forestry. ODF Technical Report 12, July 2001

Hibbs, D.E. and Bower, A.L. (2001) Riparian forests in the Coast Range. Forest Ecology and Management 154:201-213

Hughes, R.M., Howlin, S., Kaufmann, P. R. (2004) A Biointegrity Index (IBI) for Coldwater Streams of Western Oregon and Washington, Transactions of the American Fisheries Society 133 (6):1497-1515

Kauffman, J.B., Bayley, P., Li, H., McDowell, P., Beschta, R.L. (2002) Chapter 1 Riparian Vegetation Composition in Paired Grazed and Ungrazed Stream Reaches in Northeastern Oregon in Research/Evaluate Restoration of NE Oregon Streams: Effects of Livestock Exclosures (Corridor Fencing) on Riparian Vegetation, Stream Geomorphic Features, and Fish Populations. Final Report to the Bonneville Power Administration. Oregon State University and University of Oregon, September 17, 2002

Morley, S.A. and Karr, J.R. (2002) Assessing and restoring the health of urban streams in the Puget Sound basin. Conservation Biology 16 (6):1498-1509

Nierenberg, T.R., and Hibbs, D.E. (2000) A characterization of unmanaged riparian areas in the central Coast Range of western Oregon. Forest Ecology and Management 129:195-206

Tait, C.K., Li, J.L., Lamberti, G.A., Pearsons, T.N., Li, H.W. (1994) Relationships between riparian cover and community structure of high desert streams. Journal of the North American Benthological Society 13 (1):45-56

e) Vegetated Riparian Corridor Width

MEASURE TEXT

What is the average width of the vegetated riparian corridor within the PAA?

An intact vegetated riparian corridor is defined as one typified by largely undisturbed ground cover and dominated by "natural" species. Natural does not necessarily mean pristine and can include both upland plants and species with wetland indicator status, and native and non-native species. Natural does not include pasture or cropland, recreational fields, recently harvested forest, pavement, bare soil, gravel pits, or dirt roads. Note that relatively small features, such as a narrow walking trail, that likely have negligible effects on water quality can be included within the vegetated riparian corridor width.

MEASURE DESCRIPTION

This measure quantifies the length between the wetted edge of the channel and the point at which natural vegetation ceases, averaged across transects within the PAA. An intact vegetated riparian corridor acts as a filter for water and other material entering the stream from the adjacent watershed. Riparian vegetation provides a buffer from the potential negative impacts of adjacent land uses and reduces the amount of nonpoint source pollutants (sediment, nutrients) that reach the stream.

Function Group: Water Quality
Functions Informed: Nutrient Cycling (NC), Chemical Regulation (CR)
Stratification: This measure is not stratified
Metric: Absolute value (feet)

Model:
IF RipWidth < 33, THEN = 0.0091*RipWidth
IF RipWidth = 33–99, THEN = 0.0061*RipWidth + 0.1;
IF RipWidth > 99, THEN = 0.0013*RipWidth + 0.5703;
IF RipWidth > 328, THEN = 1.0

Table 4.12 Vegetated Riparian Corridor Width Scoring Index

Vegetated Riparian Corridor Width (feet)				
Function Value Ranges	Low	Moderate	High	
Field Value	< 33	33–99	> 99–328	> 328
Index Value	0.0 – < 0.3	0.3–0.7	> 0.7–1.0	1.0

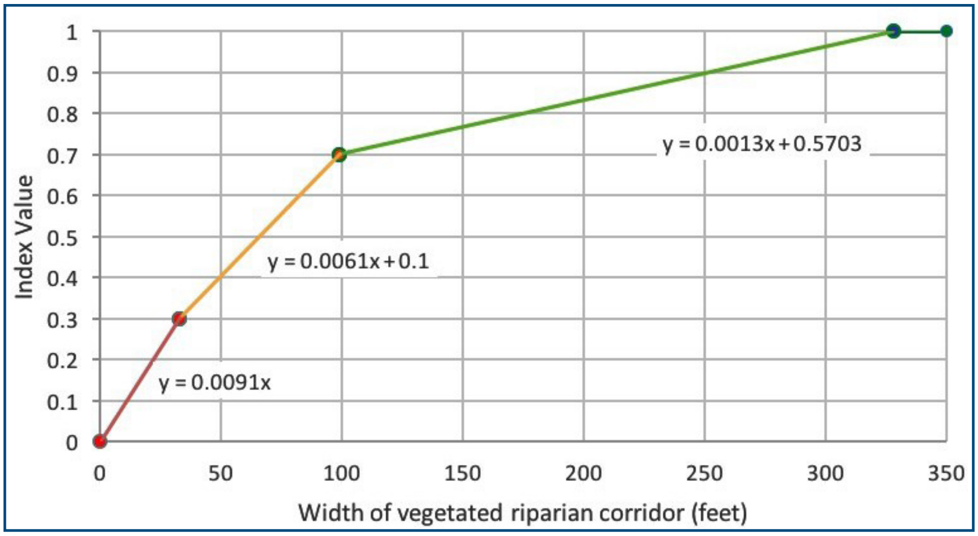

Figure 4.12 Vegetated Riparian Corridor Width Standard Performance Index

STANDARD PERFORMANCE INDEX

Development Method

Extensive work has been done evaluating the effectiveness of vegetated riparian corridors, and the width of such corridors, in attenuating excess nutrients and other pollutants and improving stream water quality (e.g. Mayer *et al*., 2005) and it remains an active area of research. The development of the standard performance index for this measure was informed by data from studies conducted primarily in the western U.S., and index thresholds are based on an assessment of these studies.

SCIENTIFIC SUPPORT FOR ECOLOGICAL FUNCTIONS

Water Quality Functions

Individual studies (Wigington *et al*., 2003; Sakamaki and Richardson, 2011) and literature reviews (Gomi *et al*., 2005; Sweeney and Newbold, 2014) have found the effect of riparian buffer width on stream water quality measures and nutrient inputs, cycling, and removal to be geographically specific and related to site and regional variables such as hillslope, upslope land management, evapotranspiration potential, stream gradient, and discharge. While riparian harvest clearly impacts stream ecosystems, in a meta-analysis of studies the direction and magnitude of change in water chemistry, primary production, and organic matter inputs was highly variable (Richardson and Béraud, 2014). Anderson *et al.* (2007) find that effective riparian buffer width can be defined by topographic variation or vegetation community transition, while Gomi *et al.* (2005) suggest that riparian substrate composition be considered. Despite the variable influence of riparian buffer width, studies in the Pacific Northwest lead to some generalizations, discussed below.

In the literature reviewed here, stream discharge data is not always given. Streams were typically identified as "headwaters," "tributaries," or by stream order. Based on the description of the streams available in the text and photographs, almost all streams studied would be considered small to medium in size (< 70 feet wide). The review by Sweeney and Newbold (2014) considers results from studies of 1st–5th order streams; however, results are not given by stream size. It is possible that larger streams are less studied because of challenges with manipulating the riparian buffer and detecting changes in function on a large scale.

Nutrient Cycling

In the Willamette Valley, Oregon, Sobota *et al.* (2012) used a ^{15}N tracer to look at the fate of nitrate in forested streams compared to urban and agricultural streams with and without a riparian buffer. Urban and agricultural streams with a buffer displayed export and uptake storage components more similar to forested streams than did those without a buffer. Nitrogen was more likely to be taken up by filamentous algae in streams without a riparian buffer (Sobota *et al.,* 2012). Uptake by autotrophic organisms may help explain why some studies have found no difference in dissolved nutrients when comparing post-harvest treatments in small streams (0 m, 10 m [33 ft], 20 m [66 ft] buffer) (Kiffney *et al*., 2003).

Studies done on small streams in an experimental forest in southwestern British Columbia find that the chemical signature of fine stream sediment POM varied with reach-scale conditions, including inputs of coarse POM (Sakamaki and Richardson, 2011), but that clear-cut reaches contributed significantly less litter than reaches with either a 10 m (33 ft) or 30 m (99 ft) riparian buffer (Kiffney and Richardson, 2010). However, decomposition rate of alder litter was significantly slower in clear-cut, 10 m (33 ft) buffer, and 30 m (99 ft) buffer reaches compared to reference reaches (Lecerf and Richardson, 2010). Therefore, we conclude that any buffer as narrow as 10 m (33 ft) for forested, agricultural, or urban streams may indicate a nutrient cycling function of moderate, but that buffers equal to or greater than 30 m (99 ft) are required, even in small streams, to ensure high functioning nutrient cycling similar to function prior to harvest or land use changes (Lecerf and Richardson, 2010; Sweeney and Newbold, 2014).

Chemical Regulation

Though many pollutants can impact stream health, the most commonly studied in the literature are excess nitrate (Wigington *et al*., 2003; Sweeney and Newbold, 2014) and excess or contaminated sediment input (Gomi *et al.,* 2005; Sweeney and Newbold, 2014). In understanding how buffer width relates to nitrate and sediment removal, we point to the review by Sweeney and Newbold (2014) where the authors consider 30 studies on nitrate removal by riparian corridors ranging from 5-220 m (16–722 ft), and 22 studies on sediment removal by riparian corridors ranging from 3-65 m (10–213 ft) in width. Plant compositions ranged from grass, sedge, herb, and shrub mix to forest. By combining data from these studies, Sweeney and Newbold (2014) developed an exponential relationship between buffer width and nitrate removal efficiency and a hyperbolic relationship between buffer width and sediment removal which are shown in graphical form below (**Figure 4.13**). Since Sweeney and Newbold (2014) included studies with riparian corridor plant composition dominated by a range of vegetation types (grass and sedge, shrub, herb, or forest), the results are applicable to both the Western Mountains and Xeric ecoregions in the Pacific Northwest.

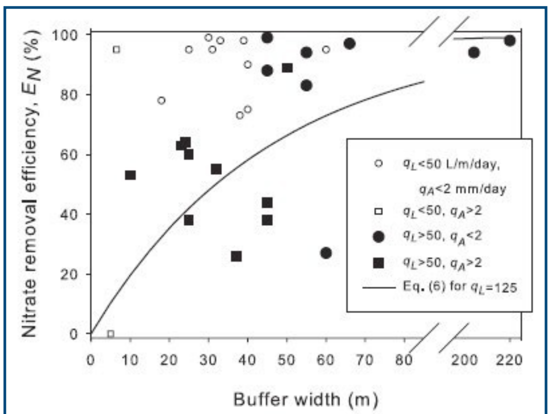

FIGURE 1. Nitrate Removal Efficiency *vs*. Buffer Width. Solid fill designates buffers receiving water flux $q_L \geq 50$ l/m/day. Square symbols designate areal loadings $q_A > 2$ mm/day. The curve is Equation (6) for $\alpha = 2.72$ l/m^2/day and $q_L = 125$ l/m/day.

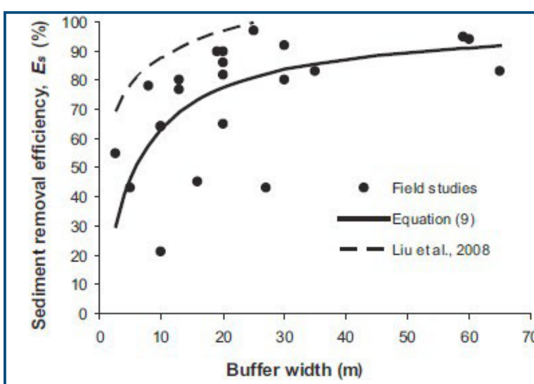

FIGURE 3. Sediment Removal Efficiency *vs*. Buffer Width. Studies were conducted in unconfined field settings or in plots where hydraulic loading was >1.0 l/m/s. Also shown are the least-squares fit of Equation (8) and the equation obtained by Liu *et al.* (2008), as fitted to 79 studies conducted under a broad range of conditions.

Figure 4.13 Relationship between Riparian Buffer Width and Nitrate or Sediment Removal Efficiency

Note: data from (Sweeney and Newbold, 2014)

Critical to being able to use the nitrate removal equation for buffer width is knowing the amount of subsurface flow (q) through the buffer at medium depth since that will affect removal efficiency (1.5–2.1 m [5-7 ft] depth) (Wigington *et al.,* 2003; Sweeney and Newbold, 2014). In addition, it is important to know the contribution of subsurface flow to total streamflow. For instance, a study of grassy agricultural 30-48 m (99-158 ft) buffers in the Willamette Valley found that buffers removed significantly more nitrate than the non-buffered treatment, but that in this case, poorly draining soils reduced subsurface flow and subsurface flow was such a small component of streamflow it did not have a measurable effect on stream nitrogen (Wigington *et al.,* 2003). Higher subsurface flow may enhance nitrate removal in waters passing through the biologically active root zone of the riparian area. To meet the objective that SFAM be a relatively rapid assessment of stream function, it is understood that subsurface flow may not be quantitatively characterized for most study sites. However, substrate conductivity may be roughly estimated based on known local geology. For sites where subsurface flow is sufficient to contribute substantially to streamflow, Sweeney and Newbold (2014) suggest a simplified model for nitrate removal efficiency where a 30 m (99 ft) buffer will have 48% nitrate removal efficiency, increasing to 90% removal efficiency for a 100 m (328 ft) buffer.

For sediment removal, the relationship is more straightforward, yet knowledge of K_{50}, the 50% efficiency buffer width, is still required and may not be readily available. Sweeney and Newbold (2014) suggest a simplified model for sediment removal efficiency where a 10 m (33 ft) buffer would remove approximately 65% of sediments and a 30 m (99 ft) buffer will trap about 85%. Sediment removal (and therefore chemical regulation for other pollutants) occurs at the surface and depends less on subsurface connectivity than nitrate removal.

We have plotted these relationships below, with nitrate removal in blue and sediment removal in black (**Figure 4.14**). An important observation is that for all stream sizes, riparian buffers show more efficient removal of sediment than nitrates for a given buffer width, as shown by the difference between the blue and black lines in **Figure 4.14**. It should also be noted that for streams with poor subsurface flow conductivity, the curves for nitrate removal efficiency would be shifted farther toward the left in this plot.

Nutrient cycling is largely driven by nitrogen cycles. Nitrate removal shows a similar response to riparian buffer width as nutrient cycling. **Table 4.13** shows a comparison of the magnitude of the response of each type of chemical response summarized by the literature presented here.

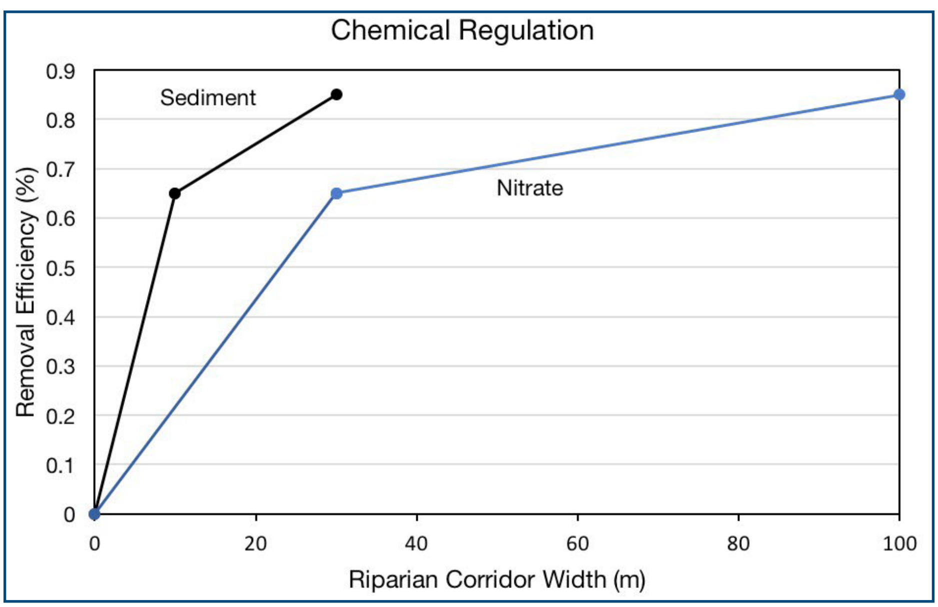

Figure 4.14 Relationships between Vegetated Riparian Corridor Width and Chemical Removal for Small to Medium Streams (Watersheds from 5-10,000 ha or 1st-5th Order Streams)

Table 4.13 Summary of Magnitude of Change in Stream Function with Increase in Riparian Width

	Functional Response		
Riparian Buffer Width	**Nutrient Cycling**	**Nitrate Removal**	**Sediment Removal**
< 10 m (< 33 ft)	Low	--	--
10 m (33 ft)	Moderate	--	65%
30 m (99 ft)	High	48%	85%
100 m (328 ft)	--	90%	--

To support SFAM use, a relatively conservative standard performance index was developed based on the magnitude in change of nitrate removal and nutrient processing in areas of good subsurface flow in order to encompass a more general relationship between riparian buffer width and chemical and nutrient function.

Table 4.14 Summary of Supporting Literature for Vegetated Riparian Corridor Width Standard Performance Index

Reference	Metric	Function Response Variable	SFAM Functions Informed	Metric Classification	Informative Conclusion
Decision Support for Chemical and Nutrient (Water Quality) Functions					
Sweeney and Newbold, 2014	Review Paper- buffer width to maintain stream health	Relevant functions: 1) Subsurface nitrate removal, 2) Sediment trapping	CR	Various	Buffers ≥ 30 m wide are needed to protect the physical, chemical, and biological integrity of streams with watersheds 0.05-100 km2 (5-10,000 ha), or about fifth order or smaller in size.
Richardson and Béraud, 2014	Meta-Analysis: effect size of riparian harvest treatments	Water chemistry, primary production, fine and coarse organic matter	NC, CR	Various	Absolute value effect size in multiple measures was statistically significant. A publication bias for changes in conductivity, pH, phosphorus concentration results was found.
Kiffney and Richardson, 2010	Buffer width treatments: 0 m, 10 m, 30 m, control	Litter (CPOM)	NC	West, No Floodplain (headwaters)	Input of CPOM was lower at clearcut sites; "A model with both linear and quadratic terms suggests a positive slope between litter inputs and buffer width, with a unit increase in reserve width from clear-cut sites up to about 10 m to 30 m treatments, with no further increase past this point."
Lecerf and Richardson, 2010	Buffer width treatments: 0m, 10 m, 30 m, control, 50% thinning	Decomposition rate by 1) stream shredder macro-invertebrates, 2) fungal	NC	West, No Floodplain (headwaters)	Significantly slower shredder decomposition in clearcut reach regardless of buffer. No difference in fungal decomposition.

Table 4.14 Summary of Supporting Literature for Vegetated Riparian Corridor Width Standard Performance Index (Continued)

Reference	Metric	Function Response Variable	SFAM Functions Informed	Metric Classification	Informative Conclusion
Decision Support for Chemical and Nutrient (Water Quality) Functions (Continued)					
Sobota *et al.*, 2012	Land use; buffer vs. no buffer, width not given	Nitrogen tracer processing, storage, and fate	NC, CR	West, Floodplain	Urban and agricultural streams with riparian buffer had detectable denitrification and were more similar to forested streams in N cycle; non-buffered stream showed greater uptake by filamentous algae.
Wilkerson *et al.*, 2009	Buffer width treatments: 0 m, 11 m, 23 m, partial harvest with no buffer, control		NC	Maine, USA, forested	Unbuffered streams had significantly elevated concentrations of chlorophyll *a* as well as increased abundance of algae eaters 3 years after timber harvest. Streams with 11 m buffers had substantial (10-fold) but nonsignificant increases in chlorophyll *a* three years after harvest.
Kiffney *et al.*, 2003	Buffer width treatments: 0m, 10 m, 30 m, control	Dissolved nutrients	NC	West, No Floodplain (headwaters)	Dissolved N increased as buffer width decreased, but not significantly.
Sakamaki and Richardson, 2011	Buffer width treatments: 0m, 10 m, 30 m, control; vegetation (conifer or conifer + deciduous mix)	Rock biofilm (stream-origin POM), fine sediment POM, and fine POM suspended in water, and benthic macroinvertebrates	NC	West, No Floodplain (headwaters)	A six-variable model explained 72.6% of total variance in biogeochemical properties of fine POM, but riparian buffer was not significant alone. Fine POM of sediment is a good indicator of local environment, while fine POM of water is not. Sediment fine POM was significantly related to irradiance and coarse POM.
Wigington et al., 2003	Buffer widths: 0m and varying 30-48 m	Nitrate removal	CR	West, Floodplain, Small streams	Riparian buffers of variable width related to significantly lower nitrate in shallow groundwater, but groundwater was a negligible input to total streamflow.
Gomi et al., 2005	Regional review of forest management practices, buffer widths ranged from 0-30 m	Sediment inputs to stream and turbidity	CR	West, No Floodplain (headwaters)	Local hillslope, length of buffer zone along stream, and roads are important to suspended sediment input. Wider buffer should be used in areas with deep unconsolidated sediment.

Notes:
Metric to standard conversions: 10m ≈ 33ft, 15m ≈ 50ft, 20m ≈ 66ft, 30m ≈ 99ft
CR: Chemical Regulation
CPOM: Coarse Particulate Organic Matter DOC: Dissolved Organic Carbon
LWD: Large Woody Debris
NC: Nutrient Cycling
POM: Particulate Organic Matter PP: Primary Production
WQ: Water Quality

Measure Development

This measure underwent significant revision during the development process. The original question determined the (relative) ratio of existing buffer to the minimum buffer width throughout the PAA, where the minimum buffer width varied depending on stream size (estimated discharge). This measure also originally informed the Thermal Regulation function, as a surrogate for natural cover, but proved challenging because it was only appropriate to apply the measure to the Thermal Regulation function when riparian buffers provided overstory cover.

Reviewers found this to be an important measure but suggested that it would difficult for people to estimate discharge (cfs), and that ratios and classes of buffer widths should be avoided. Thus, the measure was subsequently simplified to the length between the wetted edge of the channel and the point at which natural vegetation ceases, averaged across transects within the PAA. Additionally, we developed a Natural Cover measure (see **Section 4.2 (a)**) which better informs the Thermal Regulation function and optimized the Vegetated Riparian Corridor Width measure to inform the Nutrient Cycling and Chemical Regulation functions, as described.

As SFAM continues to develop and relevant information becomes available, stratification of this standard performance index based on stream size could be considered.

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f) Fish Passage Barriers

Measure Text

Is there a man-made fish passage barrier in the PAA?

Select an answer from the drop-down menu. Man-made barriers to fish passage can include structures such as dams, culverts, weirs/sills, tide gates, bridges and fords that can block physical passage or can create unsuitable conditions for passage (e.g. high velocity). The level of passage provided can first be researched in the office using the Man-made Fish Passage Barriers data layer (Fish Passage Barriers in the Habitat Group) in the SFAM Map Viewer, then confirmed in the field. Do not include natural barriers. If more than one barrier is present, answer for the one with the most restricted level of passage (e.g. Blocked).

Not all fish passage barriers are documented, and recent actions to improve fish passage at a barrier may not be reflected in the Fish Passage Barrier data layer. Oregon's fish passage design criteria are found in Oregon Administrative Rule (OAR) 635-412-0035, which can be found at https://sos.oregon.gov/archives/pages/oregon_administrative_rules.aspx. Contact your local Oregon Department of Fish and Wildlife office with questions.

Measure Description

This measure asks about the level of fish passage provided at man-made obstructions within the PAA. Connectivity allows fish to move, unhindered by man-made structures, between habitats. This affects not only the variety and life forms of fish species, but the broader biological community composition, genetics, and resources necessary to sustain a variety of aquatic species.

Function Group: Biology
Functions Informed: Maintain Biodiversity (MB), Create and Maintain Habitat (CMH)
Stratification: This measure is not stratified
Metric: Degree of access

Model:
IF Passage = blocked, THEN = 0.0;
IF Passage = partial, THEN = 0.5;
IF Passage = passable, THEN = 1.0;
IF Passage = unknown or none, THEN = 1.0

Table 4.15 Fish Passage Barriers Scoring Index

Passage measured as degree of access			
Function Value Ranges	**Low**	**Moderate**	**High**
Field Value	Blocked	Partial	Passable, Unknown, or None
Index Value	0.0	0.5	1.0

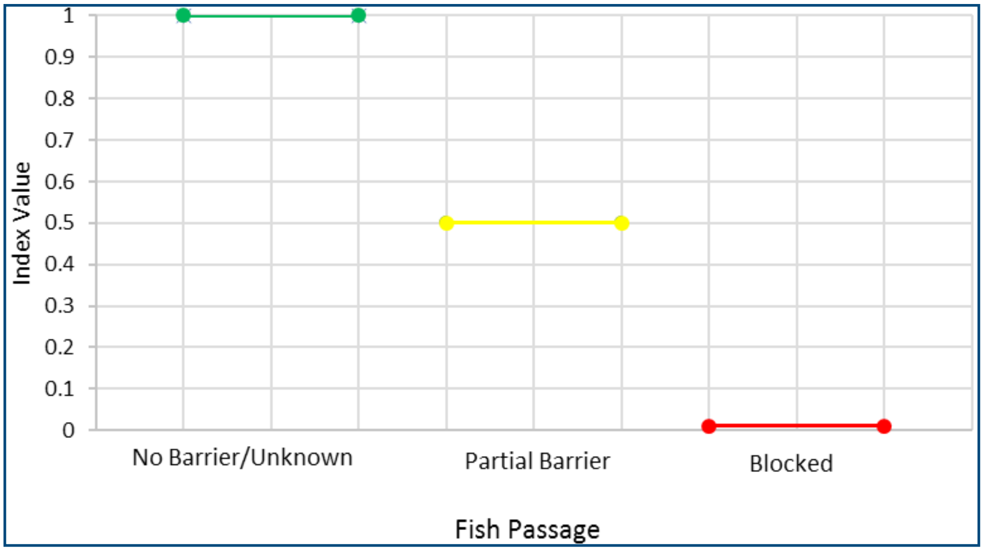

Figure 4.15 Fish Passage Barrier Standard Performance Index

STANDARD PERFORMANCE INDEX

Development Method

There are extensive data related to fish passage barriers, as well as scientific literature linking fish passage connectivity to biologic functions. The standard performance index for this measure was supported by data available through the Oregon Fish Passage Barrier Data Standard (OFPBDS) dataset (2017) (see **Appendix C**). The OFPBS contains over 40,000 barrier features from nineteen different sources. The Oregon Department of Fish and Wildlife's latest inventory shows over 27,800 artificial obstructions to fish passage in the State of Oregon. Of those, only 17% are documented as providing adequate fish passage for native migratory fish.

The model for this measure uses categorical data (as opposed to continuous) given the relative difficulty in objectively assessing the degree of passage at different flow conditions, for different fish species, and for different life stages. Categorical breaks were informed by the relevant literature.

SCIENTIFIC SUPPORT FOR ECOLOGICAL FUNCTIONS

Biologic Functions

Barriers to fish passage can negatively impact a stream's functional ability to Create and Maintain Habitat (CMH) and Maintain Biodiversity (MB) by limiting fish access to needed habitats and resources including spawning grounds, juvenile rearing habitats, food resources, cold-water refugia and protection from high velocities during storm events.

Barriers to fish migration and the resulting fragmentation of stream networks has been recognized as a serious threat to the population diversity, abundance and persistence of many aquatic species world-wide (e.g., Sheldon, 1988; Dunham *et al*., 1997). The construction of infrastructure such as dams, culverts, and other water diversion structures are largely to blame for these connectivity losses (Park *et al*., 2008; Doehring *et al*., 2011). There are over two million dams and other structures across the United States that block fish from migrating to habitats used to complete their lifecycles (NOAA, 2017).

In the Pacific Northwest, barriers to native diadromous fish (salmon and steelhead) to access their spawning grounds has caused significant decreases in fish abundance and contributed to the listing of several Evolutionarily Significant Units (ESUs) on the endangered species list. In an evaluation of the impact of passage barriers to salmon in the Lower Columbia and Willamette River basins, Sheer and

Steele (2006) identified 1,491 anthropogenic barriers to fish passage blocking 14,931 km (9278 mi) of streams; an estimated loss of 40% of fish habitat. Fish passage barriers not only limit access to spawning grounds but can exclude fish from important rearing habitat. In a case study on Washington's Skagit River, Beechie *et al*. (1994) estimated that the summer rearing habitat for Coho salmon (*Oncorhynchus kisutch*) has been reduced by 24% and linked 10% of that reduction directly to culvert barriers.

Salmon are not the only species impacted by fish passage barriers. Lampreys, another important native species, also migrate up many Pacific Northwest streams and are unable to transverse many artificial barriers. Lacking paired fins, lampreys are weak swimmers and have no jumping ability. To climb, they must find rough surfaces that they can cling to in areas with low or moderate currents (Kostow, 2002).

Native non-migratory fish can also be impacted by fish passage barriers. Results from a genetic study of coastal cutthroat trout in southwest Oregon concluded that fish separated by passage barriers can persist as partially independent populations, and that fish passage barriers can dramatically and rapidly influence coastal cutthroat trout genetic variation (Wofford *et al*., 2005).

Some barriers allow for partial fish passage (dependent on season and fish size), meaning that the habitat can be accessed during certain parts of the year. SFAM acknowledges that some function may be provided when passage is only partially blocked.

Table 4.16 Summary of Supporting Literature for Fish Passage Standard Performance Index

Reference	Metric	Function Response Variable	SFAM Functions Informed	Metric Classifications	Informative Conclusions
Decision Support for Biologic Resources					
Beechie *et al*., 1994	Habitat loss	Smolt production	MB	Western Streams	Human impacts, including fish passage barriers (culverts) reduce the rearing capacity of the Skagit river in Washington State.
Sheer and Steele, 2006	Fish passage barriers	Fish habitat	CMH, MB	Fish-bearing streams Oregon	Lower Columbia and Willamette Basin fish passage barriers result in an estimated loss of 40% of fish habitat.
Wofford *et al*., 2005	Fish passage barriers	Genetic variation	MB	Fish-bearing streams coastal Oregon	Fish-passage barriers can dramatically and rapidly influence coastal cutthroat trout genetic variation.

Notes:
CMH: Create and Maintain Habitat
MB: Maintain Biodiversity

MEASURE DEVELOPMENT

Fish Passage Barriers was added as a field measure following pilot testing by the Oregon Department of Transportation. Reviewers commented that SFAM did not seem to properly account for aquatic organism passage needs, especially in the context of evaluating likely restoration activities to improve passage. When present, this measure is used as a 'modifier' (by multiplication) to the instream aspects of the functions it informs (MB, CMH), rather than as a contributing factor to be averaged with other measures informing those functions (**Section 3.3, Table 3.2**). This is the only measure in SFAM used in this way.

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g) Floodplain Exclusion

MEASURE TEXT

What percent of the floodplain area has been disconnected within the PAA?

For alluvial rivers, the floodplain is defined by a distinct break in slope at valley margins, a change in geologic character from alluvium to other, indications of historical channel alignments within a valley, or as the 100-year flood limit.

Disconnection refers to any portion of the floodplain area no longer inundated due to levees, channel entrenchment, roads or railroad grades, or other structures (including buildings and any associated fill) within the proximal assessment area. All barriers should be included when estimating disconnection, even if the barrier is not present during all flood stages (e.g. a barrier up to the 25-year flood, but not during the 100-year flood); except where the structure is expressly managed for floodplain function and inundation.

MEASURE DESCRIPTION

This measure represents a stream's ability to access its floodplain. Floodplain connectivity results in areas that are capable of storing water and providing floodplain habitat. Connectivity to the floodplain allows organisms and material (water, sediment, organic matter) to move, unhindered by anthropogenic structures, perpendicular to the axis of the stream corridor with a frequency consistent with natural flood regimes.

Function Groups: Hydrology, Biology
Functions Informed: Surface Water Storage (SWS) and Create and Maintain Habitat (CMH)
Stratification: This measure is not stratified
Metric: Percent exclusion

Model:
IF Exclusion > 80%, THEN=0.0;
IF Exclusion > 40–80%, THEN=0.2;
IF Exclusion > 20–40%, THEN=0.5;
IF Exclusion ≤ 20%, THEN=1.0

Table 4.17 Floodplain Exclusion Scoring Index

Exclusion measured as percent disconnection				
Function Value Ranges	**Low**		**Moderate**	**High**
Field Value	> 80%	> 40–80%	> 20–40%	≤ 20%
Index Value	0.0	0.2	0.5	1.0

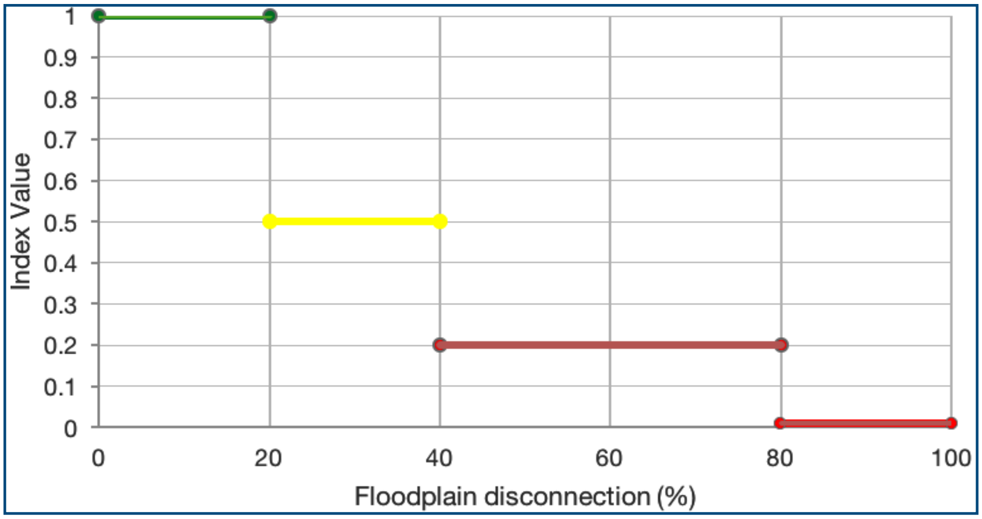

Figure 4.16 Floodplain Exclusion Standard Performance Index

STANDARD PERFORMANCE INDEX

Development Method

There is extensive data related to floodplain exclusion, as well as literature that links floodplain connectivity to hydrologic and biologic functions. The development of the standard performance index for this measure was supported by data from numerous studies throughout the Pacific Northwest.

The model for this measure uses categorical data (as opposed to continuous) given the relative difficulty in rapidly and objectively assessing a precise degree of disconnection. Bin breaks were informed by the relevant literature.

SCIENTIFIC SUPPORT FOR ECOLOGICAL FUNCTIONS

Hydrologic Function

Exclusion, as defined in the SFAM model, has been reported in the literature in terms of floodplain connection or disconnection. Where streams can access their floodplains, floodplains can provide surface water storage in intermittent or ephemeral meanders or wetlands. Most floodplains and floodplain wetlands are highly disconnected from streams in the Pacific Northwest, and it is widely recognized that during high flows, surface water storage can be reduced and flow velocities can increase in the main channel, conveying larger-magnitude flood peaks to downstream areas than under historic conditions. However, little work has been done to directly measure the effect of floodplain disconnection in the Pacific Northwest on surface water storage as a function provided by floodplains. The loss of surface water storage is a growing area of research in the Pacific Northwest due to the desire to better mitigate for large floods that cause damage to developed areas and infrastructure downstream. As a part of a proposal to restore floodplain surface water storage to the Chehalis River Basin in Washington, Abbe *et al.* (2016) reviewed case studies from around the world that could be applicable to floodplain conditions in the Pacific Northwest. Abbe and co-authors (2016) found that maintenance or restoration of connected floodplain, off-channel meanders, and wetland complexes reduced the magnitude of large peak flood events by measurable amounts. For example, in Otter Creek, Vermont, stream flow during Tropical Storm Irene was reduced by more than 50% after flowing through 30 miles of connected floodplain and wetlands in the 9,000-acre Otter Creek swamp complex, which includes conservation and agricultural land (Watson *et al.,* 2016). In Western Alberta, Canada, flood volume from a beaver dam failure was reduced to 7% of the upstream event volume after overbank flow passed through a 90-hectare (222 acre) connected wetland complex (Hillman, 1998). In the Pacific Northwest, the role of the floodplain in the attenuation of flows can be observed in the Skagit River of Western Washington, where during some large precipitation events, peak flow has been observed to decrease across an area of 38 miles of river that is connected to its floodplain between two stream gauges (Abbe *et al.,* 2016). Several recent examples exist from the state of Washington where levee setbacks and active floodplain reconnection are the focus of river restoration projects that have successfully increased surface water storage by allowing inundation of floodplain areas or by restoring perennial flow to abandoned side-channels (Floodplains by Design, 2017). For instance, in the Skagit River tidal floodplain, an increase in connected freshwater marsh area from 10 acres to 56 acres resulted in an increase in flood storage capacity from 64 acre-feet to 309 acre-feet (The Nature Conservancy, 2017). In the City of Portland, Oregon, access to 63 acres of floodplain was restored in the Johnson Creek drainage, allowing for 140 acre-feet of flood storage and reducing downstream flooding and impacts to transportation infrastructure (City of Portland, 2017). Many more small- scale floodplain reconnection projects are in the process of development, and future data on the magnitude of function will result from post-project monitoring.

In summary, evidence from the literature suggests that naturally connected floodplains can provide surface water storage to a large proportion of the volume of large flood events. Relatively smaller-scale, ongoing floodplain reconnection projects have successfully reduced risk of damage by large floods to communities downstream, as well as increased floodplain area available to be shaped by geomorphic processes and to be used as aquatic habitat. Initial monitoring of floodplain reconnection projects suggests that surface water storage function can increase in a roughly linear manner in relation to the area of reconnected floodplain (**Table 4.17**).

Biologic Function

In western coastal regions, emergent floodplain wetlands that are connected to mainstem rivers create ephemeral habitat for non-salmon fish species (Henning *et al.,* 2006), amphibians, and other aquatic species. For instance, extensive surface area of shallow, flooded riverine wetlands with slow-moving water provides habitat for foraging and resting water birds. Riverine wetlands have been reduced by approximately 52% in Oregon's Willamette Valley, with associated shifts in water bird numbers; species that were previously common but are now rare or of unknown abundance include trumpeter swans, snow goose, long-billed curlew, and red-necked phalarope (Taft and Haig, 2003).

Coho salmon appear to thrive and grow in ephemerally connected floodplain wetlands; these habitats are a component of the diverse life histories of the species that allow for resilience to variable river and ocean conditions (Henning *et al.,* 2006). Overall fish abundance appears to be driven by emigration which occurs in summer with an increase in temperature and decline in dissolved oxygen (DO) that occurs with contraction of habitat and disconnection from mainstem flow due to desiccation in summer (Henning *et al.,* 2007). In the floodplain wetland habitats of the Chehalis River Basin in Washington, connections to the mainstem flow occur over variable durations (e.g. 3–275 days), however duration of connection was not related to fish abundance, suggesting even short duration connections are enough to allow fish to use good quality habitat (Henning *et al.,* 2007).

For species that use floodplain habitat for portions of their life-cycle, such as rearing juvenile Coho salmon, floodplain habitat can be more productive than mainstem stream habitat, therefore loss of floodplain connections have an inordinately large effect on the total creation and maintenance of habitat. In a small stream with a relatively narrow floodplain (Carnation Creek, British Columbia) floodplain habitat made up 13.5% of winter habitat for Coho salmon, but contributed 15.3% and 23.1% of the Coho salmon smolts for 1983 and 1984, respectively (Brown and Hartman, 1988). High flows in the main channel reduced contribution of fish rearing in the main channel to total productivity of the population, evidence of the dependence of Coho salmon on slow-water habitat in winter. Annual productivity of floodplain habitat was related to degree of connection created by magnitude of fall flood events, and water levels in ephemeral habitat in spring related positively to Coho production.

In the Skagit and Stillaguamish Rivers of Washington, 52% and 68% of historic floodplain habitat in sloughs and beaver ponds had been lost due to disconnection from the river (Beechie *et al.,* 1994; Pollock *et al.,* 2004). Coho salmon smolt production was estimated to be reduced by a constant factor in relation to floodplain habitat disconnection. In the Skagit River, floodplain disconnection accounted for 73% and 91% of the total reduction in Coho smolt production losses compared to historical condition for summer and winter rearing areas, respectively. In the Stillaguamish River, losses due to floodplain disconnection only were not estimated, but the loss of slough habitat combined with loss of beaver pond habitat in floodplains was extensive, accounting for 28% and 96% of the reduction in Coho smolt production in summer and winter, respectively. These studies suggest that in large rivers with broad floodplains, moderate levels of floodplain disconnection can have a disproportionately large impact on total habitat area for species like Coho salmon that use the floodplain extensively for rearing.

Installation of dams on Oregon's McKenzie River has reduced peak flows to bankfull discharge or less, disconnecting the river from its floodplain and causing channel simplification and reduced habitat complexity for native salmonids (Ligon *et al.,* 1995). Since the installation of dams, there has been a reduction in availability and transport of island-building material (cobble and wood), reduced erosion and transport of spawning gravel from floodplain areas, and reduced area available for spawning, leading to redd superimposition. From 1930 to 1990, wetted area (m^2) was reduced by 27% mainly due to channel simplification and loss of braided reaches. Additionally, the number of islands was reduced by 53%, island area was reduced by 51%, and island perimeter was reduced by 59%. In this case, a moderate reduction in active floodplain area (represented by wetted area) has resulted in a loss of 50–60% of habitat features created by islands.

In the Oregon's Willamette River floodplain, lower mean maximum flows have been reduced compared to historical conditions due to flood storage in reservoirs and riprapped banks impairing habitat-shaping geomorphic processes (Dykaar and Wigington, 2000). Mean annual maximum flow has been reduced to 64% historic flows at Albany (from 3,128 to 1,996 m^3/sec, pre-dam versus post-dam), a city located along the Willamette River. Island area was reduced by 80% between 1910 and 1988. Islands are an important physical substrate to support riparian cottonwood forest development, which create and maintain habitat by adding large woody debris, cause deposition of fine sediment, make fluvial landforms resistant to erosion, and add organic matter to substrate and water. This study (Dykaar and Wigington, 2000) demonstrates that a moderate reduction in flood flows caused a disproportionately large reduction in instream habitat.

The geomorphic response to floods at a 30-year and 7-year recurrence interval was observed to be a function of the degree of confinement and distance downstream of a diversion dam in Washington's Cedar River (Gendaszek *et al.,* 2012). Higher flood stages have been associated with revetments and channel simplification post-dam. Redistribution of sediment, localized channel widening, limited avulsions, and recruitment of large wood occurred mainly in relatively unconfined reaches. In confined reaches, gravel was eroded and redeposited on topographically higher bars where gravel cannot be used by spawning salmon. Pools (used by fish as habitat) were least frequent within an engineered channel at the mouth of the river (river mile 0–3.1) and most frequent in a relatively unconfined section between river mile 9.3 and 12.4. A roughly linear, negative relationship exists between the inverse of the percent of the river bank artificially confined (representing floodplain disconnection) and pool number across sections of river that range from an average of 20-80% artificially confined.

Few studies were found that address the effect of floodplain disconnection on surface water storage or creating and maintaining habitat in xeric areas of Eastern Washington or Oregon, likely because the hydrology in these areas is not driven by winter rain events as on the west side of the Cascades. However, it is clear that prior to the era of dams and diversion of surface water for irrigation, connected floodplains and off-channel habitats were an important habitat and source of temperature refuge in rivers east of the Cascades (Stanford *et al.,* 2002). Blanton and Marcus (2013) observed that in floodplains on both the west and east sides of the Cascades in Washington (Chehalis River Basin and Yakima River Basin, respectively), roads and railroads in valley bottoms are associated with truncated meanders, lower sinuosity, reduced channel complexity, fewer bars and islands, less large wood, reductions in side channel habitat, and less riparian forest cover. Results were similar in the west and east region, and across different channel sizes and valley settings. Similarities in stream response to confinement support that stratification by region or stream size is not warranted for the Floodplain Exclusion measure in the SFAM model.

To summarize, a review of the literature revealed several case studies that demonstrate magnitudes of floodplain connection, disconnection, or channel confinement in association with metrics related to creating and maintaining habitat. Based on the data reviewed, low to moderate levels of floodplain disconnection are associated with disproportionately large losses in stream function, especially creating and maintaining habitat (**Table 4.18**). It is notable that in cases of relatively high floodplain disconnection (e.g., Pollock *et al.,* 2004; Gendaszek *et al.,* 2012), some geomorphic function and habitat use persists, supporting a standard performance index that allows for small increases in stream function indexing up to approximately 80% floodplain disconnection. These data come from disparate sources and represent different methods; however, they provide a general sense of the magnitude of the stream function response to floodplain disconnection.

Table 4.18 Summary of Magnitude of Change in Stream Function with Floodplain Disconnection

Reference	Floodplain Connection Metric	Functional Response Metric
The Nature Conservancy, 2017	5.6-fold area reconnected	4.8-fold increase in flood storage capacity
Beechie *et al.,* 1994	52% loss of floodplain slough area	Floodplain smolt productivity 38% (summer) and 47% (winter) of historic levels
Pollock *et al.,* 2004	68% loss of floodplain slough and beaver pond area	Floodplain smolt productivity 14% (summer) and 9% (winter) of historic levels
Ligon *et al.,* 1995	27% loss of wetted area	Island habitat 41– 49% of historic levels
Dykaar and Wigington, 2000	36% loss of mean annual maximum flow	Island area 20% of pre-dam era
Gendaszek *et al.,* 2012	51%–79% average river bank confinement	0.7–2.8 pools per km; roughly linear correlation with river bank confinement

Table 4.19 Summary of Supporting Literature for Floodplain Exclusion Standard Performance Index

Reference	Metric	Function Response Variable	SFAM Functions Informed	Metric Classifications	Informative Conclusions
Decision Support for Hydrologic Resources					
Abbe *et al.,* 2016	Floodplain, off-channel meander, and wetland disconnection	Annual peak flow magnitude and timing	SWS	West, Floodplain, Perennial	Review of literature identifies examples of flood water storage by connected floodplain systems in North America.
Decision Support for Biologic Resources					
Beechie *et al.,* 1994; Pollock *et al.,* 2004	Loss of Coho salmon floodplain rearing habitat	Coho salmon smolt production capacity	CMH	West, Floodplain, Perennial	Loss of large areas of floodplain slough and beaver pond habitat can account for the majority of total Coho smolt production losses in large rivers.

Table 4.19 Summary of Supporting Literature for Floodplain Exclusion Standard Performance Index (continued)

Reference	Metric	Function Response Variable	SFAM Functions Informed	Metric Classifications	Informative Conclusions
Decision Support for Biologic Resources (continued)					
Brown and Hartman, 1988	First fall storm maximum discharge, off-channel water level, mainstem flow, accessibility	Contribution by floodplain winter habitat to total population productivity	CMH	West, Floodplain, Ephemeral and Intermittent	Seasonally inundated floodplain habitat contributed relatively more Coho salmon smolts than main channel habitat. Productivity was related to connectivity.
Henning *et al.,* 2006, 2007	Duration of ephemeral floodplain wetland connectivity, flow, water quality	Fish abundance, Coho salmon growth and survival	CMH	West, Floodplain, Ephemeral	Multiple fish species use floodplain wetland habitat. Short duration connections can allow large numbers of fish to use habitat. Fish emigration is related to water quality changes that result from seasonal disconnection.
Taft and Haig, 2003	Loss of riverine wetlands	Change in bird species status from common to uncommon or rare	CMH	West, Floodplain, Perennial	Loss of riverine wetlands due to floodplain disconnection contributes to rarity of water birds.
Ligon *et al.,* 1995	Reduction in peak flows due to water storage behind dams	Wetted area of river below dams, island number, island area, island perimeter, redd superimposition, salmon declines	CMH	West, Floodplain, Perennial	Reduced peak flows have led to decreases in wetted area, channel complexity, and substrate available for habitat.
Dykaar and Wigington Jr., 2000	Reduction in peak flows due to water storage behind dams	Reduced island area for cottonwood development	CMH	West, Floodplain, Perennial	Reduced floodplain inundation impairs geomorphic processes and riparian cottonwood forest development that shape habitat for fish.
Gendaszek *et al.,* 2012	Proportion of river banks artificially confined per river mile	Mean pool frequency per every 5 river miles	CMH	West, Floodplain, Perennial	Artificial channel confinement ranging from 20% to 80% was related to pool number and reduced geomorphic response to large floods.
Blanton and Marcus, 2013	Presence or absence of transportation infrastructure	Difference in wetted channel area, large wood, off-channel habitat, riparian forest	CMH	West, East, Floodplain, Perennial	Presence of channel-confining infrastructure is associated with impaired geomorphic and riparian processes that shape habitat. Similar responses seen in a coastal River and interior river, suggesting response to exclusion is similar across ecoregions.

Notes:
CMH: Create and Maintain Habitat
SWS: Surface Water Storage

MEASURE DEVELOPMENT

This measure was ranked highly by the Technical Working Group as an indicator for hydrologic functions. Reviewers commented that it is relatively easy to measure in the field and that it provides valuable information for assessing function, especially in the context of evaluating stream impacts and mitigation activities. The protocol for assessing this measure is based on best professional judgment. Originally, the assessment scale for this measure was the EAA, but this was adjusted to the PAA to limit potential challenges of assessing larger rivers. Additionally, based on the data reviewed in developing the standard performance index, the initial scoring bins were changed to those used currently to reflect that low to moderate levels of floodplain disconnection are associated with disproportionately large losses in stream function, even while in cases of relatively high floodplain disconnection (up to 80%) some geomorphic function and habitat use persists.

Reviewers commented on the seemingly similar nature of this measure and the Overbank Flow measure; Floodplain Exclusion describes the spatial extent of floodplain connectivity while Overbank Flow captures whether or not flooding or overbank flow occurs. Each measure captures a different process.

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h) Bank Armoring

MEASURE TEXT

What percentage of the banks are armored?

What percentage of the streambank has been stabilized using rigid methods to permanently prevent meandering processes? Examples of armoring include gabion baskets, sheet piles, rip rap, large woody debris that covers the entire bank height, and concrete. Bank stabilization methods that return bank erosion to natural rates and support meandering processes are not counted as armoring. Examples include many bioengineering practices, large woody debris placed along the bank toe, and in-stream structures that still use native vegetation cover on the streambanks. Percent armoring is calculated as the sum of the armored lengths of the left and right banks, divided by the sum total of both banks within the PAA (i.e. twice the total PAA length).

MEASURE DESCRIPTION

This measure is an indicator of whether a stream has access to sediment on its banks. Armoring of stream banks prevents natural erosion of channel banks and bottoms during runoff events.

Stream banks can be major contributors of sediment to hydrologic systems. Stream bank armoring can occur naturally due to aggregations of substrate (pebbles, rocks, etc.), but this measure is an indicator of the degree to which manmade armoring (that does not use low-impact bio-engineering techniques) is present.

Function Group: Geomorphology
Function Informed: Substrate Mobility (SM)
Stratification: This measure is not stratified
Metric: Percent of banks stabilized

Model:
IF Armor > 40%, THEN=0.0;
IF Armor > 20–40%, THEN = -0.015*Armor + 0.6;
IF Armor = 10–20%, THEN = -0.04*Armor + 1.1;
IF Armor < 10%, THEN = -0.03*Armor + 1.0

Table 4.20 Bank Armoring Scoring Index

Bank Armoring measured as percent stabilized				
Function Value Ranges	**Low**		**Moderate**	**High**
Field Value	> 40%	> 20–40%	10–20%	< 10%
Index Value	0.0	0.0 – < 0.3	0.3–0.7	> 0.7–1.0

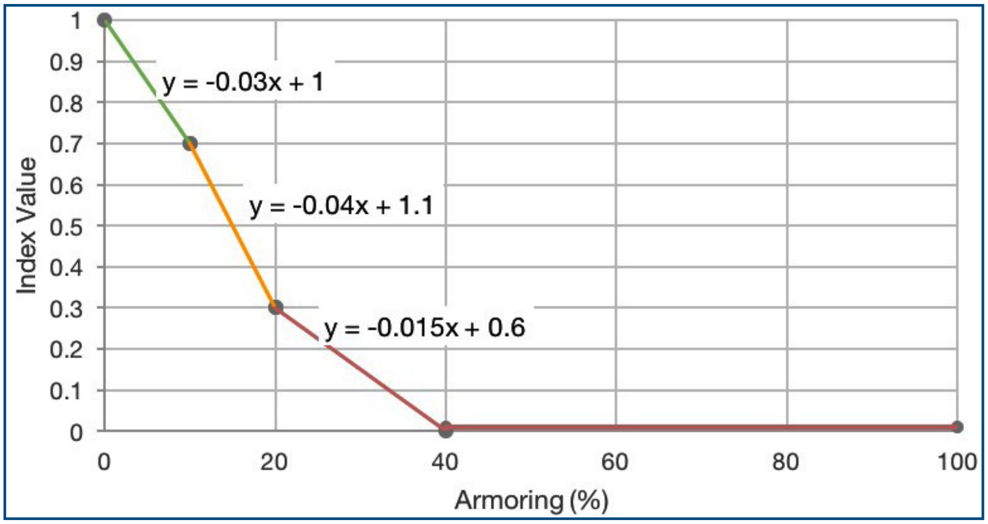

Figure 4.17 Bank Armoring Standard Performance Index

STANDARD PERFORMANCE INDEX

Development Method

Data and literature related to this metric is extremely limited. While scientific studies could not be used to directly inform the development of this standard performance index, the index is supported by current scientific understanding of how stream channel armoring relates to geomorphologic function.

This measure uses continuous data. Calculating the index score using a continuous scale allows for better detection of any change that results from impacts or mitigation activities.

SCIENTIFIC SUPPORT FOR ECOLOGICAL FUNCTIONS

Geomorphic Function

Generally, it is recognized that assessing the change in stream function associated with modifications to geomorphic condition is challenging to do in a rapid assessment or at project- level scales. Geomorphic processes are affected by surrounding landscapes and occur across long distances longitudinally in a stream so that processes that occur many miles upstream are linked to conditions downstream. In streams with high function, sediment transport and sorting occur over such large areas that evaluation on the scale of the PAA represents a snapshot of the overall balance in aggradation and erosion or channel migration. Therefore, it is acknowledged that evaluating geomorphic conditions in one PAA does not fully define the overall geomorphic function of that PAA since it is also affected by processes occurring upstream and downstream.

Anthropogenic bank armoring is assessed in SFAM as an impairment to geomorphic processes and thus an adverse effect on stream function, specifically sediment mobility (SM) (regular movement of the channel bed substrate that provides sorting and flushing). Bioengineered armoring can effectively increase resistance to erosion occurring at an accelerated rate due to anthropogenic disturbance and counteract the adverse effect of unbalanced rates of erosion on stream function.

The relative change in stream function associated with a given geomorphic condition is context-dependent. Generally, controls on the suite of geomorphic processes include climate, geology, vegetation and topography, in addition to past natural or anthropogenic disturbances (Montgomery and MacDonald, 2002). While these controls contribute to the variability in sensitivity of the response of a certain measure of stream function over time and space, we did not find sufficient information to meaningfully stratify the standard performance index at this time.

MEASURE DEVELOPMENT

This measure was highly-ranked by the Technical Working Group and was determined to be relatively easy to measure and highly repeatable. Additionally, statistical analysis of field data indicated that this measure is value-added to the function it informs. Although some reviewers commented that this measure is similar to the Lateral Migration measure, both measures were retained because while bank armoring is a subset of lateral migration, they are not interchangeable as used in SFAM:

- Data for each measure is collected on different scales, PAA and EAA, respectively.
- Bank Armoring informs the Substrate Mobility function, while Lateral Migration informs the Sediment Continuity function.
- There is no redundancy/double counting as they inform different functions.

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i) Bank Erosion

MEASURE TEXT

What percentage of the bank is actively eroding or recently (within previous year or high flow) eroded?

Bank erosion is indicated by vertical or near vertical streambanks that show exposed soil and rock, evidence of tension cracks, active sloughing, or are largely void of vegetation or roots capable of holding soil together. Percent eroding is calculated as the sum of the eroded lengths of the left and right banks, divided by the sum total length of both banks within the PAA (i.e. twice the total PAA length).

MEASURE DESCRIPTION

This measure is an indicator of how active the channel banks are. Channel bank stability is influenced by the cohesiveness and character of bank materials (soil composition, subsoil composition), bank vegetation (rooting characteristics), and the hydraulic forces acting on the bank, particularly at the toe of the bank slope. Stream banks exhibit evidence of eroding, advancing, or stable conditions at rates consistent with natural channel process and in the absence of anthropogenic controls on this process. Stream banks provide sediment supply and allow natural rates of meander to occur within the channel through a process of bank retreat and advancement over time. However, bank erosion and instability can be exacerbated by impacts to channel banks, especially vegetation removal, and by changes in channel hydraulics due to changes in hydrology or channel form. Excessive bank erosion can lead to sedimentation. In some systems, this process is accelerated in response to changing watershed conditions or when the natural process has been retarded by anthropogenic controls (e.g., rip-rap, concrete) applied at the channel-bank interface.

Function Group: Geomorphology
Function Informed: Sediment Continuity (SC)
Stratification: This measure is not stratified
Metric: Percent of bank eroding

Model:
IF Erosion ≥ 60%, THEN = 0.0;
IF Erosion ≥ 40 – <60%, THEN = -0.015*Erosion + 0.9;
IF Erosion ≥ 20 – <40%, THEN = -0.02*Erosion + 1.1;
IF Erosion ≥ 10 – <20%, THEN = -0.03*Erosion + 1.3;
IF Erosion < 10%, THEN = 1.0

Table 4.21 Bank Erosion Scoring Index

Bank Erosion measured as percent eroding					
Function Value Ranges	Low		Moderate	High	
Field Value	≥ 60%	≥ 40 – < 60%	≥ 20 – < 40%	10 – < 20%	< 10%
Index Value	0.0	0.0 – < 0.3	0.3–0.7	> 0.7–1.0	1.0

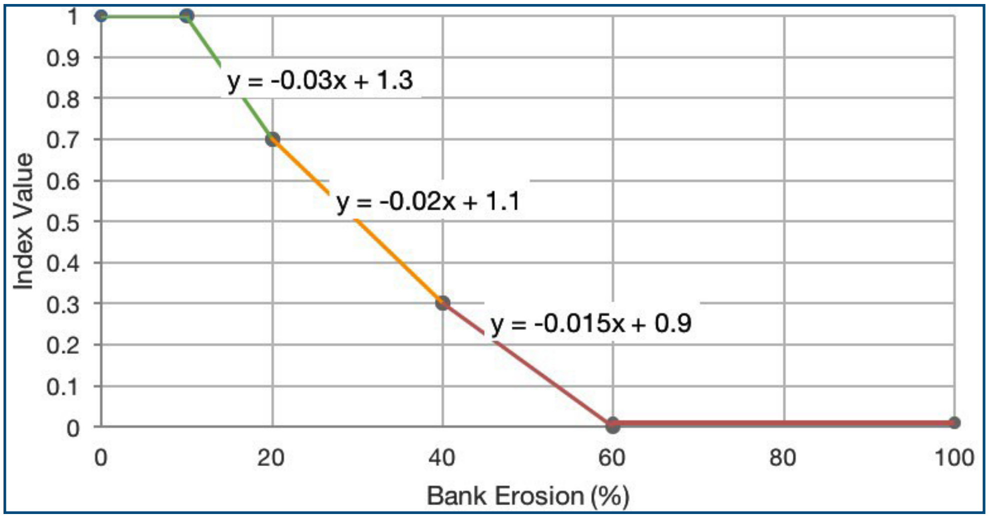

Figure 4.18 Bank Erosion Standard Performance Index

STANDARD PERFORMANCE INDEX

Development Method

Data and literature related to this metric is extremely limited. While existing data could not be used to directly inform the development of this standard performance index, the index is supported by current scientific understanding of how stream bank erosion relates to geomorphologic function.

This measure uses continuous data. Calculating the index score using a continuous scale allows for better detection of any change that results from impacts or mitigation activities.

SCIENTIFIC SUPPORT FOR ECOLOGICAL FUNCTIONS

Geomorphic Function

Generally, it is recognized that assessing the change in stream function associated with modifications to geomorphic condition is challenging to do in a rapid assessment or at project- level scales. Geomorphic processes are affected by surrounding landscapes and occur across long distances longitudinally in a stream so that processes that occur many miles upstream are linked to conditions downstream. In streams with high function, sediment transport and sorting occur over such large areas that evaluation on the scale of the PAA represents a snapshot of the overall balance in aggradation and erosion or channel migration. Therefore, it is acknowledged that evaluating geomorphic conditions in one PAA does not fully define the overall geomorphic function of that PAA since it is also affected by processes occurring upstream and downstream.

SFAM evaluates the relative area of impairments to geomorphic processes (e.g. barriers to lateral migration) and the area actively undergoing changes in geomorphology (e.g. bank erosion). The relative equilibrium of geomorphic processes is estimated by using measures of function that counterbalance each other (i.e. low scores given for high bank erosion would be counterbalanced by high scores for high opportunity for lateral migration).

The relative change in stream function associated with a given geomorphic condition is context-dependent. Generally, controls on the suite of geomorphic processes include climate, geology, vegetation and topography, in addition to past natural or anthropogenic disturbances (Montgomery and MacDonald, 2002). Montgomery and MacDonald (2002) state that, “The site-specific interactions between channel type, forcing mechanism, and channel response must be understood to select the variables for monitoring and design effective monitoring projects... when designing a monitoring project, one must consider the relative sensitivity of each channel characteristic by channel type, forcing mechanism and biogeomorphic context." Channel type, forcing mechanisms, and channel responses for bank stability are described below.

Channel Type

Channel types proposed by Montgomery and Buffington (1997) integrate seven stream characteristics that could each individually be considered controlling factors of geomorphic function (**Table 4.22**).

Table 4.22 Diagnostic Features of Each Channel Type
(Adapted from Montgomery and Buffington, 1997)

	Dune ripple	Pool riffle	Plane bed	Step pool	Cascade	Bedrock	Colluvial
Typical bed material	Sand	Gravel	Gravel-cobble	Cobble-boulder	Boulder	Rock	Variable
Bedform pattern	Multilayered	Laterally oscillatory	Featureless	Vertically oscillatory	Random	Irregular	Variable
Dominant roughness elements	Sinuosity, bedforms (dunes, ripples, bars) grains, banks	Bedforms (bars, pools), grains, sinuosity, banks	Grains, banks	Bedforms (steps, pools), grains, banks	Grains, banks	Boundaries (bed and banks)	Grains
Dominant sediment sources	Fluvial, bank failure	Fluvial, bank failure	Fluvial, bank failure,	Fluvial, hillslope, debris flows	Fluvial, hillslope, debris flows	Fluvial, hillslope, debris flows	Hillslope, debris flows
Sediment storage elements	Overbank, Bedforms	Overbank, bedforms	Debris flows	Bedforms	Lee (steep) and stoss (gentle) sides of flow obstructions	Pockets	Bed
Typical confinement	Unconfined	Unconfined	Overbank	Confined	Confined	Confined	Confined
Typical pool spacing (channel widths)	5–7	5–7	Variable	1–4	< 1	Variable	Unknown

Forcing Mechanisms

Interacting forcing mechanisms of bank erosion:

Table 4.23 Interacting Factors that Influence Erosion
(Adapted and modified from Fischenich, 2001; Montgomery and MacDonald, 2002)

Factor	Relevant Characteristics
Spatial location within the channel network	Sediment production zone, sediment transfer zone, or sediment deposition zone
Substrate size	Boulder to silt
Soil cohesion	Cohesive soils are more resistant to erosion
Flow properties	Frequency, variability, velocity, sheer stress and turbulence
Climate	Rainfall, freezing
Subsurface conditions	Seepage forces, piping, soil moisture levels
Channel geometry	Width, depth, height and angle of bank, bend curvature
Vegetation	Roughness displaces velocity upwards away from soil; roots add cohesion, elevates critical velocity/ sheer stress
Sediment load	High suspended sediment load dampens turbulence; elevates critical thresholds 1.5 to 3x
Anthropogenic factors	Urbanization, flood control, boating, irrigation

Channel Response

In the SFAM model, bank stability, measured as amount of bank erosion, affects sediment continuity (SC) (the balance between transport and deposition). Fischenich (2001) states that, “The stability of a stream refers to how it accommodates itself to the inflowing water and sediment load,” and that, “When the ability of the stream to transport sediment exceeds the availability of sediments within the incoming flow, and stability thresholds for the material forming the boundary of the channel are exceeded [due to hydraulic forces], erosion occurs.”

The extent to which minor erosion should be considered an adverse effect on stream function depends largely on duration of high flow and deviation from sediment transport processes that are considered “normal” for a given climate and position in the watershed (Fischenich, 2001). Evaluation of erosion within a single PAA may not be adequate to understand the magnitude of deviation from normal sediment transport processes that occur over larger areas and periods of time. A PAA with large areas of eroding banks would receive a reduced SFAM score for Bank Erosion, even if sediment transport and deposition are relatively well balanced over a larger geographic area. Nonetheless, the score of a PAA with actively eroding banks would be counterbalanced with higher scores if lateral migration is not confined.

MEASURE DEVELOPMENT

The Technical Working Group rated this as an informative measure, but one that could be potentially difficult to interpret. Because it informs the Sediment Continuity function, which represents a balance between transport and deposition, this measure has been considered important as a counterbalance to lateral migration which also informs the Sediment Continuity function.

As SFAM continues to develop and relevant information becomes available, stratification of this standard performance index could be considered based on channel type, which is the result of many of the other identified forcing mechanisms, and ecoregion, which dictates other forcing mechanisms including duration of peak flow, subsurface conditions and vegetation. While bank erosion can be considered broadly to diminish stream function, the magnitude of change in stream function may depend on channel type and other forcing mechanisms described above.

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j) Overbank Flow

MEASURE TEXT

Does the stream interact with its floodplain?

Is there evidence of fine sediment deposition (sand or silt) on the floodplain, organic litter wrack on the floodplain or in floodplain vegetation, or scour of floodplain surfaces, extending more than 0.5 × BFW onto either the right or left bank floodplain within the PAA? Do not include evidence from inset floodplains developing within entrenched channel systems.

If the abutting land use limits the opportunity to observe evidence of overbank flow, is there other credible information that would indicate regular (at least every two years) overbank flow in the PAA? Examples of "other credible information" include first-hand knowledge, discharge/ stream gauge measures, etc. Note the evidence on the Cover Page.

MEASURE DESCRIPTION

This measure represents a stream's interaction with its floodplain. Floodplain deposition, the accumulation on the floodplain of material from overbank flow, is a valid indicator of natural channel maintenance processes and is an important feedback mechanism for nutrient transfer. The connection between a stream channel and its floodplain (for alluvial rivers) is maintained primarily via periodic flood inundation. Connectivity to the floodplain allows organisms and material (water, sediment, organic matter) to move, unhindered by anthropogenic structures, perpendicular to the axis of the stream banks with a frequency consistent with natural flood regimes. Flood inundation supports detention and moderation of flood flows, groundwater and baseflow recharge, filtration to maintain water quality, access to side-channel and off-channel refuge and feeding habitats, and sedimentation and seed distribution to maintain riparian vegetation succession. Stream connectivity is essential to a number of theories of energy and material transfer in the river system and the process of overbank flow provides food resources to the stream's surrounding habitat.

Function Groups: Hydrology, Biology, Water Quality
Functions Informed: Surface Water Storage (SWS), Sub-surface transfer (SST), Sustain Trophic Structure (STS), Nutrient Cycling (NC), Chemical Regulation (CR)
Stratification: This measure is not stratified
Metric: Presence/absence

Model:
Cannot be answered if no floodplain
IF OBFlow = no, THEN=0.0;
IF OBFlow = yes, THEN=1.0

Table 4.24 Overbank Flow Scoring Index

Overbank flow measured as presence or absence		
Function Value Ranges	**Low**	**High**
Field Value	No	Yes
Index Value	0.0	1.0

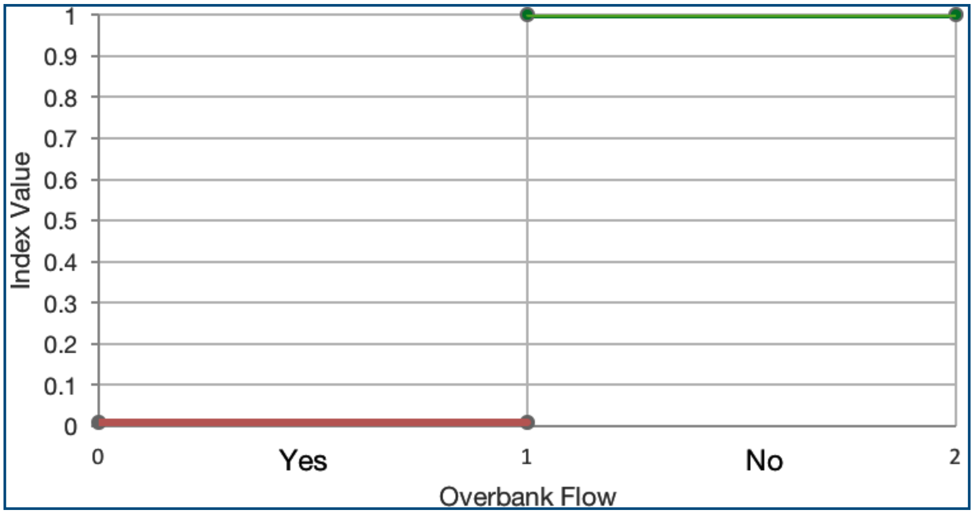

Figure 4.19 Overbank Flow Standard Performance Index

STANDARD PERFORMANCE INDEX

Development Method

There is extensive information in the literature linking overbank flow to hydrologic, biologic, and water quality functions. The development of the standard performance index for this measure was supported by numerous studies throughout the Pacific Northwest.

The model for this measure is binary, simply absence or presence, given the relative difficulty in rapidly and objectively assessing the degree of overbank flow.

SCIENTIFIC SUPPORT FOR ECOLOGICAL FUNCTIONS

Overbank flows shape alluvial floodplains in two ways, 1) by controlling hydrology and nutrient cycles that support distinct vegetative patterns, and 2) through recurrent destruction and reformation of soils and vegetation as rivers move laterally within valley bottoms (Naiman *et al.,* 2010).

In temperate areas that experience powerful fall and winter storms, such as the Pacific Coast Range ecoregion, overbank flows may occur on a seasonal basis, resulting in more frequent and regular priming of the floodplain processes (Naiman *et al*., 2010; Sutfin *et al*., 2010). In the Xeric ecoregion of Eastern Oregon, Washington, and Idaho, flooding may occur as flash floods that are infrequent, and re-initiation of floodplain processes may occur more randomly (Sutfin *et al*., 2010). Nevertheless, the basic premise that overbank flow supports processes such as surface water storage, recharge of subsurface flows, and nutrient storage in deposited sediments are similar in xeric regions compared to temperate regions (Elmore and Bechsta, 1987).

Hydrologic Function

Overbank flow supports the Surface Water Storage (SWS) function of streams by allowing the stream to expand across large areas of floodplain, redistributing water and slowing velocity of the flow. Where streams can access their floodplains, floodplains can provide SWS in intermittent or ephemeral meanders or wetlands. Most floodplains and floodplain wetlands are highly disconnected from streams in the Pacific Northwest, and it is recognized that during high flows larger-magnitude flood peaks can be conveyed to downstream areas than under historic conditions. Evidence from the literature around the world suggests that naturally connected floodplains can provide SWS of a large proportion of the volume of large flood events. For a review of case studies on floodplain storage see the rationale for Floodplain Exclusion (this **Section (f)**). The loss of SWS provided by overbank flow is a growing area of research in the Pacific Northwest due to the desire to better mitigate for large floods that cause damage to developed areas and infrastructure downstream. A few relatively smaller-scale, ongoing floodplain reconnection projects in the Pacific Northwest have successfully reduced the risk of damage by large floods to communities downstream, as well as increased floodplain area available to be shaped by geomorphic processes and to be used as aquatic habitat (e.g., Floodplains by Design, 2017; City of Portland, 2017). Many more projects are in the early stages of development and data on the magnitude of surface water storage provided has yet to be collected. Initial monitoring of floodplain reconnection projects suggests that SWS function can increase in a roughly linear manner in relation to the area of reconnected floodplain (City of Portland, 2017).

In unconfined, alluvial floodplains, overbank flow can recharge areas of sub-surface flow, also described as areas of hyporheic flow connected to the main channel.

Biologic Function

Overbank flow supports biologic function by sustaining trophic structure in floodplain areas and adjacent stream reaches in primarily two ways, 1) by providing nutrient subsidies in temporarily flooded floodplain areas (Tockner and Stanford, 1999) and 2) by connecting stream reaches with a shifting mosaic of floodplain habitats (i.e. surface riparian zones and subsurface hyporheic zones) that provide thermal and structural heterogeneity and as a result, supports a broader range of species than in streams that do not undergo overbank flooding (Ward and Stanford, 1995).

Transport of nutrient rich-sediment and other organic material (such as wood and salmon carcasses) from the river to the floodplain are why floodplains are among the most productive landscapes on earth. Depositional floodplains enhance primary productivity not only in riparian vegetation, but also phytoplankton in temporarily flooded areas that provides a boost to aquatic invertebrate production (Tockner and Stanford, 1999; Schemel *et al*., 2004). Areas of high productivity in ephemerally-flooded areas can support diverse assemblages of vertebrate species (Sommer *et al*., 2001 [terrestrial and aquatic wildlife]; Taft and Haig, 2003 [waterbirds]; Henning *et al.*, 2007 [fish]) or can provide concentrated resources for fast growth of discrete life stages of certain key species such as coho salmon (Henning *et al.*, 2006).

In many streams in the Pacific Northwest, flood control has reduced channel complexity and connection to thermally heterogeneous areas of gravel islands and off-channel habitats or spring- brook areas fed by groundwater (e.g., the McKenzie River, OR [Ligon *et al.*,1995]; the Yakima River, WA [Stanford *et al.*, 2002]). Overbank flows historically maintained these connections on a seasonal basis and large floods caused major rerouting of sediments and river avulsions that contributed to channel complexity. It is estimated that the loss of overbank flows has contributed to the decline of salmon species in these rivers, in part due to lack of overbank flows that used to connect salmon with trophic resources in off-channel habitats (Stanford *et al*., 2002).

Water Quality Functions

Surface nutrient processes

Globally, flooding controls nutrient cycles by increasing contact time between water and soil and by controlling the mode of nutrient delivery to the ecosystem (Pinay *et al*., 2002). Nutrient cycles are driven by processes that occur at the interface between particulate material and water, both at the surface and subsurface. Lateral expansion of wetted areas during overbank flows increases the interface area between soil and water. Floods affect nutrient cycling directly by controlling the duration of oxic and anoxic phases, as well as indirectly by influencing soil structure.

Floodplains are recognized as important storage areas for nutrients that retain higher amounts of organic matter compared to stream reaches in confined valley segments (Bellmore and Baxter, 2014). In the Pacific Coast Range ecoregion, nutrients are exported to the floodplain from the main channel during overbank flows via the deposition of organic matter attached to fine sediment that has been eroded and transported from upstream areas (Naiman *et al*., 2010). Carbon is stored in the floodplain in several organic forms, such as in plants and animals, but dissolved organic carbon attached to floodplain sediments is the major component of floodplain carbon storage (Sutfin *et al.*, 2016). Soil type influences nutrient (dissolved organic carbon) storage; fine grained sediments serve as organic carbon sinks whereas sandy soils release available carbon during high flows (Sutfin *et al*., 2016). Overbank flow not only mobilizes nutrients by deposition of sediment or plant material, but in the Pacific Northwest where salmon runs are still sustained at historic levels, the deposition of salmon carcasses in the floodplain during seasonal floods is a measurable nitrogen subsidy that becomes incorporated in riparian vegetation and higher trophic levels that feed upon that vegetation, such as small rodents (BenDavid *et al*., 1998).

Distribution of floodplain sediment depends on hydrologic cycles. In temperate areas, seasonal redistribution of sediment and resetting of nutrient cycles may occur, whereas sediment and nutrient redistribution is more random in xeric areas that experience flash flooding. Following an overbank flow event, fresh depositional surfaces are quickly exposed to chemical weathering that releases nutrients in usable forms for plants, particularly nutrients that are often limiting such as phosphorous and base cations (Naiman *et al*., 2010). Young floodplain soils can be considered open systems because coarse soils allow leaching and a high level of export of nutrients to the main channel. As floodplain vegetation and fine soils mature, floodplains transition to closed systems with more efficient nutrient retention (Naiman *et al*., 2010). Overbank flows may reset the floodplain soil development cycle, reinitiating the process of high nutrient delivery to the main channel. In a plan to restore environmental flows to the Willamette River basin below high head dams, Gregory and co-authors (2008) suggest that releases that create small floods (of a magnitude observed on a 2–10 year interval) may increase nutrient transport from the floodplain with mobilization of sediment, but that nutrient concentrations imported from the floodplain may decrease with large floods that maintain floodplain processes (of a magnitude greater than a 10 year interval) due to dilution.

Subsurface nutrient processes

Subsurface flow, often affected by overbank flows, enhances nutrient cycling between the floodplain and channel. High flows rearrange hyporheic zone sediments, increasing hydraulic conductivity and surface area for nutrient exchange (Pinay *et al*., 2002). Large floods in coastal Oregon in 1996 caused major changes in stream morphology and subsurface flow paths in alluvial areas, but less change was observed in bed-rock controlled reaches (Wondzell and Swanson, 1999). When the water table was high and connected to hyporheic flow paths, nitrate was leached from rooting zone of streamside alders, a nitrogen-fixing plant (Wondzell and Swanson, 1996, 1999). In the Willamette Basin, Laenen and Bencala (2001) found solute storage in the hyporheic zone occurred for longer periods during high stream discharge. These cases demonstrate ways in which overbank flow can affect nutrient storage and delivery to the stream via rearranging or forcing the direction of flow paths below the surface during high flow events. For further discussion on the effect of subsurface flow through the riparian zone on nutrient cycling, refer to the rationale for Vegetated Riparian Corridor Width (this **Section (e)**).

Chemical (pollutant) regulation

Overbank flow can regulate distribution and storage of contaminants in the floodplain. Extensive and persistent contamination from a single point source can result when contaminated sediment from upstream sources are redistributed to floodplain areas and stored until subsequent overbank flows occur. Contaminants then become reintroduced from the floodplain to the main channel via erosion and mass wasting (bank slumping and cutting) (Axtmann and Luoma, 1991). In this way, the floodplain that is at first a sink, may later become a source of contaminants. This dynamic is important to consider when assessing overall contaminant budgets of a watershed; declining contaminant levels in stream water may not reflect an overall reduction in contaminants at the watershed level, but rather a temporary redistribution and storage in the floodplain (Walling and Owens, 2003). For more detail on contaminant mobilization, see the rationale for Vegetated Riparian Corridor Width (this **Section (e)**).

Table 4.25 Summary of Supporting Literature for Overbank Flow Standard Performance Index

Reference	Metric	Function Response Variable	SFAM Function Informed	Metric Classifications	Informative Conclusions
Decision Support for Hydrologic Function					
Elmore and Beschta, 1987	Floodplain processes	Functions provided by floodplain riparian vegetation	SWS, SST	East, Floodplain	Authors review knowledge on contribution of riparian vegetation in xeric areas with linkages to overbank flow. Similar dynamics of surface water storage, subsurface recharge, and sediment trapping occur in xeric areas of Eastern Oregon compared to temperate areas.
Decision Support for Biologic Function					
Tockner and Stanford, 1999	Review of global floodplain status	Productivity	STS	Global	Describes global and historic trends in floodplain productivity resulting from flood pulses.
Schemel *et al.,* 2004	Flood cycle	Water chemistry, phytoplankton biomass	STS	West, Perennial, Floodplain	Yolo bypass on the Sacramento River, CA, is a managed seasonally flooded floodplain. Phytoplankton biomass increased with length of time flooded and discharge from floodplain to river was enriched in Chlorphyll *a* (phytoplankton).
Sommer *et al*. 2001; Taft and Haig, 2003; Henning *et al.*, 2007; Henning *et al*., 2006	Ephemerally flooded habitat in the floodplain	Vertebrate uses of floodplain habitat resources	STS	West, Perennial, Floodplain	Each of these studies documents the use of floodplain areas by vertebrate species and demonstrates the uniquely role that productive ephemeral floodplain environments can play in sustaining aquatic species.
Ward and Stanford, 1995	Flow regulation	Disconnection from floodplain processes	STS	Global, Floodplain	Spatio-temporal heterogeneity of physical attributes floodplains creates a diversity of habitats and successional stages of riparian vegetation.
Ligon *et al*., 1995	Reduction in peak flows due to water storage behind dams	Wetted area of river below dams, island number, island area, island perimeter, redd superimposition, salmon declines	STS	West, Floodplain, Perennial	Reduced peak flows have led to decreases in wetted area, channel complexity, and substrate available for habitat.
Stanford *et al*., 2002	Water storage and diversion	Disconnection from alluvial floodplain	STS	East, Floodplain, Perennial	In the Yakima River Basin, WA, the Yakima River no longer floods and reconnects with floodplain features that create habitat complexity and thermal heterogeneity like spring brooks. Fish observed using spring brook habitat in the Yakima Basin likely benefited from unique trophic structure away from the main channel.

Table 4.25 Summary of Supporting Literature for Overbank Flow Standard Performance Index (continued)

Reference	Metric	Function Response Variable	SFAM Function Informed	Metric Classifications	Informative Conclusions
Decision Support for Water Quality Function					
Naiman *et al.*, 2010	Floodplain processes	Nutrient dynamics, soil deposition, riparian vegetation successional processes	NC	West (Pacific Coast Range ecoregion), Perennial, Floodplain	In the Pacific Coast Range ecoregion where flooding occurs seasonally, nutrients are exported to the floodplain with soil deposition and nutrients are imported back to the river during early phases of riparian soil development.
Pinay *et al.*, 2002	Floodplain processes	Nitrogen cycling	NC	Global; Floodplain	Review article on mechanisms by which flooding affects nutrient cycling. Two main themes are the way floods increase contact time between soil and water, and how floods resort soils and increase contact area between substrate and water. Applies to both surface and subsurface flow.
Sutfin *et al.*, 2010	Floodplain dissolved organic carbon	Dynamics of retention, accumulation, and storage	NC	Global; Floodplain	A global review of carbon cycling in floodplains. Distribution of sediment- associated DOC depends on hydrologic cycles and sediment type.
Bellmore and Baxter, 2014	Confined vs unconfined river segments	Dissolved nutrients, allochthonous inputs, aquatic primary producers, organic matter retention, aquatic macroinvertebrates	NC	East, Floodplain	In the Salmon River, ID, confined river segments had more leaf litter than unconfined segments, but unconfined floodplain areas had higher vegetation biomass and organic matter retention. Benthic macroinvertebrate diversity was higher in segments with floodplains.
BenDavid *et al.*, 1998	Flooding; Distance from channel bank	Marine-derived nitrogen	NC, STS	West, Perennial, Floodplain	In Southeast Alaska stream, regular seasonal overbank flow was identified as a mechanism for delivery of marine- derived (MD) nutrients from salmon carcasses to the floodplain. MD- nitrogen levels in vegetation declined with distance from streams and areas of salmon carcass deposition.
Wondzell and Swanson 1996, 1999	Large floods of 1996	Subsurface flow paths, subsurface nutrient transport	NC	West, Perennial, Floodplain	Large floods of 1996 represented an opportunity to study before and after changes in hyporheic flow paths. High flow also allowed for nitrogen transport from alder root zones.
Laenen and Bencala 2001	Subsurface flow paths	Solute transport	NC	West, Perennial, Floodplain	Dye tracer experiments demonstrate transport rates of solutes in the hyporheic zone
Axtmann and Luoma, 1991; Walling and Owens, 2003	Floodplain deposition of contaminated sediment	Contaminant retention and transport	CR	Global	Floodplains alternately become sinks and sources for contaminants as sediment becomes deposited and then remobilized

Notes:
CR: Chemical Regulation
NC: Nutrient Cycling
SST: Sub/Surface Transfer
STS: Sustain Trophic Structure
SWS: Surface Water Storage

MEASURE DEVELOPMENT

This measure was highly recommended by the Technical Working Group and is informed by the "Floodmarks" worksheet of the Floodplain Habitat Metric Calculator, a rapid assessment measuring floodplain habitat quality to inform conservation (Defenders of Wildlife, 2012).

Reviewers suggested that the original question, which required that answers be based solely on field indicators, may be too subjective and could cause inconsistencies. Field indicators may not always be present based on seasonality, land use, etc., so the measure was revised to allow for consideration of other credible information, including local knowledge.

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k) Wetland Vegetation

MEASURE TEXT

Are there wetland indicator plants adjacent to the channel and/or in the floodplain?

Determine if vegetation in the riparian area of the Proximal Assessment Area (PAA) has a wetland indicator status of obligate or facultative wet.

MEASURE DESCRIPTION

This measure is an indicator of water availability in the floodplain, as well as an indicator of diversity of habitat and food resources. Wetland vegetation provides food and critical habitat for organisms that live in or near water resources, such as algae, macroinvertebrates, amphibians, fish and birds. Wetland vegetation can also provide water quality benefits, through the uptake of nutrients, metals, and other contaminants. The biotic community is the most visible testament to the overall health of the river system. The vegetation community provides a spatially persistent and somewhat long-lived metric to evaluate the conditions of a specific location on the floodplain or at the stream margin.

Function Groups: Hydrology, Biology, Water Quality
Functions Informed: Sub/Surface Transfer (SST), Maintain Biodiversity (MB), Sustain Trophic Structure (STS), Nutrient Cycling (NC), Chemical Regulation (CR)
Stratification: This measure is not stratified
Metric: Presence/absence and distribution

Model:
IF plants with wetland indicator status are absent from the stream banks and floodplain throughout the PAA; THEN = 0.0;
IF plants with wetland indicator status are present within the PAA but are located less than 0.5 × bankfull width (BFW) away from the bankfull edge; THEN = 0.25;
IF plants with wetland indicator status are present within the PAA and are located more than 0.5 × BFW from the bankfull edge, but are present along less than 70% of the reach length on at least one side of the stream; THEN = 0.5;
IF plants with wetland indicator status are present within the PAA and are located more than 0.5 × BFW from the bankfull edge, and are present along 70% of the assessment reach; THEN = 1.0

Table 4.26 Wetland Vegetation Scoring Index

Wetland Vegetation as measured by presence and proximity/distribution				
Function Value Ranges	Low		Moderate	High
Field Value	Wetland plants absent	Wetland plants present, but are located < 0.5 x BFW from stream	Wetland plants present; located more than 0.5 x BFW from stream, but distributed along < 70% of assessment reach	Wetland plants present; located more than 0.5 x BFW from stream for ≥ 70% of assessment reach
Index Value	0.0	0.25	0.5	1.0

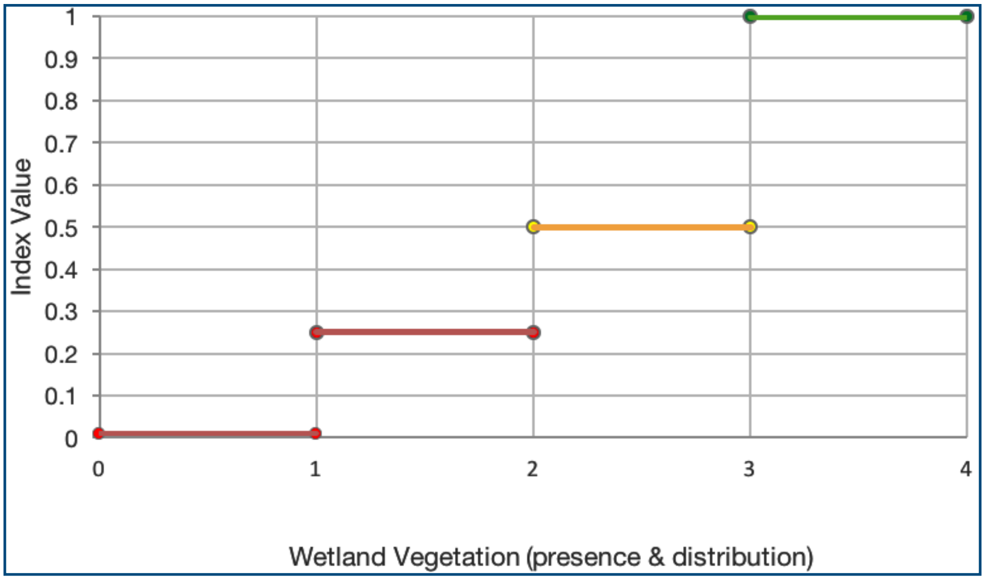

Figure 4.20 Wetland Vegetation Standard Performance Index

STANDARD PERFORMANCE INDEX

Development Method

While there are many studies that discuss how wetlands (and therefore wetland vegetation) are related to hydrologic, biologic, and water quality functions, there is limited information indicating critical abundance and/or proximity measurements of wetland vegetation that can be linked to stream functioning. Therefore, the categorical bins and the associated index values for this measure were informed by current scientific understanding of how hydrophytic vegetation is linked to ecological functioning. The bins resulted from consultation with technical experts and the scoring thresholds are designed to align with the indexing scale established for SFAM.

SCIENTIFIC SUPPORT FOR ECOLOGICAL FUNCTIONS

Hydrologic Function

The presence and distribution of wetland plants can be used as an indicator of the duration of soil saturation in or near stream channels. Hydrophytic plants have long been used as one of the three defining features of wetted areas (e.g. U.S. Army Corps of Engineers, 1987), and it is well-established that flooding and soil saturation foster conditions that a majority of plants cannot tolerate (Cronk and Fennessy, 2001). Streams interact with ground water in all types of landscapes—they may gain water from the inflow of ground water, lose water to ground water by outflow, or gain in some reaches and lose in others (Winter *et al*., 1998). Most wetlands are ground water discharge sites, and floodplain wetlands also recharge ground water (Tiner, 1999). In the bed and banks of streams, water and solutes can exchange in both directions across the streambed and into riparian areas and alluvial deposits (Winter *et al*., 1998); this subsurface zone of exchange is the hyporheic zone. This exchange can occur in both flooded and non-flooded conditions (Bencala, 2011). Given that they are subject to periodic changes in water-level, riverine wetlands have especially complex hydrological interactions (Winter *et al.*, 1998).

Biologic Function

Riparian areas and floodplains are dynamic areas of periodic or episodic inundation, resulting in a shifting landscape mosaic that supports plant and animal species adapted to such environmental gradients and stochasticity, including wetland plants. Riparian systems are generally an ecotone between aquatic and upland ecosystems, with continuous interactions between these ecosystems through exchanges of energy, nutrients, and species (Mitsch and Gosselink, 1993). They are functionally connected to upstream and downstream ecosystems, and are laterally connected to upslope (upland) and downslope (aquatic) ecosystems (Mitsch and Gosselink, 1993). Thus, there is often high primary productivity of plants and algae in riparian areas which provides abundant food resources for foraging, hunting, and breeding for fish, amphibians and aquatic invertebrates, and draws in terrestrial species such as birds and mammals (see papers cited in USEPA, 2015). While the seeds and other parts of riparian wetland plants provide food for many animals, a major aspect of riparian plant primary productivity is that the biomass is broken down into fine particulate organic matter, both physically and through the action of microbes and invertebrates - the foundation of the aquatic food web (Allan, 1995; Tiner, 1999). The combination of diverse habitat structure and abundant food resources in riparian systems results in high species diversity and high species densities (see papers cited in USEPA, 2015).

Water Quality Function

Wetland plants as components of riparian areas both in and outside of floodplains affect the biogeochemistry of riverine systems through overbank flooding, internal biogeochemical processes, and hyporheic exchange (see papers cited in USEPA, 2015). These processes influence nitrogen, carbon, phosphorous, and pollutant cycling in the riverine environment. Transport from upstream reaches, surface flow, or through the hyporheic zone is an important source of these substances. Wetland plants remove nutrients from flooding and other waters, through absorption and assimilation, for biomass production; this can result in long term storage and/or subsequent burial in sediments (Tiner, 1999; Cronk and Fennessy, 2001). Additionally, adsorption, sedimentation, or other transformational processes exert major influences on the availability of these substances (Mitsch and Gosselink, 1993). Wetland and riparian areas reduce water velocity, trapping sediments which often transport adsorbed nutrients, pesticides, heavy metals and other polluting toxins, lowering turbidity, and reducing siltation (Mitsch and Gosselink, 1993; Tiner, 1999; Cronk and Fennessy, 2001). The presence of both anaerobic and aerobic sediments also promotes denitrification, chemical precipitation, and other chemical reactions, mostly mediated by microbial populations, that remove certain chemicals from the water (Mitsch and Gosselink, 1993). Plant uptake and plant tissue accumulation can also be reversed when plants die back after the growing season, which can break down and serve as a source of nutrients and minerals (Mitsch and Gosselink, 1993; Cronk and Fennessy, 2001).

MEASURE DEVELOPMENT

While not included in the initial method, the presence of wetland plants within 0.5 x BFW width was among the supplementary data that were collected during the field testing. Prior to the second season of the field study, the measure was expanded to assess both presence and distribution of hydrophytic vegetation as an indicator of groundwater flux and hyporheic exchange, and of riparian structure. It provides a relatively rapid alternative to other indicators of groundwater flux that are challenging to measure. Reviewers considered this to be a strong measure, and statistical analysis consistently identified wetland plants as a value-added measure. The original question included facultative plants; however, the measure was limited to facultative wet and obligate wetland plants after technical reviewers suggested that the criteria were too broad, especially in very wet areas of western Oregon where facultative plants may not indicate connection to the stream.

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l) Side Channels

MEASURE TEXT

What proportion of the Extended Assessment Area (EAA) length has side channels?

Side channels include all open conveyances of water, even if the channel is plugged (i.e. there is no above-ground flow to/from the main channel) on one end. If both ends are plugged, do not count as a side channel. A side channel that exists due to an instream island has less flow by volume relative to the main channel.

MEASURE DESCRIPTION

This measure is an indicator of the extent of seasonally inundated areas that have surface water connections to the main channel. Side channels are flowing water bodies having identifiable upstream and downstream connections to the main channel. Side channels support hydrologic functions by slowing stream flow and creating more opportunity for groundwater replenishment, support nutrient cycling and water quality functions, and create specialized habitat for fish and wildlife by providing refuge from high velocity flows, thermal refugia during summer low flows, and access to food sources.

Function Groups: Hydrology, Biology
Functions Informed: Surface Water Storage (SWS), Sub-Surface Transfer (SST), Maintain Biodiversity (MB), Create and Maintain Habitat (CMH)
Stratification: This measure is not stratified
Metric: Percent of channel with adjacent side channels

Model:
IF SideChan < 10%, THEN=0.03*SideChan;
IF SideChan = 10–50%, THEN=0.01*SideChan + 0.2;
IF SideChan > 50%, THEN=0.006*SideChan + 0.4

Table 4.27 Side Channels Scoring Index

Side channels measured as proportion of EAA length			
Function Value Ranges	**Low**	**Moderate**	**High**
Field Value	< 10%	10–50%	> 50%
Index Value	0.0 – < 0.3	0.3–0.7	> 0.7–1.0

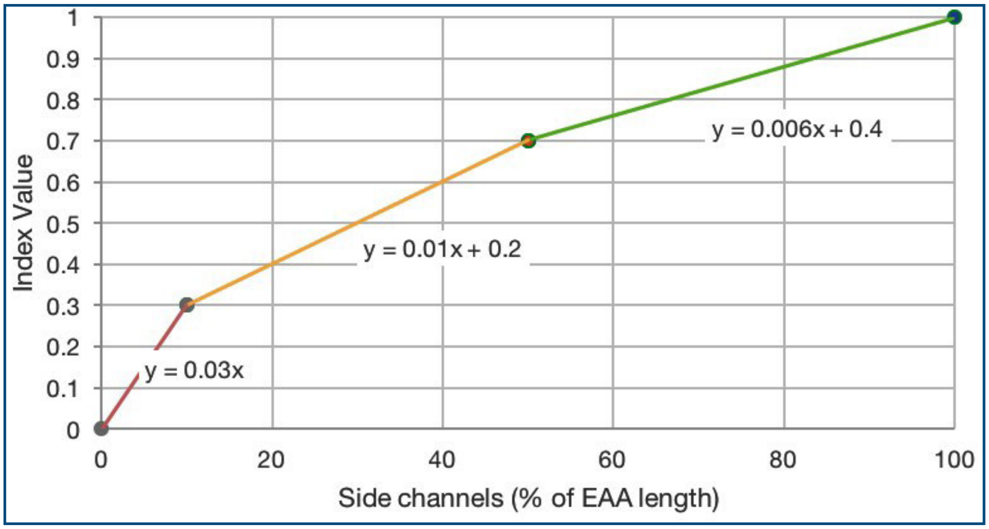

Figure 4.21 Side Channels Standard Performance Index

STANDARD PERFORMANCE INDEX

Development Method

As an active area of research in the fisheries and restoration arena, there is a solid body of information in the literature linking the presence of side channels to hydrologic and biologic functions. Studies throughout the Pacific Northwest supported development of the standard performance index for this measure.

This measure uses continuous data. Calculating the index score using a continuous scale is supported by the literature, and allows for better detection of any change that results from impacts or mitigation activities.

SCIENTIFIC SUPPORT FOR ECOLOGICAL FUNCTIONS

Hydrologic Function

Side channels are features of alluvial river systems created through fluvial processes, that are adjacent to the main channel at some flows (Landers *et al.,* 2002). They are off-channel flowing water bodies having identifiable upstream and downstream connections to the main channel (Landers *et al.,* 2002). Over time, side channels generally evolve into back water sloughs or alcoves.

In the Umatilla River, a high desert gravel and cobble bedded river in a well-developed floodplain in northeastern Oregon, baseflow water temperatures of hyporheic discharge to side channels were monitored using potentiometric surface maps, piezometers, and temperature loggers (Arrigoni *et al.,* 2008). Data were collected on the scale of channel units (e.g. a single gravel bar created side channel). These researchers found that hyporheic exchange enhances temperature diversity in surface and subsurface habitats, moderates both diel and annual temperature cycles, and creates dynamic reach-scale mosaics of channel water temperatures observable across channel habitats.

Data in the supporting literature cited in **Table 4.29** indicate that water exchange with the stream subsurface creates spatial and temporal thermal variation across geomorphic features or channel unit types (i.e., side channel, spring channel, and main channel) (e.g. Ock *et al.,* 2015). Fernald *et al.* (2006) found that cooling patches were associated with longer flow paths and higher flow rate. Higher flow was associated with younger bar features (Fernald *et al.,* 2006). Cooler patches can provide thermal refugia for species stressed by peak mainstem temperatures (Fernald *et al.,* 2006).

Raw data—local time-varying temperature and lag—while not converted to the metric used in SFAM, provide support for the standard performance index based on percent length of side channels in the EAA because increasing length would imply an increasing contribution to the SWS and STS functions, as well as increasing thermal refugia. The index supporting the SFAM model was plotted with two assumptions: 1) that "per channel unit" data provided in the available literature are scalable to an EAA with multiple units; and 2) that percent total length is a reasonable measure of the units.

Biologic Function

Stream forming processes may occur within side channels, and pool-riffle sequences may also develop (Landers *et al.,* 2002). Many species rely on off-channel habitats for some, or all of their life history. For thermally sensitive aquatic species, these habitats provide cold water refugia during summer low flow periods. Juvenile salmonids use these habitats for their abundant resources and to escape high velocity flows. For example, the Oregon Conservation Strategy (2016) notes that seasonal floodplain habitats in the lower Willamette River are occupied by subyearling Chinook from lower Columbia River and upper Columbia River summer-fall evolutionarily significant units (ESU), in addition to those from the upper Willamette ESU. Many native nongame fish species develop in these habitats before moving into the main river channel, while fish like the Oregon chub require these habitats year-round. Native plant communities, amphibians, turtles, and freshwater mussels also depend on these habitats.

Several studies in the Pacific Northwest have evaluated the contribution of stream side channels to fish habitat. Researchers (Roni *et al.,* 2006; Rosenfeld *et al.,* 2008; Ogston *et al.*, 2015) measured Coho smolt production in response to side channel habitat area at restored sites. The side channels studied span three orders of magnitude in size. Raw data from these studies were plotted and a line fitted to the natural changes in slope to understand how data might inform SFAM function value ranges (i.e., Low, Moderate, High). For the relationship between side- channel habitat area and smolt productivity, smolt numbers may increase with relatively small increases in habitat area, as suggested by the data plotted in **Figure 4.22.**

Data in these papers provide a physical measure of side channel habitat and quantify the ability to create habitat in terms of Coho smolt production. Although these data give a measure of side channel habitat specifically for Coho salmon, Coho salmon are considered an umbrella species for side channel habitat. Benefits of side channel habitat conferred to Coho salmon are related to biodiversity and population responses of other fishes; therefore, data can be used to quantify the ability to Maintain Biodiversity (MB) for fish (Branton and Richardson, 2014). The relationships to habitat for other species (e.g. amphibians and benthic invertebrates), however, is less clear (Branton and Richardson, 2014). Restored side channel habitat area can be used as a surrogate for natural side channel habitat area; no difference in the amount of smolt production was observed between natural and constructed side channel habitat (Morley *et al.,* 2005).

Data from the literature are not an exact fit for the Side Channel measure because they are absolute area of side channel habitat rather than percent length of an EAA as used in SFAM; however, length proportion scales to stream size better than area does and one can infer that greater side channel length and area are correlated.

There is a linear relationship between log (area) and smolt production, with raw data showing an asymptotic effect at approximately 20,000–30,000 m^2 (2–3 ha) (**Figure 4.22**). The biological response (number of smolts produced) increases rapidly relative to the difference in area of the sampled side channels, supporting the SFAM model scoring index for side channels (**Table 4.28**).

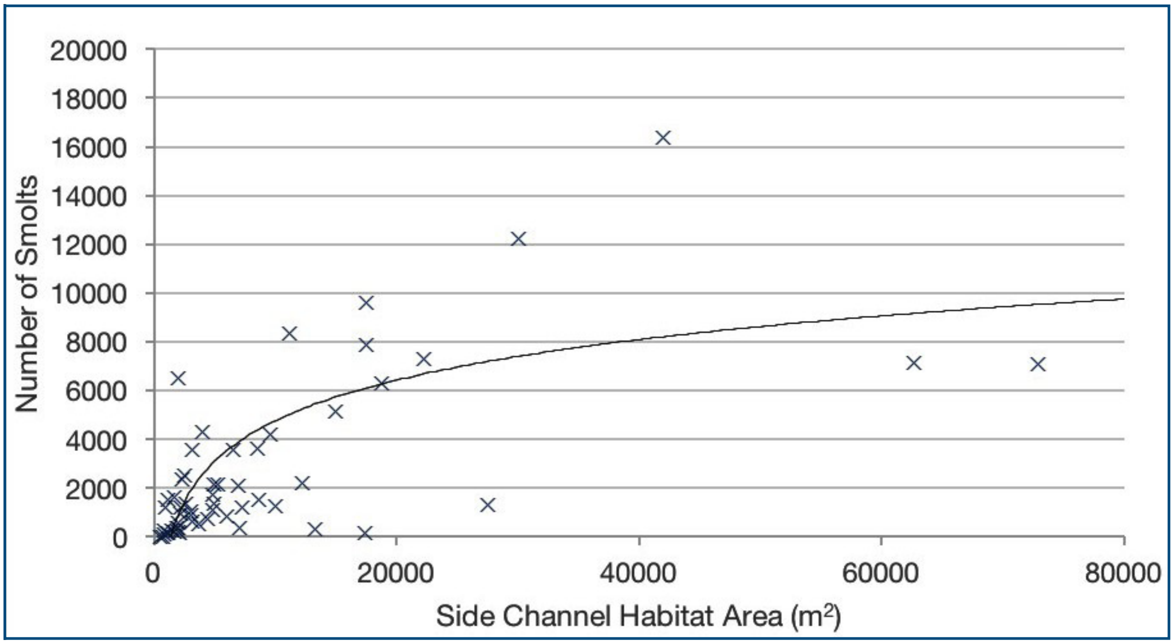

Figure 4.22 Biological Response Curve - Smolt Production per Side Channel Area
Note: Data from Roni et al., 2006, Rosenfeld et al., 2008, and Ogston et al., 2015. Graphic is focused on an area that emphasizes the shape of the curve but excludes the highest data points.

Table 4.28 Biological Response Scale - Smolt Production per Side Channel Area

Function Value Ranges	Low	Moderate	High
Relative Difference in Area of Sampled Side Channels	0–10%	11–50%	> 50%
Side Channel Area *(m^2)*	565–6,000	6,500–27,492	30,100–140,000
Number of Smolts Produced	11–6,500	156–9,590	3,916–32,050

Note:
Data from Roni et al., 2006; Rosenfeld et al., 2008; and Ogston et al., 2015

Smolt production in the data presented in **Figure 4.22** is similar to the mean smolt production reported by Rosenfeld *et al.* (2008) (0.476 smolts/m^2) and was also consistent with the Beechie *et al.* (1994) estimate of 0.319–0.775 smolts/m^2 for slough habitat in the Skagit watershed in Washington. Beechie *et al.* (1994) suggests that summer slough potential smolt production should be 0.319/m^2, while winter smolt production would be higher. Data from Ogsten *et al.* (2015) show similar trends between side channel area and smolt production.

Table 4.29 Summary of Supporting Literature for Side Channels Standard Performance Index

Reference	Metric	Function Response Variable	SFAM Functions Informed	Metric Classifications	Informative Conclusions
Decision Support for Hydrologic Functions					
Arrigoni *et al.,* 2008	Location, time	Channel water temperature, hyporheic discharge temperature, phase, and variation	SST, CMH	East, Floodplain, Perennial	Hyporheic discharge had little effect on overall stream water temperature but created patches of cooler and warmer water.
Burkholder *et al.,* 2008	Channel temperature, time	Hyporheic discharge temperature, mainstem temperature	SST, CMH	West, Floodplain, Perennial	Hyporheic discharge had little effect on overall stream water temperature but created patches of cooler and warmer water.
Ock *et al.,* 2015	Time, location, by construction type	Water temperature, phase	SST, CMH	West, Floodplain, Perennial	Constructed off- channel habitat created cooled patches but depended on construction method.
Fernald *et al.,* 2006	Location	Hyporheic, main stem, and side-channel/ alcove water temperature	SST, CMH	West, Floodplain, Perennial	Hyporheic discharge had a cooling effect in side-channel alcoves, depending gravel age and flow rate.
Decision Support for Biologic Functions					
Roni *et al.,* 2006; Rosenfeld *et al.,* 2008; Ogston *et al.,* 2015	Area of side channel habitat	Coho smolt production	CMH, MB	West, Floodplain, Spring, Perennial	The area of restored side channels is related to Coho smolt production. Coho smolt production shows a logarithmic response to increase in restored side-channel area.
Beechie *et al.,* 1994	% of historic side-channel habitat remaining	% of historic Coho smolt production	CMH, MB	West, Floodplain, Spring, Perennial	The decline in smolt production is strongly associated with the loss of side-channel habitat from the historic condition.
Morley *et al.,* 2005	Constructed vs. natural side- channel habitat	Coho smolt production	CMH, MB	West, Floodplain, Spring, Perennial	No difference in the amount of smolt production observed between constructed and natural side- channel habitat and supports rationale for using restored side channel area as a metric.
Branton and Richardson, 2014	Coho abundance, Coho biomass, environmental variables	Fish and listed fish species richness, abundance, and biomass	CMH, MB	West, Floodplain, Spring, Perennial	Coho are an umbrella species; a benefit to Coho confers benefit to populations of co-occurring species with similar habitat requirements.

Notes:
CMH: Create and Maintain Habitat
MB: Maintain Biodiversity
SST: Sub/Surface Transfer
SWS: Surface Water Storage

MEASURE DEVELOPMENT

Assessment of side channels was originally a component of a measure intended to evaluate the "extent of inundation," but that measure was disassembled due to the difficulty of measuring it consistently across sites. The side channel measure was separated and retained as an independent measure. In earlier drafts of SFAM, this measure required estimation of the total *area* of side channels, but field testing indicated that assessing side channel *length* was more appropriate for a rapid assessment method. The final protocol used to evaluate side channels is based on Beechie *et al.* (2005).

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m) Lateral Migration

MEASURE TEXT

What percent of both sides of the channel is constrained from lateral migration?

Constraints on lateral migration of the channel within 2 × BFW or 50 feet (whichever is greater) includes bank stabilization and armoring, bridges and culverts, diversions, roads paralleling the stream and any other intentional structures or features that limit lateral channel movement whether intentionally or not. For cross-channel structures (diversions, bridges, culverts, etc.), record 4x the bankfull width (BFW) as the length constrained on both sides of the channel. For linear features, record the length on each side of the channel. For segmented bank features, such as bendway weirs or log jams acting in concert, record the effective length of stabilization on each side of the channel affected. It is appropriate to include relevant armoring that is recorded in the Bank Armoring question; these measures are not double-counted in SFAM.

In the office, use aerial imagery to identify and map all constraints to lateral migration as defined above on both sides of the channel within the EAA, up to a maximum distance of 330 feet from the bankfull edge.

MEASURE DESCRIPTION

This measure is an indicator of whether important geomorphological processes, such as erosion and deposition, are occurring or are being unnaturally constrained. Lateral migration of a stream channel is expected when sediment movement is in balance. Unconstrained banks of a channel are exposed to natural erosion processes, which can lead to a widened channel, natural meandering, and creation of diversity in stream energy and sediment deposition rates.

Function Group: Geomorphology
Function Informed: Sediment Continuity (SC)
Stratification: This measure is not stratified
Metric: Percent constrained

Model:
IF LatMigr > 40, THEN=0.0;
IF LatMigr > 20–40; THEN= -0.015*LatMigr + 0.6; IF LatMigr = 10–20, THEN= -0.04*LatMigr + 1.1;
IF LatMigr < 10, THEN= -0.03*LatMigr + 1.0

Table 4.30 Lateral Migration Scoring Index

Lateral Migration measured as percent constrained				
Function Value Ranges	Low		Moderate	High
Field Value	> 40	> 20–40	10–20	< 10
Index Value	0.0	0.0 – < 0.3	0.3–0.7	> 0.7–1.0

STANDARD PERFORMANCE INDEX

Development Method

Data and literature related to this measure is extremely limited. While scientific studies could not be used to directly inform the development of this standard performance index, the index is supported by current scientific understanding of how stream channel constraint relates to geomorphologic function.

This measure uses continuous data. Calculating the index score using a continuous scale allows for better detection of any change that results from impacts or mitigation activities.

SCIENTIFIC SUPPORT FOR ECOLOGICAL FUNCTIONS

Geomorphic Function

Generally, it is recognized that assessing the change in stream function associated with modifications to geomorphic condition is challenging to do in a rapid assessment or at project- level scales. Geomorphic processes are affected by surrounding landscapes and occur across long distances longitudinally in a stream so that processes that occur many miles upstream are linked to conditions downstream. In streams with high function, sediment transport and sorting occur over such large areas that evaluation on the scale of the EAA represents a snapshot of the overall balance in aggradation and erosion or channel migration. Therefore, it is acknowledged that evaluating geomorphic conditions in one EAA would not be adequate to define the overall geomorphic function of that EAA since it is also affected by processes occurring upstream and downstream.

SFAM evaluates the relative area of impairments to geomorphic processes (i.e. barriers to lateral migration) and the area actively undergoing changes in geomorphology (i.e. bank erosion). Geomorphic stream function is represented in SFAM by measuring condition, but the relative equilibrium of geomorphic processes is estimated by using measures of function that counterbalance each other (i.e. low scores given for high bank erosion would be counterbalanced by high scores for high opportunity for lateral migration).

The relative change in stream function associated with a given geomorphic condition is context-dependent. Generally, controls on the suite of geomorphic processes include climate, geology, vegetation and topography, in addition to past natural or anthropogenic disturbances (Montgomery and MacDonald, 2002). Montgomery and MacDonald (2002) state that, "The site-specific interactions between channel type, forcing mechanism, and channel response must be understood to select the variables for monitoring and design effective monitoring projects…. When designing a monitoring project, one must consider the relative sensitivity of each channel characteristic by channel type, forcing mechanism and biogeomorphic context." Channel type, forcing mechanisms, and channel responses for lateral migration are described below.

Channel Type

Channel types proposed by Montgomery and Buffington (1997) integrate seven stream characteristics that could each individually be considered controlling factors of geomorphic function (**Table 4.31**).

Table 4.31 Diagnostic Features of Each Channel Type
(Adapted from Montgomery and Buffington, 1997)

	Dune ripple	Pool riffle	Plane bed	Step pool	Cascade	Bedrock	Colluvial
Typical bed material	Sand	Gravel	Gravel-cobble	Cobble-boulder	Boulder	Rock	Variable
Bedform pattern	Multilayered	Laterally oscillatory	Featureless	Vertically oscillatory	Random	Irregular	Variable
Dominant roughness elements	Sinuosity, bedforms (dunes, ripples, bars) grains, banks	Bedforms (bars, pools), grains, sinuosity, banks	Grains, banks	Bedforms (steps, pools), grains, banks	Grains, banks	Boundaries (bed and banks)	Grains
Dominant sediment sources	Fluvial, bank failure	Fluvial, bank failure	Fluvial, bank failure	Fluvial, hillslope, debris flows	Fluvial, hillslope, debris flows	Fluvial, hillslope, debris flows	Hillslope, debris flows
Sediment storage elements	Overbank, bedforms	Overbank, bedforms	Debris flows	Bedforms	Lee (steep) and stoss (gentle) sides of flow obstructions	Pockets	Bed
Typical confinement	Unconfined	Unconfined	Overbank	Confined	Confined	Confined	Confined
Typical pool spacing (channel widths)	5–7	5–7	Variable	1–4	< 1	Variable	Unknown

Forcing Mechanisms

Other interacting forcing mechanisms of Lateral Migration:

- Spatial location within the channel network in a sediment production zone, sediment transfer zone, or sediment deposition zone
- Temporal variability in inputs (peak flows or mass wasting events versus monthly or annual averages)
- Valley slope
- Proximity to sources or sinks of sediment, water, or wood
- Vegetation
- Disturbance history

While these controls contribute to the variability in sensitivity of the response of a certain measure of stream function over time and space, there was not sufficient information to meaningfully stratify the standard performance index at this time.

Channel Response

In the SFAM model, anthropogenic constraints to lateral migration affect sediment continuity (SC) (the balance between transport and deposition). The rationale for this relationship is rooted in a statement from Montgomery and MacDonald (2002) that “lateral confinement provides an initial guide to the potential range of channel response,” since channel confinement in wide floodplains may limit a stream’s ability to change course, sinuosity or planform in response to disturbance. Channels confined by anthropogenic infrastructure such as roads are narrower, simpler in planform, and are devoid of depositional surfaces such as bars and islands and the associated floodplains lack the channel complexity that supports other functions like water quality and habitat (Blanton and Marcus, 2013). Broadly speaking, anthropogenic constraints to lateral migration alter sediment transport processes resulting in diminished stream function.

MEASURE DEVELOPMENT

This measure underwent significant revision during the development process. The original question asked users to assess the number of individual structures (e.g., road crossings, culverts, utility poles, etc.) that existed within the assessment reach that could constrain the channel's ability to move laterally. Reviewers suggested that this measure could be made more meaningful by determining the percent of stream channel that is physically constrained.

Although some reviewers commented that this measure is similar to the Bank Armoring measure, the development team chose to retain both measures because while bank armoring is a subset of lateral migration, they are not interchangeable as used in SFAM:

- Data for each measure is collected on different scales, PAA and EAA, respectively.
- Bank armoring informs the Substrate Mobility function, while lateral migration informs the Sediment Continuity function.
- There is no redundancy/double counting as they inform different functions.

As SFAM continues to develop and as relevant information becomes available, stratification of this standard performance index based on channel type could be considered. While anthropogenic constraint to lateral migration can be considered broadly to diminish stream function, the magnitude of change in stream function may depend on channel type and other forcing mechanisms.

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n) Wood

MEASURE TEXT

What is the frequency of large wood in the bankfull channel?

What is the frequency (pieces per 328 feet (100 m) of channel) of independent pieces of wood, defined here as woody material with a diameter of at least 4 inches (10 cm) for a length of 5 feet (1.5 m) within the EAA? This means that at least 5 feet of the piece of wood must be larger than 4 inches in diameter (i.e. a circumference > 12.5 inches). Independent pieces include all those individual pieces that meet size criteria either separate from or within log jams. To be counted, wood must have some part of its length within the bankfull channel. Exclude any wood that has been intentionally anchored to or within channel banks (using spikes, cables, ballast, etc.) for the purpose of permanently preventing bank erosion or meandering processes (armoring). Wood that is incorporated into an armored streambank for the purpose of providing habitat (e.g. as may be required by the agencies as a best management practice), or that is anchored in-stream to support meandering processes, may be counted. Live trees (i.e. trees that are standing, rooted, having or producing foliage) are not considered "wood" for this measure. Trees that are fully or partially fallen, have an exposed root wad, show evidence of being removed from the soil, or show other signs of dying (e.g. bare branches) are counted as "wood."

MEASURE DESCRIPTION

This measure quantifies the amount of wood that is in the stream channel and available to contribute to several stream ecosystem components, including: habitat diversity for fish and macro-invertebrates; substrate for primary producers; sediment storage; transient hydraulic storage and water velocity variability.

Function Groups: Hydrology, Biology
Functions Informed: Surface Water Storage (SWS), Maintain Biodiversity (MB), Create and Maintain Habitat (CMH)
Stratification: This measure is stratified by both ecoregion (Western Mountains; Xeric) and stream size (small ≤ 50 feet (~15 m) width; large > 50 feet width)
Metric: Pieces of wood per 328 feet (100 meters)

Model:
Western Mountains ecoregion; ≤ 50 feet wide:
IF Wood < 1.3, THEN = 0.2308*Wood;
IF Wood ≥ 1.3–24, THEN = 0.0176*Wood + 0.2771;
IF Wood > 24–45, THEN = 0.0143*Wood + 0.3571;
IF Wood > 45, THEN = 1.0

Western Mountains ecoregion; > 50 feet wide:
IF Wood ≤ 3.6, THEN = 0.1111*Wood + 0.3;
IF Wood > 3.6–8.2, THEN = 0.0652*Wood + 0.4652;
IF Wood > 8.2, THEN = 1.0

Xeric ecoregion; ≤ 50 feet wide:
IF Wood ≤ 8.2, THEN = 0.0488*Wood + 0.3;
IF Wood > 8.2–25, THEN = 0.0179*Wood + 0.5536;
IF Wood > 25, THEN = 1.0

Xeric ecoregion; > 50 feet wide:
IF Wood ≤ 1.3, THEN = 0.3077*Wood + 0.3;
IF Wood > 1.3–4.8, THEN = 0.0857*Wood + 0.5886;
IF Wood > 4.8, THEN = 1.0

Table 4.32 Wood Scoring Index

Pieces of wood (per 328 feet)				
Function Value Ranges	**Low**	**Moderate**	**High**	
Western Mountains; ≤ 50 ft width	< 1.3 pcs	1.3–24	> 2 4–45	> 45
Western Mountains; > 50 ft width	N/A	≤ 3.6	> 3.6–8.2	> 8.2
Xeric; ≤ 50 ft width	N/A	≤ 8.2	> 8.2–25	> 25
Xeric > 50 ft width	N/A	≤ 1.3	> 1.3–4.8	> 4.8
Index Value	0.0 – < 0.3	0.3–0.7	> 0.7 – < 1.0	1.0

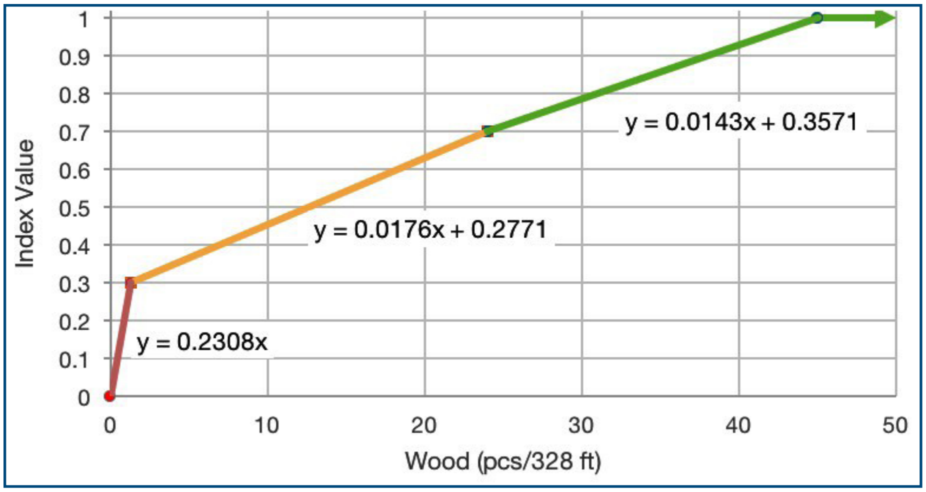

Figure 4.24 Wood Standard Performance Index - Western Mountains Ecoregion; ≤ 50 ft width

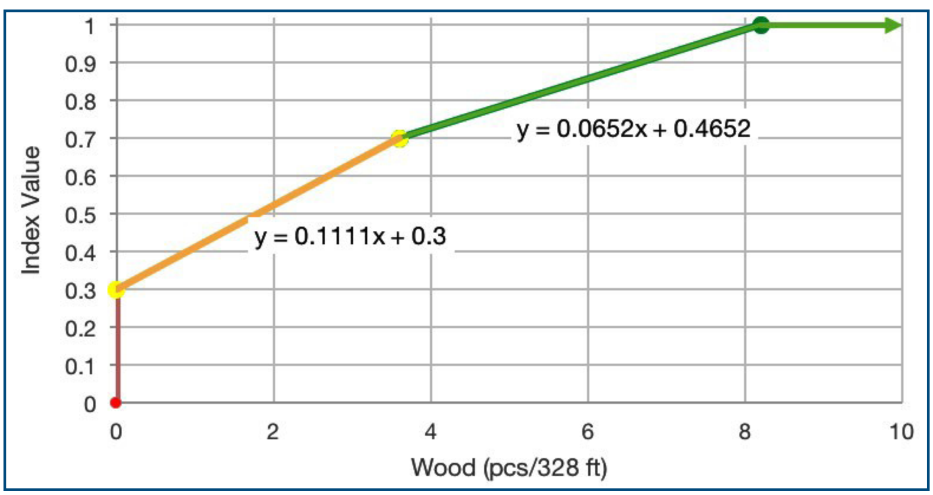

Figure 4.25 Wood Standard Performance Index - Western Mountains Ecoregion; > 50 ft width

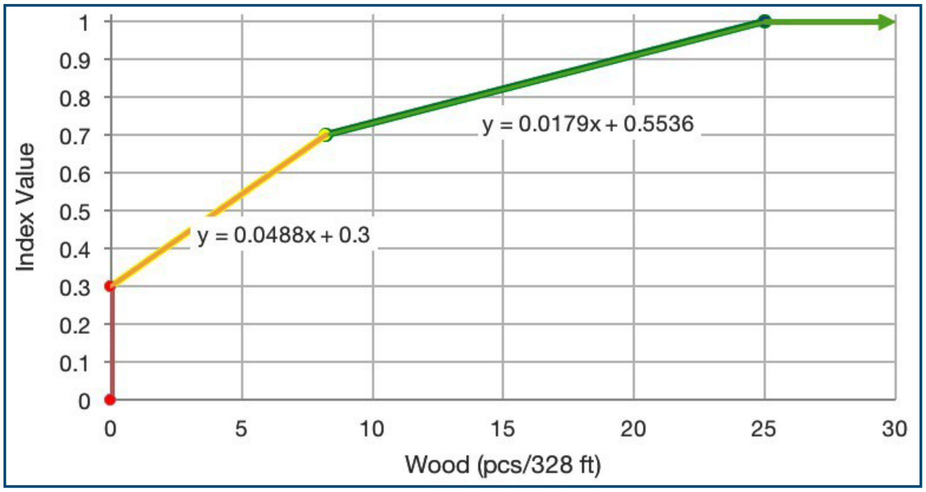

Figure 4.26 Wood Standard Performance Index - Xeric Ecoregion; ≤ 50 ft width

Figure 4.27 Wood Standard Performance Index - Xeric Ecoregion; > 50 ft width

STANDARD PERFORMANCE INDEX

Development Method

While there are many studies that relate the presence of wood, or a specific treatment of added wood to stream function (typically channel complexity and/or salmonid habitat/abundance) there is limited literature indicating critical loadings of wood for function response or regressions of wood-loading to response functions. Therefore, the standard performance indices presented here were developed based on the distribution of field-collected data from the USEPA NRSA surveys (USEPA, 2007; 2016). The index thresholds were determined using the approach described in **Section 4.1**. Threshold values are presented in **Table 4.33**, below.

This measure uses continuous data. Calculating the index score using a continuous scale allows for better detection of any change that results from impacts or mitigation activities.

Stratification

Streams occurring in dry (xeric) climates, where riparian vegetation is less dense and streams have lower wood recruitment rates than streams in wetter climates, are generally expected to have lower amounts of in-stream wood (Berg *et al.,* 1998; Hering *et al.,* 2000; Lester *et al.,* 2006; Dunkerley, 2014).

Additionally, one would expect larger streams to have a smaller quantity of wood because wood is less stable and more easily transported downstream than in smaller streams (Hyatt and Naiman, 2001; Curran, 2010). Therefore, we evaluated using ecoregion (Western Mountains and Xeric) and two stream width categories, small (width ≤ 50 feet (15 m)) and large (width > 50 feet), to stratify the NARS in-stream wood data.

The frequency distribution plots of the NARS data (**Figure 4.28**) show that wood amounts tend to be greater in streams in the Western Mountains ecoregion than in the Xeric ecoregion and greater in smaller (width ≤ 50 feet) streams versus larger streams, especially in the Western Mountains ecoregion. Given the differences in wood frequency by stream size and ecoregion in the NARS data, in addition to support of these expectations in the scientific literature, this measure is stratified on both ecoregion and stream width. A standard performance index was developed for each combination of stratifiers.

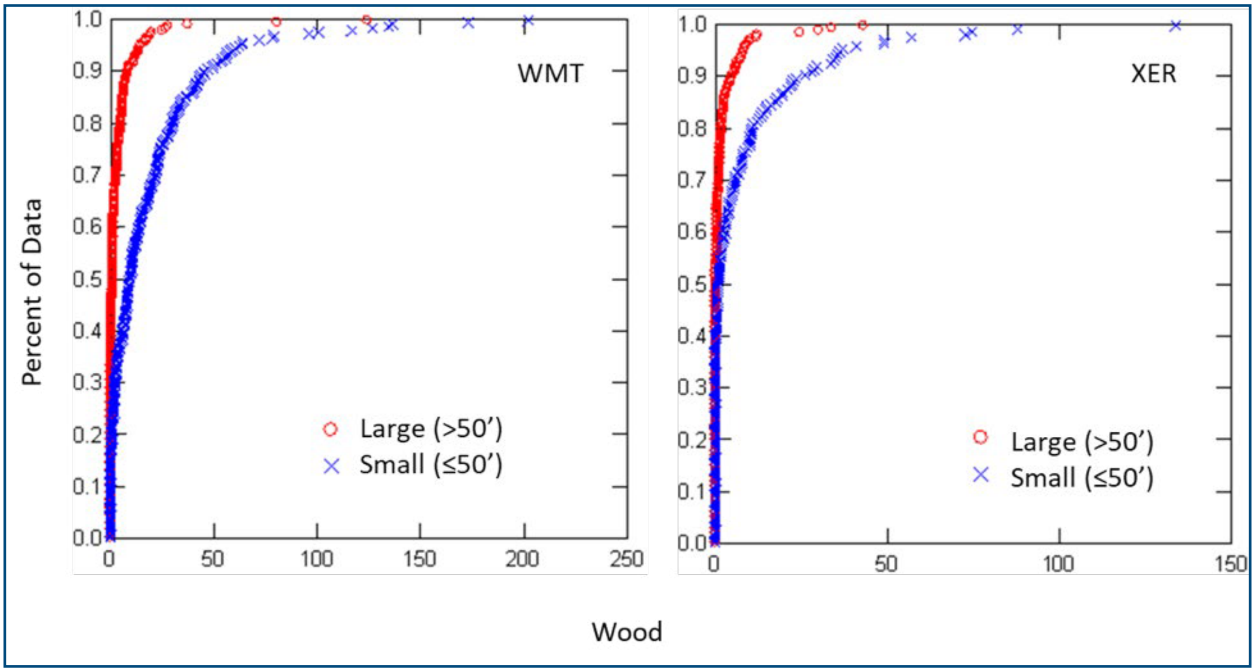

Figure 4.28 Frequency Distribution of Large Woody Debris Counts (per 328 feet) for 916 Stream Reaches by Size and Ecoregion

Table 4.33 Frequency Distribution of NARS Large Wood Counts (per 328 feet [100 m]), Stratified by Ecoregion and Stream Size

The 25th percentile of data, establishing the threshold between "low" and "moderate" function index values, is highlighted in red. The 75th percentile of data, establishing the threshold between "moderate" and "high" function index values, is highlighted in green. The 90th percentile of the data, establishing the threshold for the maximum index value (1.0), is highlighted in blue.

Wood				
Summary Statistics	**Western Mountains**		**Xeric**	
	Small (≤ 50')	**Large (> 50')**	**Small (≤ 50')**	**Large (> 50')**
Number of Sites	262	254	178	222
Minimum	0	0	0	0
Maximum	202	124.158	133.838	42.929
Arithmetic Mean	18.726	3.68	8.197	1.746
Standard Deviation	27.533	10.384	17.168	4.89
Distribution of Data				
1.00%	0	0	0	0
5.00%	0	0	0	0
25.00%	1.342	0	0	0
50.00%	9.512	0.909	0.715	0
75.00%	24.161	3.636	8.207	1.364
90.00%	45.727	8.227	25.369	4.814

SCIENTIFIC SUPPORT FOR ECOLOGICAL FUNCTIONS

Hydrologic & Biologic Functions

There is extensive literature on the topic of wood function in streams. A recent review article by Roni *et al.* (2014) focuses on studies regarding wood placement used in river restoration and concludes, among other things, that "the vast majority of studies on wood placement have reported improvements in physical habitats (e.g., increased pool frequency, cover, habitat diversity) and most evaluations of fish response to wood placement have shown positive responses for salmonids."

As noted in the Roni *et al.* review (2014), many studies show that large woody debris (LWD) contributes to stream complexity including studies conducted in Oregon (Johnson *et al.,* 2005; Kaufmann *et al.,* 2012). Kaufmann *et al.* (2012) also show a positive linear correlation between LWD and transient hydraulic storage in Western Oregon streams with LWD loads ranging from 6–97 pcs/100 m.

Studies have shown positive responses of stream biota to LWD. Johnson and co-authors (2005) found juvenile Steelhead and Coho survival increased in a stream where the volume of wood was increased from ~20 m^3 per 100 m to 60 m^3 per 100 m. In a study in the Upper Midwest (Johnson *et al.,* 2003), 85% and 95% of the total macroinvertebrate taxa encountered were found in wood habitats in Michigan and Minnesota streams, respectively. In the Michigan streams, 17% of the taxa were unique to the wood habitats.

Table 4.34 Summary of Supporting Literature or Data for Wood Standard Performance Indices

Reference	Metric	Function Response Variable	SFAM Functions Informed	Metric Classifications	Informative Conclusions
Data source					
USEPA NARS Rivers and Streams Assessment data	LWD counts (pcs per 100 m)	None	None	Many available; evaluated ecoregion and stream width (large (> 50 ft) vs. small (< 50 ft))	Evaluation of this large data set (n=916) from stream reaches representative of the ecoregions which occur in Oregon provide the expected range and distribution of stream wood counts.
Decision Support for Hydrologic and Biologic Functions					
Kaufmann *et al*., 2012	LWD counts (pcs per 100 m) by size class; estimated volume	Transient hydraulic storage	MB, CMH, SWS,	Western Oregon wadeable streams	LWD as well as variability in stream depth and width contribute to transient hydraulic storage, a channel process important for biotic habitat as well as nutrient retention and cycling.
Johnson *et al*., 2005	LWD counts by size class; estimated volume	Abundance and survival of juvenile salmonids	CMH, MB	Coastal Oregon	An increase in LWD increased fish habitat (summer pool habitat and side-channel habitat) as well as measured freshwater survival of Steelhead and Coho.
Johnson *et al*., 2003	Wood volume and “length density”	Macroinvertebrate taxa richness and abundance	MB, CMH, SWS	Low gradient streams in the Upper Midwest	Wood represents an important habitat for macroinvertebrates in this region. A significant portion of local macroinvertebrate diversity can be attributed to the presence of large wood.
Roni *et al*., 2014	Review of wood placement literature	Effectiveness of placed wood	CMH, MB, SWS	Considered literature from around the world	The majority of studies report improvements in physical habitat in response to wood placement, and most evaluations of fish response to wood placement were positive for salmonids.

Notes:
CMH = Create and Maintain Habitat
MB = Maintain Biodiversity
SWS = Surface Storage

MEASURE DEVELOPMENT

This measure was highly ranked by the Technical Working Group and was determined to be relatively easy to measure in the field. The original measure had a higher size threshold for what counted as "large wood" but the threshold was reduced to capture functional wood in smaller streams, informed by the available literature, field testing, and NARS protocols. In an earlier SFAM draft, data resulting from this measure were placed into frequency bins, but field testing and input from reviewers found the bins to be too constrained, lumping most observations into just two categories. This measure now uses continuous data, with stratified standard performance indices based on NARS data.

Based on input from pilot testing, wood that is incorporated into an armored streambank for the purpose of providing habitat (e.g. as may be required by the agencies as a best management practice), or that is anchored in-stream to support meandering processes, is now counted positively when assessing this measure whereas all anchored wood was previously excluded. Pilot testers also recommended that the Wood measure should inform the Sub/Surface Transfer function. Large wood may indirectly affect hydraulic gradients within the hyporheic zone by creating geomorphic features that enhance hyporheic exchange (Arrigoni *et al.,* 2008). To test potential benefits of including the Wood measure in calculating the SST function subscore, we:

1. Ran the scenario of adding the Wood measure to the SST function calculation using the 2013 field data set (39 sites x 2 field seasons), in which the standard performance indices had not yet been developed to set index values; this resulted in a greater response variability/worse fit (more assessment site residuals outside +/- 2; see **Section 2.3** for a description of this analysis) than not including the Wood measure in calculating the SST function subscore.
2. Ran the same scenario using the current (weighted) SST calculation formula and standard performance indices, using 9 sites from 2017 field assessments. Adding the Wood measure to the SST function calculation had little or no impact on the SST subscore.

Thus, the Wood measure is not used in calculating the SST function. We believe the geomorphic features created by large wood are captured by the Channel Bed Variability measure, which does inform the SST function.

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o) Incision

MEASURE TEXT

What is the degree of channel incision within the EAA?

At each of the 11 transects within the EAA, measure the Bank Height Ratio (BHR). The BHR is the height from the stream thalweg to the level of the first terrace of the valley floodplain divided by the bankfull height. Do not consider inset floodplains. Note that in a very connected/ non-incised stream, the first terrace height and bankfull height are equal.

MEASURE DESCRIPTION

This measure provides information about hydrologic connectivity and channel stability. Stream bank incision ratios are a measure of the vertical containment of a stream and indicate the potential for a stream to interact with its floodplain. A lower bank height ratio corresponds with more frequent access to the floodplain by the stream's waters.

Function Groups: Hydrology, Geomorphology, Biology
Functions Informed: Surface Water Storage (SWS), Sediment Continuity (SC), Create and Maintain Habitat (CMH)
Stratification: This measure is not stratified
Metric: Bank height ratio

Model:
IF Incision > 3.06, THEN = 0.0;
IF Incision > 2.18–3.06, THEN = -0.3409*Incision + 1.0432;
IF Incision = 1.33–2.18, THEN = -0.4706*Incision + 1.3259;
IF Incision < 1.33, THEN = -0.9091*Incision + 1.9091

Table 4.35 Incision Scoring Index

Incision measured as bank height ratio				
Function Value Ranges	**Low**		**Moderate**	**High**
Field Value	> 3.06	> 2.18–3.06	1.33–2.18	< 1.33–1
Index Value	0.0	> 0.0 – < 0.3	0.3–0.7	> 0.7–1.0

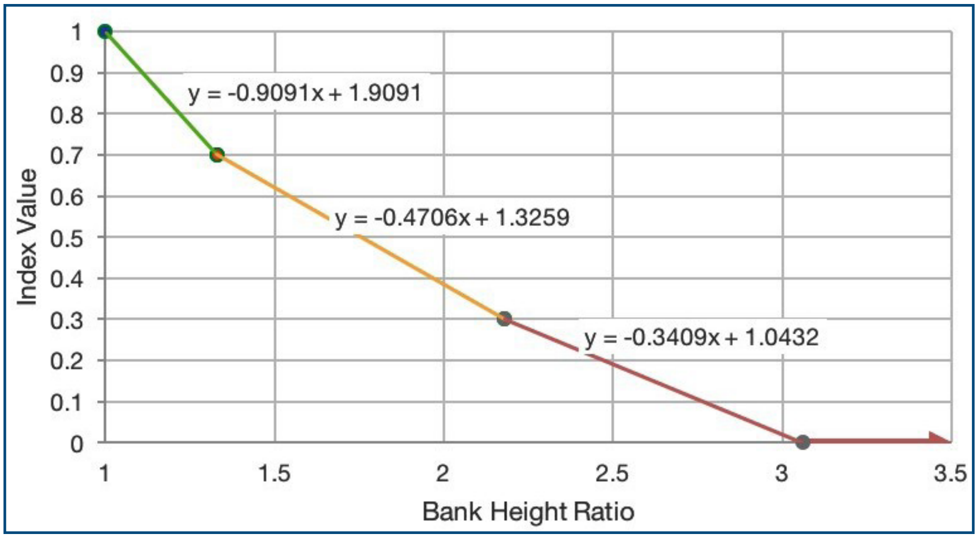

Figure 4.29 Incision Standard Performance Index

STANDARD PERFORMANCE INDEX

Development Method

While there is significant information in the literature to support that the degree of incision influences floodplain interaction and streambank erosion processes, there is limited indication of critical bank height ratios for function response. Therefore, the standard performance index presented here was developed based on the distribution of field-collected data from the USEPA NRSA surveys (USEPA, 2007; 2016). The index thresholds were determined using the approach described in **Section 4.1**. Threshold values are presented in **Table 4.35**, above.

Stratification

The Incision measure is not stratified as the bank height ratio is normalized by the bankfull depth. Therefore, a BHR of 1.0 means that water will flow out of the banks at a stage above bankfull. Evaluation of the NARS BHR data by ecoregion and stream size show that while there is some difference in BHR between large and small streams in the Western Mountains ecoregion sites, it only occurs at BHR values that would likely be considered “low” and is not significant enough to warrant stratification for BHR (**Figure 4.30**). There is no indication of significant differences in BHR between the two Oregon ecoregions.

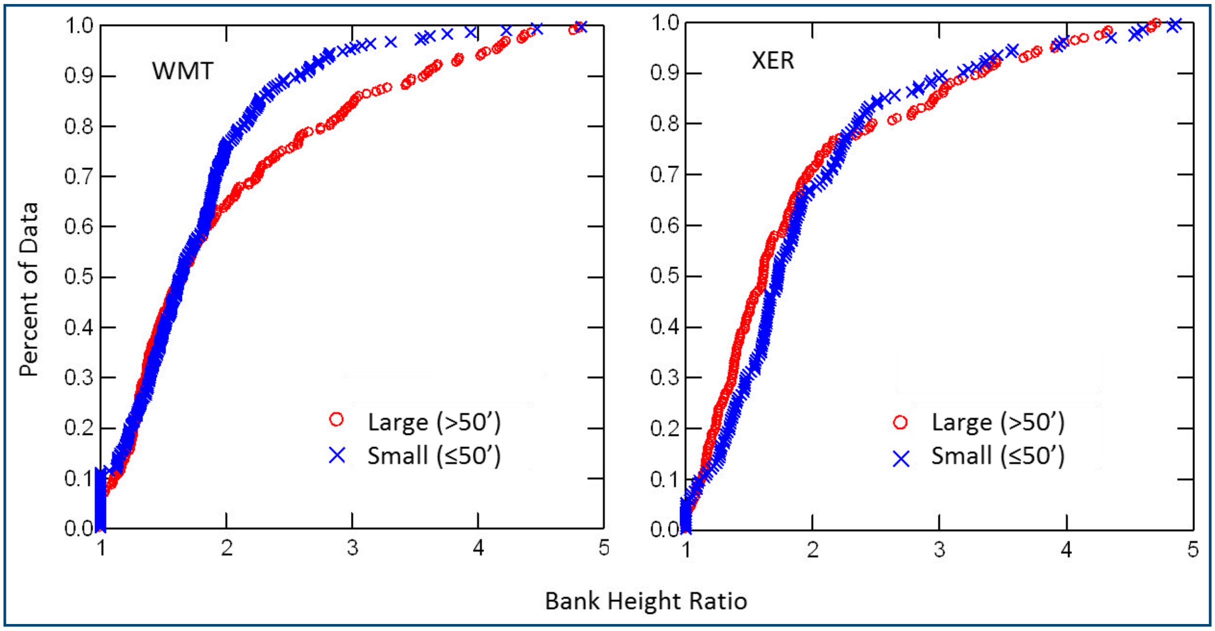

Figure 4.30 Frequency Distribution of Bank Height Ratio Values for 885 Stream Reaches by Ecoregion and Stream Width. WMT Western Mountains; XER Xeric.

Table 4.36 Frequency Distribution of NARS Incision Data (Bank Height Ratio)

This measure has an inverse scale; higher ratios indicate lower functioning. The 25th percentile of data, establishing the threshold between "moderate' and "high" function index values, is highlighted in green. The 75th percentile of data, establishing the threshold between "low" and "moderate" function index values, is highlighted in red. The 90th percentile of data, establishing the threshold for an index value of 0.0 is highlighted in blue.

Incision (bank height ratio)	
Summary Statistics	
Number of Sites	885
Minimum	1
Maximum	4.862
Arithmetic Mean	1.894
Standard Deviation	0.823
Distribution of Data	
1.00%	1
5.00%	1
25.00%	1.326
50.00%	1.655
75.00%	2.181
90.00%	3.062

SCIENTIFIC SUPPORT FOR ECOLOGICAL FUNCTIONS

Stream and river channel incision is recognized as a widespread environmental problem that has caused extensive ecosystem degradation (Wang *et al*., 1997; Montgomery, 2007). Incision is the process of downcutting into a stream channel leading to a decrease in the channel bed elevation and therefore higher stream banks (Darby and Simon, 1999). While natural processes can cause channel incision, many instances of channel incision have been shown to be caused by or to be correlated with changes in land use (Cooke and Reeves, 1976; Montgomery, 2007).

Rosgen (1997) describes an incised stream as:

> *"…a vertically contained stream that has abandoned previous floodplains due to a lowering of local base level and is characterized by high streambanks bounded by alluvial terraces. Incised rivers, however, can also be located in certain landforms and valley types that are naturally associated with entrenched rivers. However, the consequence of river channelization, straightening, encroachment, confinement (lateral containment), urban development, major floods, change in sediment regime and riparian vegetation conversion can create incised rivers. The consequence of creating an incised channel is associated with accelerated streambank erosion, land loss, aquatic habitat loss, lowering of water tables, land productivity reduction and downstream sedimentation."*

Hydrologic Functions

One significant result of channel incision is the disconnection of a stream from its floodplain. Floodplain disconnection has significant impact on hydrologic functions, especially the storage of surface water (SWS). When a stream is unable to access its floodplain, water cannot be transferred away from the main channel during high flow events and instead the full volume must instead by transferred by the channel resulting in increased velocity of flow and an increase in downstream flood severity.

While the literature contains few studies directly linking stream incision (and magnitude thereof) to functional loss, there are several case studies citing a significant reduction in downstream flooding following the re-connection of stream floodplain. A number of these case studies are discussed in a recent review paper by Abbe *et al*. (2016). Additionally, the loss of hydrologic functions resulting from floodplain disconnection is further discussed in the rationale for the SFAM Floodplain Exclusion measure (**Section 4.2 (g)**).

In addition to reducing water storage during high-water periods, an incised stream can effectively lower the local water table thereby reducing stored water available for discharge during dry periods and reducing water available for riparian vegetation (Chaney *et al*., 1990; Rosgen, 1997; Green, 2016).

In summary, the evidence in the scientific literature clearly demonstrates that stream incision can have significant negative impacts on the surface water storage function, which in-turn can increase downstream flooding and reduce water availability during low-flow periods.

Geomorphic Functions

It is generally recognized that assessing the change in stream function associated with modifications to geomorphic condition is challenging to do using a rapid assessment or at project-level scales. Geomorphic processes are affected by surrounding landscapes and occur across long distances longitudinally in a stream, such that processes that occur many miles upstream are linked to conditions downstream. In high functioning streams, sediment transport and sorting occur over large areas, and evaluation on the scale of the EAA (in the case of Incision) represents a snapshot of the overall stream geomorphology.

In SFAM, the average BHR as measured in the EAA helps describe the overall balance (or imbalance) of sediment transport processes (i.e. Sediment Continuity (SC)). When sediment transport increases or erosion resistance decreases such that the excavation rate of streambed sediment is faster than its replacement rate, channel incision will occur (Beechie *et al*., 2008; Cluer and Thorne, 2014). While BHR does not indicate timing or direction (aggradation or degradation), an incised stream is less likely to have sediment processes that are in balance.

As the BHR increases over 1.0 (floodplain height is greater than the bankfull height), indicating some degree of incision, the streambank heights increase, become less stable and are prone to erosion adding sediment to the downstream bedload (Rosgen, 1997). As discussed above, an incised stream is less connected to its floodplain and therefore has less opportunity to deposit fine material outside the channel. This increased bedload affects instream structure, including substrate embeddedness and the filling of pools (Greene, 2016). Stream incision is widely recognized by stream geomorphologists as both a consequence and cause of stream sediment process instability.

Biologic Functions

Stream incision can affect both riparian and instream habitat. The floodplain disconnection which results from incision reduces surface water storage and can lower the local water table, which in turn reduces the available water for wetland and riparian plants dependent on connection to the stream water. The reduction in stored water and lowered water table also limits source water in the dry season, which can result in the drying of streams or the warming of water due to a lower volume of cool water inputs (Chaney *et al*., 1990; Rosgen, 1997; Green, 2016).

During high flow periods, incised channels must transfer the full volume of water downstream, reducing access to the floodplain, low-velocity refugia and other resources used by fish (Beechie *et al*., 1994; Henning *et al*., 2006, 2007). The increased velocities in incised channels also results in reduced channel complexity. Channels that have been disconnected from their floodplains through incision will tend to have fewer side-channels, islands and pools reducing the available area for species who depend on those habitats (Gendaszek *et al*., 2012). **Section 4.2 (g)**, Exclusion, discusses several studies detailing the impacts of floodplain disconnection on riparian and aquatic habitat and associated biota.

MEASURE DEVELOPMENT

This measure, originally titled Entrenchment (**Table 2.1**), was highly-ranked by the Technical Working Group but required several major revisions to arrive at a sufficiently quantitative and feasible data collection protocol. In the earliest versions of SFAM, users were instructed to conduct visual estimations of entrenchment, but reviewers suggested that such estimates may require a well-developed understanding of riparian species assessment and that it may be difficult to distinguish between channel bars and inset floodplains. In response to these comments, the visual method was replaced with a more quantitative method: calculating the ratio of active channel width height to floodplain terrace height. Reviewers further suggested replacing this measure with one more commonly used (such as the bank height ratio) and increasing the number of transects at which measurements are taken (increased from 3 to 11 transects). The final data collection protocol for this measure is consistent with the methods used in NARS (USEPA, 2007).

Compared to incision values found in the scientific literature, the values used in the standard performance index for this measure seem to be relatively high (incised) values. This difference may be due to the difference in data collection protocols (in riffles only versus systematically throughout the reach as in SFAM). To explore this, we evaluated BHR data from ten sites in Oregon's Calapooia basin and compared all BHR measures to those taken only at riffles. The results from this analysis showed no significant difference in the mean site BHR between the two protocols. In the absence of more information, the model and standard performance index for this measure reflects the data expectations resulting from the NARS data analysis as described above.

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p) Embeddedness

MEASURE TEXT

What is the degree of substrate embeddedness in the stream channel?

To what extent are larger stream substrate particles surrounded by finer sediments (i.e. silt and/or sand) on the surface of the streambed? Measurements are taken at 11 transects within the EAA.

MEASURE DESCRIPTION

This measure represents the degree to which rocks, gravel, and cobble are surrounded by (embedded in) fine substrates, such as sand, silt, and mud. Measuring stream bed embeddedness provides information about the stream's sediment regime (influenced by substrate type and flow regime), and quantifies the availability of interstitial spaces that can provide shelter and spawning habitat for fish and macroinvertebrate species. Increases in fine sediment deposition within a stream reach can indicate decreases in stability and habitat quality.

Function Groups: Hydrologic, Geomorphology, Biology
Functions Informed: Flow Variation (FV), Substrate Mobility (SM), Create and Maintain Habitat (CMH)
Stratification: This measure is not stratified
Metric: Percent embeddedness

Model:
IF Embed > 78, THEN = -0.0136*Embed + 1.3636;
IF Embed = 37–78, THEN = -0.0098*Embed + 1.061;
IF Embed = 25–37, THEN = -0.025*Embed + 1.625;
IF Embed < 25, THEN = 1.0

Table 4.37 Embeddedness Scoring Index

Embeddedness as measured by percent				
Function Value Ranges	**Low**	**Moderate**	**High**	
Field Value	> 78%	37–78%	25–37%	< 25%
Index Value	0.0 – < 0.3	0.3–0.7	> 0.7–1.0	1.0

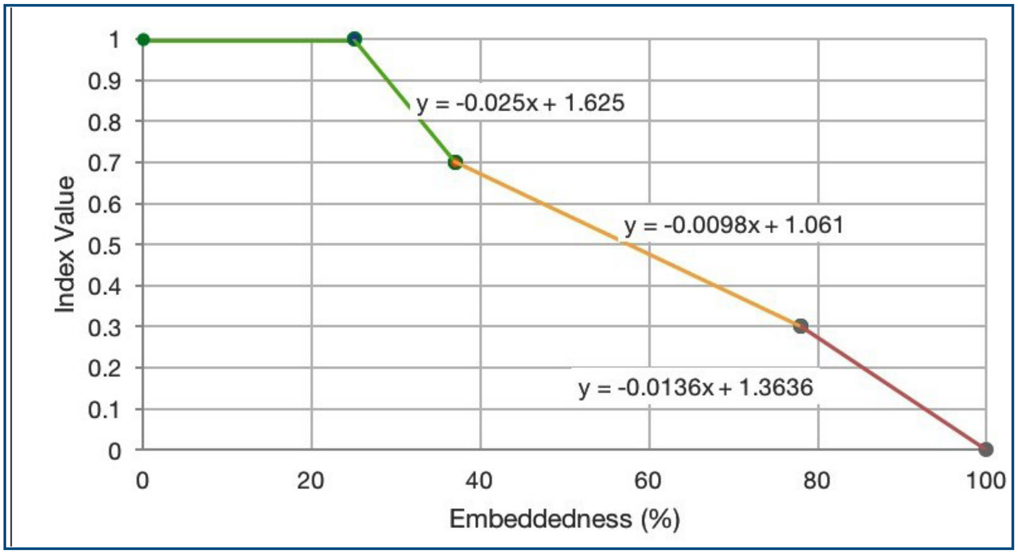

Figure 4.31 Embeddedness Standard Performance Index

STANDARD PERFORMANCE INDEX

Development Method

While there are many studies that relate the degree of embeddedness to various biological and physical stream functions, there is limited literature indicating critical values for function response. Therefore, the standard performance index presented here was developed based on the distribution of field-collected data from the USEPA NRSA surveys (USEPA, 2007; 2016). The index thresholds were determined using the approach described in **Section 4.1**. Threshold values are presented in **Table 4.38.**

Table 4.38 Frequency Distribution of NARS Embeddedness Data (Percent Embedded)

This measure has an inverse scale; higher ratios indicate lower functioning. The 25th percentile of data, establishing the threshold between "moderate' and "high" function index values, is highlighted in green. The 75th percentile of data, establishing the threshold between "low" and "moderate" function index values, is highlighted in red. The 10th percentile of data, establishing the threshold for the maximum index value (1.0) is highlighted in blue.

Embeddedness (%)	
Summary Statistics	
Number of Sites	615
Minimum	0
Maximum	100
Arithmetic Mean	57.249
Standard Deviation	25.241
Distribution of Data	
1.00%	6.391
10.00%	**25.273**
25.00%	**36.932**
50.00%	55.818
75.00%	77.773
90.00%	**94.182**

SCIENTIFIC SUPPORT FOR ECOLOGICAL FUNCTIONS

Hydrologic & Geomorphic Function

Embeddedness is a measure of the degree to which fine particles surround coarse substrate (gravel and cobble) on the surface of the streambed and is a common measure used to indicate excessive stream sedimentation (Sennatt *et al.,* 2006; Sutherland *et al.,* 2010). Excessive sediment inputs from land disturbance has significant impacts on streams and rivers in North America and elsewhere (Canadian Council of Ministers of the Environment [CCME], 1999; USEPA, 2002).

There are many causes of excessive sedimentation in streams, including the flushing of fine material from roadways, excessive bank erosion caused by streamside disturbances (e.g., grazing, roads, vegetation removal, etc.), and impoundments that cause changes in the magnitude or timing of stream flows. Multiple studies show a positive relationship between increases in stream sedimentation and watershed land use disturbance (Waters, 1995; Walser and Bart, 1999; Price and Leigh, 2006; Sutherland *et al.,* 2010).

As stream substrates become more embedded, the interstitial space between particles is reduced, effectively reducing streambed roughness and altering channel bedform and hydraulics, limiting the opportunity for hyporheic flow. Substrate mobility can also be substantially affected by the quantity and characteristics of deposited fine material (Wilcock, 1998). It is also well documented that changes to stream flow regime (i.e. changes in flow variation) often result in altered stream sediment characteristics (Williams and Wolman, 1984; Elliot and Parker, 1997; Sylte and Fischenich, 2002).

To inform the Flow Variation and Substrate Mobility functions, SFAM uses substrate embeddedness as a measure of changes to the hydrologic flow regime and to indicate impairment to the mobility of stream substrate.

Biologic Function

Substrate embeddedness resulting from excessive fine sediment deposition reduces the interstitial spaces and substrate surface area relied on by macroinvertebrates, amphibians and fish for shelter and food resources. It reduces streambed roughness that creates habitat and provides respite from stream flow and excessive currents. Embeddedness has been correlated with degraded benthic habitat and a decline in stream macroinvertebrate diversity and abundance (Waters, 1995; Angradi, 1999). Additionally, high embeddedness has been shown to reduce amphibian abundance (Lowe and Bolger, 2000).

As part of a fish assemblage and stream physical habitat survey across streams in the Willamette River Basin, Oregon, Waite and Carpenter (2000) found substrate embeddedness to be correlated with low abundance of salmonids and higher abundances of non-native fish species at “heavily impacted” sites within the basin. Further, controlled experiments (Suttle *et al.,* 2004) evaluating varying degrees of embeddedness concluded that embeddedness results in significant decreases in juvenile salmon growth and survival, as well as a decrease in the macroinvertebrate community used by the juvenile salmon as food.

MEASURE DEVELOPMENT

This measure underwent significant revision during SFAM development. Originally, SFAM included a measure that assessed vegetation type on channel bars as a surrogate measure of successional processes and the extent of channel dynamics, but reviewers commented that such a protocol would make it difficult to detect change and would not be applicable to all channel types (see **Section 5.1**). The current measure was then developed to focus more directly on sediment processes rather than rely on vegetation communities as a proxy. The final protocol is from Kaufmann *et al.* (1999) and is consistent with the methods used in the NARS assessments (USEPA, 2007), on which the standard performance index for this measure is based.

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q) Channel Bed Variability

MEASURE TEXT

Is the channel bed variable?

Channel bed variability submeasures include variation in wetted channel width and stream thalweg depth along the Extended Assessment Area (EAA).

MEASURE DESCRIPTION

Channel bed variability is a summary measure of two geomorphic characteristics of the stream: wetted width variability and thalweg depth variability. This measure informs several functions and is a surrogate for assessing the effects of sediment transport and aquatic habitat. Heterogeneity in the elevation along the cross section and the longitudinal axis is indicative of hydraulic variability that maintains the dynamic nature of the channel. Overall bed elevation changes dictate stream power and are reflective of flow and sediment transport. Impacted systems tend to exhibit low variability.

Function Groups: Hydrology, Geomorphology, Biology, Water Quality
Functions Informed: Surface Water Storage (SWS), Sub/Surface Transfer (SST), Flow Variation (FV), Substrate Mobility (SM), Maintain Biodiversity (MB), Create and Maintain Habitat (CMH), Nutrient Cycling (NC), Chemical Regulation (CR)
Metric: Coefficient of variation

Model:
Overall measure = AVERAGE (WidVar,DepthVar)

Wetted Width Variability (WidVar) submeasure:
IF WidVar < 0.215, THEN = 1.3953*WidVar;
IF WidVar = 0.215–0.384, THEN = 2.3699*WidVar – 0.2089;
IF WidVar > 0.384–0.509, THEN = 2.4*WidVar - 0.2216;
IF WidVar > 0.509, THEN = 1.0

Thalweg Depth Variability (DepthVar) submeasure:
IF DepthVar < 0.323, THEN = 0.9288*DepthVar;
IF DepthVar = 0.323–0.567, THEN = 1.6393*DepthVar - 0.2295;
IF DepthVar > 0.567–0.744, THEN = 1.6949*DepthVar - 0.261;
IF DepthVar > 0.744, THEN =1.0

Table 4.39 Channel Bed Variability Scoring Index

Wetted Width and Thalweg Depth as a coefficient of variation				
Function Value Ranges	**Low**	**Moderate**	**High**	
Wetted Width Variability	< 0.215	0.215–0.384	> 0.384–0.509	> 0.509
Thalweg Depth Variability	< 0.323	0.323–0.567	> 0.567–0.744	> 0.744
Index Value	0.0 – < 0.3	0.3–0.7	> 0.7–1.0	1.0

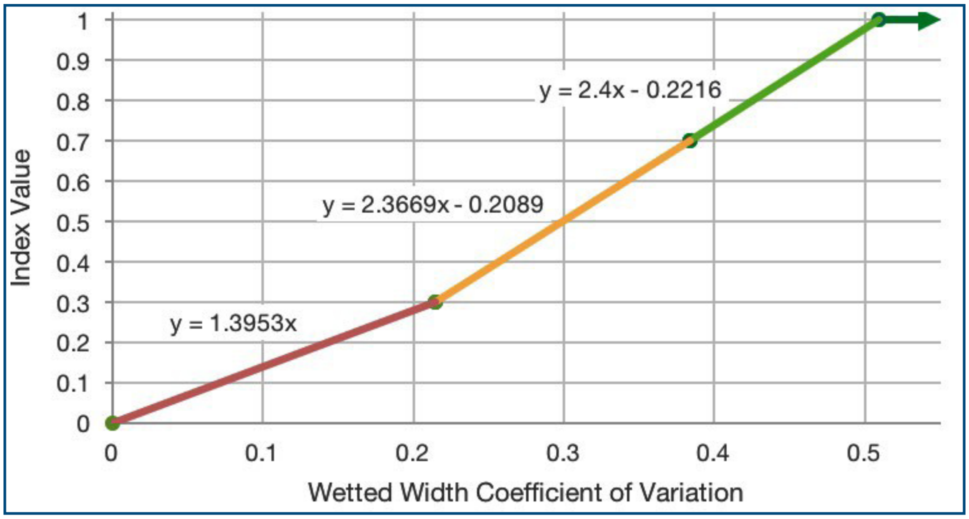

Figure 4.32 Wetted Width Standard Performance Index

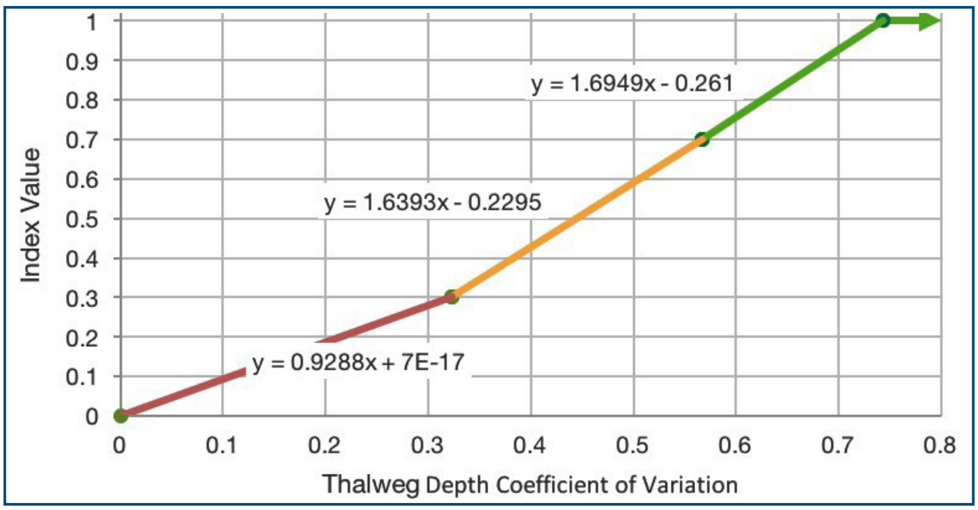

Figure 4.33 Thalweg Depth Standard Performance Index

STANDARD PERFORMANCE INDICES

Development Method

There is significant information in the literature to support that channel bed variability factors have positive relationships with numerous hydrologic, geomorphic, biologic, and water quality functions. The range of specific function responses and the variety of methods used to quantify channel bed variability made it difficult to use the literature to establish standard expectations from the resulting influence of channel bed variability on stream function. Therefore, development of standard performance indices for included submeasures was based on the distribution of field-collected data from the USEPA NRSA surveys (USEPA, 2007; 2016). The index thresholds were determined using the approach described in **Section 4.1**. Threshold values are presented in **Tables 4.40** and **4.41** below.

Stratification

Stratification by stream size is unnecessary, given that the coefficient of variation is a scaled metric.

Initially, channel slope was considered as a potential factor for stratification of the wetted width and thalweg depth variability measures, but analysis of the NARS data provided no evidence to support stratification (i.e. the differences in variation between streams with low [<2%], moderate [2-6%], and high [>6%] slopes were small and not significant).

Table 4.40 Frequency Distribution of NARS Wetted Width Data (Coefficient of Variation)
The 25th percentile of data, establishing the threshold between "low" and "moderate" function index values, is highlighted in red. The 75th percentile of data, establishing the threshold between "moderate" and "high" function index values, is highlighted in green. The 90th percentile of the data, establishing the threshold for the maximum index value (1.0), is highlighted in blue.

Wetted Width (coefficient of variation)	
Summary Statistics	
Number of Sites	967
Minimum	0
Maximum	1.805
Arithmetic Mean	0.325
Standard Deviation	0.175
Distribution of Data	
1.00%	0.066
5.00%	0.131
25.00%	0.215
50.00%	0.294
75.00%	0.384
90.00%	0.509

Table 4.41 Frequency Distribution of NARS Thalweg Depth Data (Coefficient of Variation)
The 25th percentile of data, establishing the threshold between "low" and "moderate" function index values, is highlighted in red. The 75th percentile of data, establishing the threshold between "moderate" and "high" function index values, is highlighted in green. The 90th percentile of the data, establishing the threshold for the maximum index value (1.0), is highlighted in blue.

Thalweg Depth (coefficient of variation)	
Summary Statistics	
Number of Sites	970
Minimum	0.044
Maximum	3.192
Arithmetic Mean	0.472
Standard Deviation	0.244
Distribution of Data	
1.00%	0.095
5.00%	0.203
25.00%	0.323
50.00%	0.423
75.00%	0.567
90.00%	0.744

SCIENTIFIC SUPPORT FOR ECOLOGICAL FUNCTIONS

In SFAM, Channel Bed Variability is measured by the average of two dimensionless metrics: 1) the coefficient of variation (CV) of thalweg depth and 2) the CV of stream wetted width. These metrics capture structural components of what is often referred to as channel habitat complexity.

It is challenging to quantify channel habitat complexity in a meaningful way as part of a rapid stream function assessment intended to be applied across a broad range of stream types and sizes. The two measures used here are common components of many protocols used to quantify channel complexity; are relatively easily applied to most stream reaches; and, are applicable to a wide variety of stream sizes. Because of their operational simplicity, measures of stream width and depth variance have been used to characterize channel complexity (e.g., Moore and Gregory, 1988; Gooseff *et al*., 2007; Kaufmann and Faustini, 2012; Laub *et al.*, 2012)

The literature demonstrates that channel bed variability contributes to a wide range of stream ecological functions. SFAM uses this measure to inform functions of all four functional groups; hydrology, geomorphology, biology and water quality.

Hydrologic Function

Streams that have variable widths and depths create the opportunity for hydrological complexity within that stream. Such complexity results in increases in residual time of water, residual pool volumes, and hydraulic roughness providing Surface Water Storage (SWS) and Flow Variation (FV) (Gooseff *et al*., 2007; Kaufmann and Faustini, 2012). In a study of small upland cobble/ gravel bottom streams, Kaufmann and Faustini (2012) predicted with significant precision the transient hydraulic storage fraction using the thalweg depth variance ($R^2 = 0.64–0.91$). Transient hydraulic storage is a process by which water is temporarily stored in flow 'dead zones' in the surface waters (pools, eddies) or below the streambed in the hyporheic zone. These areas of stored water provide opportunity for a variety of other ecological functions to occur.

Variation in the geomorphic structure of streams has been found to significantly influence hyporheic exchange (SST) patterns and fluxes (Cardenas *et al*., 2004; Gooseff *et al*., 2006). Gooseff and co-authors (2006) used a modelling approach to identify that slope breaks in the longitudinal profile of streams can be used to predict the spacing between zones of upwelling (flux of hyporheic water into the stream) and downwelling (flux of stream water into the hyporheic zone) in the beds of mountain streams. Harvey and Bencala (1993) found exchange between stream channels and adjacent subsurface waters to be enhanced by convexities and concavities in stream bed topography.

Increases in transient hydraulic storage and retention (dead zones), residual pools, flow velocity variation, and hyporheic flow are properties of streams resulting from multiple attributes of channel structure and can have significant impact on stream hydrology, biology and chemistry.

Geomorphic Function

Variation of channel bed structure and related hydrologic variation provide the opportunity for a more complex and dynamic channel substrate. Variation in flow velocities caused by morphological heterogeneity promotes particle sorting during sedimentation and greater substrate diversity (Pearsons *et al*., 1992; Kaufmann and Faustini, 2012). Areas of low velocities created behind in-channel structure (wood, large cobble), at pool edges, and the inside of meanders will support the deposition of small gravel or fine material, while areas with higher velocities will have larger substrate. Channel bed variability also promotes the dynamic nature of the substrate as the variations in velocity will change depending on the stream stage. Thus, channel bed variability contributes to the dynamic nature of the stream substrate, which in turn supports the maintenance of the varied habitat needed for biologic and water quality functions.

Biologic Function

Biologic function of streams, including the Creation and Maintenance of Habitats (CMH) and Maintaining Biodiversity (MB), requires heterogeneity in the physical environment. Channel bed variation, as discussed above, promotes variation in critical components of the aquatic environment of streams including water depths, velocities, and substrate composition.

There is significant evidence in the literature describing the positive correlation between habitat complexity and biological diversity and abundance (e.g., Chisholm *et al*., 1976; Gorman and Karr, 1978; Downes *et al*., 1998). Habitat diversity positively influences species diversity by providing increased physical space, refuge, resources and increases niche availability.

In a study of 41 stream reaches in the Snake River basin, Walrath *et al*. (2016) found that fish species diversity was positively associated with all four components of habitat diversity (substrate, cover, water depth, and water velocity) ($P < 0.09$, Adjusted $R^2 = 0.642$). This study, conducted on reaches with a range of impacts, also concluded that habitat diversity was negatively related to each of five stream condition factors: livestock trails on streambanks, streambank stability, channel width-to-depth ratio, percent fine substrates, and woody riparian vegetation, illustrating the link between land use, stream condition, habitat complexity and fish assemblage.

Many studies have shown the relationship between macroinvertebrate community richness, stream substrate diversity, and variety of stream velocities (Erman and Erman, 1984; Principe *et al*., 2007).

In a detailed study of macroinvertebrate communities and channel meso-habitat characteristics Beisel *et al*. (1998) conclude that the relationship between community organization and environmental variables indicate that substrate may be a primary determinant of community structure. Current velocity and water depth emerged as secondary factors.

Water Quality Function

As previously discussed, channel bed variability is an indicator of hydrologic and geomorphic heterogeneity providing transient storage, increased hyporheic connection, channel roughness and varied habitat within the stream substrate. These attributes provide the time, space and surface area for the chemical processes for Nutrient Cycling (NC) and Chemical Regulation (CR) to take place.

Numerous studies discuss the importance of channel complexity and related hydrologic properties to in-stream chemical and nutrient processes (Lamberti *et al*., 1988; Gucker and Boechat, 2004; Ensign and Doyle, 2005). Kaufmann and Faustini (2012) cited the importance of transient hydraulic (‘‘dead zone’’) storage as important for retention and ‘‘spiraling’’ of dissolved and particulate nutrients. The capacity of the hyporheic zone for transient solute storage was found to correlate with channel morphology, bed roughness, and permeability (Triska, 1989).

Biofilms (bacterial and algal communities) on stream substrates provide active locations for chemical processes contributing to the mechanisms of nutrient uptake (inorganic and organic) and retention of potentially harmful chemicals (e.g. heavy metals and herbicides) (Sabater *et al*., 2007). A complex, variable channel bed provides more surface area and varied environments for biofilms to form.

In summary, channel bed variability contributes to the physical and biotic heterogeneity that provide the opportunity for nutrient cycling and chemical regulation.

MEASURE DEVELOPMENT

The original channel bed variability measure instructed the user to collect data on pool depth, pool length, riffle depth, riffle length, and wetted channel width and to provide the ratio of the largest measurement to the smallest measurement for each attribute. Technical reviewers strongly recommended that this measure be revised to be more quantitative, less broad, and better able to detect changes. Reviewers also encouraged the use of NARS protocols to improve the measure. Subsequently, the measure was extensively revised to capture a more comprehensive profile of the channel bed and to allow for finer resolution in scoring, which in turn allows for better detection of change. Use of NARS protocols also strengthens the use of NARS data in the standard performance indices for this measure.

In the course of revision, several attributes related to channel bed variability were considered but not included. For instance, sinuosity and residual pool measures were explored, but rejected because the former would be challenging given potentially short reach lengths and residual pool measures were likely beyond the data collection expectations for a rapid assessment method.

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4.3 Value Measures

Descriptions of each of the 16 value measures are included in the following section. These measures are primarily office-based and often require evaluation of spatial data sets made available on the Map Viewer, an online tool hosted on the Oregon Explorer website. Many of these measures can be answered by extracting information directly from an SFAM Report that can be generated by the Map Viewer. The Map Viewer and Report are described in more detail in **Section 2.7** and the included data layers are described in **Appendix C**.

Data collection instructions for each of the following value measures are included in the SFAM User Manual.

Table 4.42 Measures Informing Each Value Formula

Value	Value Measures																Context Measures			
	Rare Species & Habitat Designations[6]	Water Quality Impairments[7]	Protected Areas	Impervious Areas	Riparian Area	Extent of Downstream Floodplain Infrastructure	Zoning	Frequency of Downstream Flooding	Impoundments[8]	Fish Passage Barriers	Water Source	Surrounding Land Cover	Riparian Continuity	Watershed Position	Flow Restoration Needs	Unique Habitat Features	Surface Water Runoff	Aquifer Permeability	Soil Permeability	Erodibility
Surface water storage	X			X		X	X	X	X								X			
Sub/surface transfer											X							X	X	
Flow variation	X	X		X					X						X			X	X	
Sediment continuity		X		X		X			X					X						X
Substrate mobility	X			X					X							X				
Maintain biodiversity	X		X							X		X	X			X				
Create & maintain habitat		X		X	X	X	X		X				X		X	X				
Sustain trophic structure	X	X	X	X	X	X	X			X		X	X			X				
Nutrient cycling	X	X		X	X						X		X	X						
Chemical regulation	X	X		X	X						X		X	X						
Thermal regulation	X	X		X	X								X			X				

6 This measure includes six independently-scored submeasures: (1) Essential Salmonid Habitat or Rare Non-Anadromous Fish Species, (2) Rare Amphibian and Reptile Species, (3) Important Bird Areas or Rare Waterbirds, (4) Rare Songbirds, Raptors, and Mammals, (5) Rare Invertebrate Species, (6) Rare Plant Species. A value formula that uses information from this measure does not necessarily use all six subscores.

7 This measure includes five independently-scored submeasures: (1) Sediment Impairment, (2) Nutrient Impairment, (3) Metals or Other Toxics Impairment, (4) Temperature Impairment, (5) Flow Modification. A value formula that uses information from this measure does not necessarily use all five subscores.

8 This measure includes two independently-scored submeasures: (1) Upstream Impoundments, (2) Downstream Impoundments. A value formula that uses information from this measure does not necessarily use both subscores.

a) Rare Species & Habitat Designations

MEASURE TEXT

Are there rare species or special habitat designations in the vicinity of the PA?

Answer each submeasure using rare species and habitat information from the SFAM Report created for the site, as well as any available survey data for the PA and its vicinity or personal knowledge about the site.

Note: The SFAM Report provides rankings of High, Intermediate, Low, or None for each category of rare species associated with aquatic and riparian habitat. Upgrade a ranking to High if there is a recent (within 5 years) onsite observation of any of these species by a qualified observer under conditions similar to what now occur. Provide references in the notes section of the cover page.

DESCRIPTION

This measure uses information from three different databases to assess the likelihood that various rare species will access and use a particular site as habitat. Rare species ratings are determined for six categories of species (fish, invertebrates, amphibians and reptiles, birds and mammals, plants, and waterbirds) using species Element of Occurrence (EO) information from the Oregon Biodiversity Information Center. The formula for determining a score is C * [(U + D)/2] where:

C= conservation status of the EO species
with points assigned as follows: S1= 1.0, S2= 0.6, S3= 0.4, Oregon Department of Fish and Wildlife Strategy Species = 0.1

U= uncertainty of the particular record's location
with points assigned as follows: High Certainty = 1.0, Moderate = 0.5, Low = 0.1

D= zonal distance of the EO from the entered coordinates
within 100 m or within the same mapped wetland that the coordinates hit = 1.0 within 1 mile = 0.5
within same HUC6 but not within 1 mile = 0.1

Within each rare species category, this formula is applied to each EO record "on the fly" at the project area defined by the user, and then the sum, mean, and maximum for all EO records in that group around that point are reported (Institute for Natural Resources, 2018). Maximum and sum scores are then used to assign the rankings for each group **(Table 4.43).**

Table 4.43 Oregon Biodiversity Information Center, Thresholds for Rare Species Scores

Oregon Biodiversity Information Center Thresholds for Rare Species Scores	
Non-anadromous fish	**High** = ≥ 0.75 maximum score, ≥ 0.90 sum score **Intermediate** = not as described above or below **Low** = ≤ 0.33 for both maximum and group score, but not zero for both **None** = zero for both
Rare invertebrates	**High** = ≥ 0.75 for maximum score or sum score **Intermediate** = no option for intermediate **Low** = < 0.75 for maximum score or sum score, but not zero for both **None** = zero for both
Rare amphibians/reptiles	**High** = ≥ 0.60 for maximum score, or >0.90 for sum score **Intermediate** = not as described above or below **Low** = ≤ 0.21 for maximum score AND <0.15 for sum score, but not zero for both **None** = zero for both
Non-breeding waterbirds	**High** = ≥ 0.33 for maximum score **Intermediate** = no option for intermediate **Low** = <0.33 for maximum AND sum score, but not zero for both **None** = zero for both
Rare birds and mammals	**High** = ≥ 0.60 for maximum score, or >1.13 for sum score **Intermediate** = not as described above or below **Low** = ≤ 0.09 for maximum score AND <0.13 for sum score, but not zero for both **None** = zero for both
Rare plants	**High** = ≥ 0.75 for maximum score, or > 4.00 for sum score **Intermediate** = not as described above or below **Low** = ≤ 0.12 for maximum score AND < 0.20 for sum score, but not zero for both **None** = zero for both

Two special habitat designations (Essential Salmonid Habitat and Important Bird Areas) are also considered in SFAM when determining the likelihood of rare salmonid and waterbird species benefitting from the stream site. See **Appendix C** for a detailed explanation of these datasets.

Function Groups: Hydrology, Geomorphology, Biology, Water Quality
Values Informed: Surface Water Storage (SWS), Flow Variation (FV), Substrate Mobility (SM), Maintain Biodiversity (MB), Sustain Trophic Structure (STS), Nutrient Cycling (NC), Chemical Regulation (CR), Thermal Regulation (TR)

Model:

IF Fish = Essential Salmonid Habitat OR high rare species score, THEN = 1.0;
IF Fish = intermediate rare species score, THEN = 0.5;
IF Fish = low rare species score, THEN = 0.25;
IF Fish = none/not known, THEN = 0.0

IF RarInvert/RarAmRep/RarBdMm/RarPlant = high rare species scores, THEN = 1.0;
IF RarInvert/RarAmRep/RarBdMm/RarPlant = intermediate rare species scores, THEN = 0.5;
IF RarInvert/RarAmRep/RarBdMm/RarPlant = low rare species scores, THEN = 0.25;
IF RarInvert/RarAmRep/RarBdMm/RarPlant = none/not known, THEN = 0.0

IF Waterbird = Important Bird Area OR high rare species score, THEN = 1.0;
IF Waterbird = low rare species score, THEN = 0.25;
IF Waterbird = none/not known, THEN = 0.0

RATIONALE FOR INCLUSION

Rare species scores and habitat type occurrences indicate the possibility that species that are locally uncommon may be accessing and utilizing the stream site for food and shelter, reproduction, or migration. These types of species contribute disproportionately to regional biodiversity given their relative rarity. Generally speaking, a site has greater value on the landscape if the various hydrologic, geomorphic, and chemical processes are highly functioning, given that the site will be better able to support the populations of rare species with quality habitat. Each of these processes has different impacts on habitat quality and may affect some types of species more than others.

Hydrologic processes, such as water storage and flow variability, are of high value in areas where rare invertebrates, amphibians, reptiles, and fish may be present because they can create a diversity of habitats. Stream features that create low-velocity refugia and provide pathways for fish movement are important in areas used by rare species as they help individuals shelter from predators and access areas with important resources. Additionally, species of invertebrates, amphibians, reptiles, and fish may rely on environmental cues, such as variability in water flow, to trigger life stage transitions. Therefore, there is high value in maintaining natural, variable flow regimes when there are rare species in the area that may be reliant on temporal variation in hydrologic patterns. The geomorphic process of substrate movement is highly valued in areas with rare species as it can regulate the type of sediment transported to, and through, habitats. For example, some fish, reptile, and plant species may be sensitive to high levels of fine sediment. A stream system that is maintaining a balance of substrate materials would likely provide a more suitable and stable habitat for these types of organisms. Similarly, many species of fish, invertebrates, amphibians, reptiles, birds, mammals, and plants will be sensitive to imbalances in chemical and nutrient content or thermal regime. A site that can regulate these potential water quality issues will provide more suitable habitat to a variety of species, therefore providing a great value in areas that are known to support rare species. Finally, the biological processes of a stream are highly valued when there are rare species present given that they are indicators of the type of habitat that is being provided. A site with increased biodiversity and trophic complexity will be more suitable to support additional species, given that it likely has a diversity of resources.

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b) Water Quality Impairments

MEASURE TEXT

Is this reach on the 303(d) list or other Total Maximum Daily Load (TMDL; Categories 3B-5) for the following: sediment impairment, nutrient impairment, metals or other toxics impairment, temperature impairment, or flow modification?

DESCRIPTION

This measure is used to assess known water quality issues within the project reach. Water quality issues can adversely affect aquatic plant and animal species and often indicate an increased need for regulating functions. There are five categories of impairments assessed in this measure: sediment (sedimentation, total suspended solids, turbidity), nutrient (phosphorus, nitrate, dissolved oxygen, aquatic weeds or algae, chlorophyll a), chemical (toxics, dioxin, heavy metals), temperature, and flow modification. This measure can be answered by using the Oregon Department of Environmental Quality's (DEQ) water quality data. See **Appendix C** for a detailed explanation of this dataset.

Function Groups: Hydrology, Geomorphology, Biology, Water Quality
Values Informed: Flow Variation (FV), Sediment Continuity (SC), Create and Maintain Habitat (CMH), Sustain Trophic Structure (STS), Nutrient Cycling (NC), Chemical Regulation (CR), Thermal Regulation (TR)

Model:
IF SedList/NutrImp/ToxImp/TempImp/FlowMod = yes; THEN = 1.0;
IF SedList/NutrImp/ToxImp/TempImp/FlowMod = no; THEN = 0.0
The inverse model is used for CMH, STS and TR.

RATIONALE FOR INCLUSION

In stream reaches that have known water quality impairments, the ability of the stream to perform regulating functions is highly valuable. Streams receiving waters that have sediment, nutrient, chemical, temperature, or flow impairments have greater opportunity to alleviate (or at the very least, not contribute to) water quality problems. The value of such regulating functions includes benefits to aquatic life that might be adversely affected by the impairments, as well as benefits to public health, recreation, and industry. For the hydrologic, geomorphic, and water quality processes whose value is informed by impairments, a known impairment indicates that the site has the *opportunity* to provide a valuable ecological function if it has the capacity to address the impairment.

While documented impairments cause the regulating functions of the reach to be of higher value, they decrease the value of biological and thermal regulation functions. The opportunity to provide the suitable habitat and resources necessary for the biological community is likely to be negatively affected by the impairments. The presence of water quality impairments has wide- reaching impacts on biological communities. For example, the vigor and survival of aquatic species can be affected by high levels of dissolved oxygen, and increased levels of nitrates and phosphorus can have profound effects on energy consumption and transfer. While algae and macrophytes (which can increase when nutrient levels are high) provide food and habitat to aquatic species, an overabundance of these can decrease dissolved oxygen availability, leading to decreased food sources and poor habitat conditions. The significance of the thermal regulation function is less when the stream reach has a known temperature impairment. While natural cover above the stream can help prevent additional solar warming, it is not likely to cool the water within the length of the project area.

c) Protected Areas

MEASURE TEXT

Is the Project Area (PA) boundary within 300 feet of a protected natural area?

Answer using information from the SFAM Report created for the site, as well as other available data for the PA and its vicinity.

DESCRIPTION

Areas with protection designations likely provide high quality habitat or resources and, due to their protected status, may experience decreased levels of disturbance. The SFAM Report indicates whether the project site is within 300 feet of one of the following types of protected areas, as identified using the Protected Areas Data for the United States (PAD-US): open space and resource lands owned in fee by agencies and non-profits and including some lands with long-term easements, conservation easements, leases, agreements, Congressional (e.g. Wilderness Areas), Executive (e.g. National Monuments), and administrative designations (e.g. Areas of Critical Environmental Concern) documented in agency management plans. Only those lands identified as having a USGS Gap Analysis Project (GAP) Status of 1 or 2 are included because these lands are specifically managed for biodiversity. Other lands within 300 feet of the site that are protected specifically for their high ecological significance and managed for biodiversity may also qualify and should be documented in the SFAM Assessment Notes section.

Function Group: Biology
Values Informed: Maintain Biodiversity (MB), Sustain Trophic Structure (STS)

Model:
IF Protect = Yes, THEN = 1.0;
IF Protect = No, THEN = 0.0

RATIONALE FOR INCLUSION

A stream reach located in close proximity to a protected area has the potential to expand the spatial scope of habitat and resources for a variety of plant and animal species. Natural areas that have special protection designations often support species and resources that can benefit from increased habitat availability and connectivity, and they provide natural areas where human disturbance is limited. It is a well-accepted ecological theory that larger areas often contain a greater number of species, so a stream resource that exhibits the ability to support a diversity of species and the resources to sustain a trophic structure can provide significant value to biodiversity on a landscape scale when expanding on other established natural areas. A network of natural areas in close proximity allows for species movement between habitats and encourages immigration as the total amount of available resources increases.

d) Impervious Area

MEASURE TEXT

What is the percent impervious area in the drainage basin?

Answer using information from the site's StreamStats Report (IMPERV).

DESCRIPTION

This measure assesses the prevalence of impervious surfaces in the site's contributing area. Impervious surfaces are those that do not allow infiltration of surface water into the soil, such as pavements (asphalt, concrete, brick) and rooftops. Increased amounts of impervious surfaces are known to cause increased water runoff, which adversely affects water quality and alters hydrologic timing. The size of a site's drainage basin, and the total percent of impervious area within that basin, can be calculated using the U.S. Geological Survey's StreamStats tool (link provided in the SFAM Map Viewer).

Function Groups: Hydrology, Geomorphology, Biology, Water Quality
Values Informed: Surface Water Storage (SWS), Flow Variation (FV), Sediment Continuity (SC), Substrate Mobility (SM), Create and Maintain Habitat (CMH), Sustain Trophic Structure (STS), Nutrient Cycling (NC), Chemical Regulation (CR), Thermal Regulation (TR)

Model:
IF ImpArea < 10%, THEN = 0.0;
IF ImpArea = 10–25%, THEN = 0.3;
IF ImpArea > 25–60%, THEN = 0.7;
IF ImpArea > 60%, THEN =1.0

The inverse model (1-ImpArea) is used for CMH and STS.

RATIONALE FOR INCLUSION

A higher percentage of impervious surfaces in the drainage areas of a stream results in increased surface runoff and quicker delivery to streams. Surface runoff is much more common in developed watersheds (Booth and Jackson, 1997). Drainage areas with extensive impervious surfaces can have as much as five times the proportion of stream flow coming from surface runoff than for forested drainage areas (Arnold and Gibbons, 1996). Impervious surfaces retain less sediment, nutrients and chemicals than natural surfaces, and are also a direct source of heated water, nutrients and chemicals. Therefore, the value of stream reaches with capacity to delay surface water, vary flows, process sediment and nutrients, and moderate chemicals and nutrients is higher because of the opportunity to intercept surface water and benefit waters further downstream.

A lower percentage of impervious surfaces implies that land in the drainage area is more natural and that the stream reach has more opportunity to support biological functions. Macroinvertebrates that are sensitive to impervious cover are generally lost when impervious cover is in the range of 3% to 23%, depending on the taxa (Utz *et al.,* 2009). Macroinvertebrate and fish community composition begins to be impacted at about 5% impervious surface, depending on the proportion of agricultural land in the drainage area (Waite *et al.,* 2006).

REFERENCES CITED

Arnold, C.L. and Gibbons, C.J. (1996) Impervious surface coverage: The emergence of a key environmental indicator. Journal of the American Planning Association 62:243-258

Booth, D.B. and Jackson, C.R. (1997) Urbanization of aquatic systems: Degradation thresholds, stormwater detection, and the limits of mitigation. Journal of the American Water Resources Association 33:1077-1090

Utz, R.M., Hilderbrand, R.H., Boward, D.M. (2009) Identifying regional differences in threshold responses of aquatic invertebrates to land cover gradients. Ecological Indicators 9:556-567

Waite, T.A. and Campbell, L.G. (2006) Controlling the false discovery rate and increasing statistical power in ecological studies. Ecoscience 13:439-442

e) Riparian Area

MEASURE TEXT

What is the percentage of intact riparian area within 2 miles upstream of the PA?

Intact refers to a riparian area with forest or otherwise unmanaged (i.e. natural) perennial cover appropriate for the basin that is at least 15 ft wide on both sides of the channel. Unmanaged perennial cover is vegetation that includes wooded areas, native prairies, sagebrush, vegetated wetlands, as well as relatively unmanaged commercial lands in which the ground and vegetation is disturbed less than annually, such as lightly grazed pastures, timber harvest areas, and rangeland. It does not include water, pasture, row crops (e.g., vegetable, orchards, Christmas tree farms), lawns, residential areas, golf courses, recreational fields, pavement, bare soil, rock, bare sand, or gravel or dirt roads.

DESCRIPTION

This measure provides an indication of the percentage of intact riparian area that can buffer the stream from other land use types and provide habitat support and water quality benefits. Riparian areas meeting the criteria can be evaluated by locating stream and river flowlines within 2 miles upstream of the stream reach on the National Hydrography Dataset and evaluating the cover and width of adjacent riparian areas using aerial imagery. While the percentage of intact riparian area of the entire drainage basin may be an important extent to consider, this data is not readily available for users and 2 miles was chosen as a reasonable distance and level of effort to evaluate.

Function Groups: Biology, Water Quality
Values Informed: Create and Maintain Habitat (CMH), Sustain Trophic Structure (STS), Nutrient Cycling (NC), Chemical Regulation (CR), Thermal Regulation (TR)

Model:
IF RipArea > 50%, THEN = 1.0;
IF RipArea > 35–50%, THEN = 0.7;
IF RipArea = 15–35%, THEN = 0.3;
IF RipArea < 15%, THEN = 0.0

The inverse model (1-RipArea) is used for NC and CR.

RATIONALE FOR INCLUSION

Riparian areas can intercept surface flows and subsurface inputs and provide for biological and physical processing of nutrients and chemicals. Vegetation in riparian areas promotes these processes by:

- increasing roughness to slow water and filter out sediments and the nutrients and chemicals adsorbed to sediment particles;
- increasing biological activity in the soil to process nutrients and chemicals; and
- taking up nutrients through their roots and storing them.

A stream reach that lacks intact riparian areas in upstream waters is more likely to receive nutrient and chemical-rich water and sediment. The ability of the stream reach to process and moderate those sediments and nutrients provides benefits (value) to waters further downstream.

Riparian vegetation also provides shade to prevent water from heating, and provides food, cover, and habitat structure for aquatic species. Corridors of perennial vegetation connect various habitats and help protect species as they move between them. Therefore, largely intact riparian areas upstream provide greater opportunity for the health of the aquatic system to be sustained through the project area.

f) Extent of Downstream Floodplain Infrastructure

MEASURE TEXT

What is the extent of infrastructure (buildings, bridges, utilities, row crops) in the floodplain?

Consider the floodplain area between the PA and either the next largest water body (large tributary, mainstem junction, lake, etc.) or 2 miles downstream, whichever is less.

DESCRIPTION

This measure provides an indication of how developed the downstream floodplain is. An estimate of development in the floodplain can be obtained by viewing the mapped floodplain overlaid on aerial imagery to identify structures and agricultural lands.

Function Groups: Hydrology, Geomorphology, Biology
Values Informed: Surface Water Storage (SWS), Sediment Continuity (SC), Create and Maintain Habitat (CMH), Sustain Trophic Structure (STS)

Model:
IF DwnFP > 50%, THEN=1.0;
IF DwnFP = 1–50%, THEN=0.5;
IF DwnFP = none or the downstream floodplain is not mapped, THEN=0.0

The inverse model (1-DwnFP) is used for SC, CMH and STS.

RATIONALE FOR INCLUSION

In areas with more infrastructure located within the downstream floodplain, the economic and social value of water storage in upstream locations is greater as it can provide protection against flood damages. A stream that can store and delay water by diverting it into side channels or onto floodplains, or retain it within the channel due to geomorphic variability within the channel, is highly valued in areas where downstream infrastructure or agricultural lands are at-risk from floodwater inundation (Adamus *et al.,* 2016).

Conversely, increased development often causes degradation to water quality and biological functions. Development of areas surrounding the stream reach would limit accessibility and introduce stressors to the stream habitat, limiting the value of the site's habitat and trophic resources. While there is benefit in providing habitat refugia within a highly developed area, the negative effects of nearby land-uses likely restrict the site's ability to support diverse biological communities.

This measure is also used inversely to inform one of the geomorphic indicators, sediment continuity. Floodplains provide an area for streams to deposit sediment, but if the floodplain is highly developed, it is likely disconnected and therefore leads to a lower significance of the stream having the ability to moderate sediment processes.

REFERENCES CITED

Adamus, P., Morlan, J., Verble, K., Buckley, A. (2016) Oregon Rapid Wetland Assessment Protocol (ORWAP, revised): Version 3.1 calculator spreadsheet, databases, and data forms. Oregon Department of State Lands, Salem, OR

g) Zoning

MEASURE TEXT

What is the dominant zoned land use designation downstream of the PA?

Consider the floodplain area between the PA and either the next largest water body (large tributary, mainstem junction, lake, etc.) or 2 miles downstream, whichever is less.

DESCRIPTION

This measure provides an indication of the type of development that is expected to occur in the downstream floodplain. An estimate of the dominant zoning designation can be obtained by viewing the mapped floodplain (FEMA) overlaid on zoning data (Oregon Department of Land Conservation and Development) to identify the dominant designation.

Function Groups: Hydrology, Biology
Values Informed: Surface Water Storage (SWS), Create and Maintain Habitat (CMH), Sustain Trophic Structure (STS)

Model:
IF Zoning = developed, THEN = 1.0;
IF Zoning = agriculture/rural residential, THEN =0.5
IF Zoning = forest, open space, or public lands, THEN = 0.0
IF Zoning = none/no information, THEN = 0.0

The inverse model (1-Zoning) is used for CMH and STS.

RATIONALE FOR INCLUSION

This measure is used only in conjunction with the previous measure, Extent of Downstream Floodplain Infrastructure (DwnFP), such that the maximum score from only one of the two measures is used in scoring. While DwnFP is used to capture current development in the floodplain, Zoning captures the likely future use of the land. The future need for surface water storage may increase the most where zoning allows for higher-intensity development that may alter the amount, rate, and/or timing of water delivered further downstream (Adamus *et al.,* 2016). Conversely, future development is expected to cause degradation to biological functions (Adamus *et al.,* 2016).

REFERENCES CITED

Adamus, P., Morlan, J., Verble, K., Buckley, A. (2016) Oregon Rapid Wetland Assessment Protocol (ORWAP, revised): Version 3.1 calculator spreadsheet, databases, and data forms. Oregon Department. of State Lands, Salem, OR

h) Frequency of Downstream Flooding (DwnFld)

MEASURE TEXT

What is the frequency of downstream flooding?

Consider the floodplain area between the PA and either the next largest water body or 2 miles downstream, whichever is less. Determine the frequency of flooding downstream of the PA that affects infrastructure (i.e., affects use of the site, causes economic losses, etc.).

DESCRIPTION

This measure indicates whether downstream flooding is a known problem and, if so, the frequency at which it is occurring. This measure can be answered based on local knowledge and best professional judgment.

Function Group: Hydrology
Value Informed: Surface Water Storage (SWS)

Model:
IF DwnFld = frequent, THEN=1.0;
IF DwnFld = moderate, THEN=0.7;
IF DwnFld = infrequent, THEN=0.3;
IF DwnFld = never or not known, THEN=0.0

RATIONALE FOR INCLUSION

This measure is a direct indicator of the significance of a stream's capacity to store and delay surface water, as this function can provide protection to infrastructure and specific land uses. Stream characteristics that result in reduced flood speeds and reduced flood stage downstream are highly valuable when flooding is a known and frequent problem. Natural water storage function allows reduced investment and dependence on costly flood-control infrastructure.

i) Impoundments (Impound)

MEASURE TEXT

What is the prevalence of impoundments (within 2 miles upstream and downstream of the PA) that are likely to cause shifts in timing or volume of water inputs?

The shift may be by hours, days, or weeks, becoming either more muted (smaller or less frequent peaks spread over longer times, more temporal homogeneity of flow or water levels) or more flashy (larger or more frequent spikes but over shorter times).

DESCRIPTION

This measure indicates whether there are artificial structures in proximity to the site that may be altering the natural hydrologic and/or geomorphic processes by interrupting free-flowing water systems, trapping sediment, and creating access issues for aquatic species. This measure can be answered by using local knowledge and observation and by evaluating two datasets that document known barriers:

- National Hydrography Dataset includes dam locations as point features;
- Oregon Department of Fish and Wildlife maintains a database of known fish passage barriers.

See **Appendix C** for detailed explanations of these datasets. An impoundment should be counted even if it is only in place for part of the year.

Function Groups: Hydrology, Geomorphology, Biology

Values Informed: Surface Water Storage (SWS), Flow Variation (FV), Sediment Continuity (SC), Substrate Mobility (SM), Create and Maintain Habitat (CMH)

Model:
Scored separately for upstream and downstream:

IF Impound = 1 or more large dams or other impoundments, THEN=0.0;
IF Impound = 1–2 small dams or other impoundments, but 1 or more large dams or other impoundments are not present THEN=0.5;
IF Impound = none, THEN = 1.0

The inverse model (1-Impound) is used for FV (ImpoundUS only).

RATIONALE FOR INCLUSION

Impoundments impede landscape connectivity in the river corridor by changing the natural amount, rate, and/or timing of the movement of water, sediment, substrate, and wood. Impoundments may also restrict the movement of aquatic organisms and limit access to the suite of conditions and resources they need.

The opportunity for a stream reach to provide surface water storage, sediment continuity and substrate mobility is lower when there are impoundments upstream. The need for surface water storage is less because water is already being stored to some extent upstream. The opportunity to provide sediment continuity and substrate mobility functions is less because delivery of these materials to the reach is impeded. Conversely, the opportunity of a stream reach to moderate variations in flow is higher when impoundments upstream are altering natural hydrologic patterns.

Restricted movement of aquatic organisms traveling upstream or downstream reduces the value of the habitat provided in a reach. In addition, changes in habitat from free-flowing to slack water behind an impoundment can cause changes in the physical, chemical and thermal properties of the water.

j) Fish Passage Barriers (Passage)

MEASURE TEXT

Are there man-made fish passage barriers within 2 miles upstream and/or downstream of the PA?

DESCRIPTION

This measure indicates whether fish species can access a stream reach. Man-made barriers to fish passage include structures such as dams, culverts, weirs, and tide gates that can block physical passage or can create unsuitable conditions for passage (e.g. high velocity). This measure can be answered by using the Oregon Department of Fish and Wildlife's Fish Passage Barrier data. See **Appendix C** for a detailed explanation of this dataset. Impoundments noted in the previous measure (Impound) should *also* be counted here if they are barriers to fish passage. The two measures inform different functions and are not double-counted in SFAM.

Function Group: Biology

Values Informed: Maintain Biodiversity (MB), Sustain Trophic Structure (STS)

Model:
(Upstream score + Downstream score)/2

Upstream and Downstream scores are calculated as follows:
IF Passage Upstream/Downstream = blocked, THEN = 0.0;
IF Passage Upstream/Downstream = partial, THEN = 0.5;
IF Passage Upstream/Downstream = passable, THEN = 1.0;
IF Passage Upstream/Downstream = none or unknown, THEN = 1.0

RATIONALE FOR INCLUSION

A stream reach that is accessible by fish has greater opportunity to support diverse biological communities and the local food web than one that is made inaccessible by barriers. Some barriers allow for partial fish passage (dependent on season and fish size), meaning that the habitat can be accessed during certain parts of the year; this is considered more valuable than an inaccessible reach, but could still be improved upon.

k) Water Source (Source)

MEASURE TEXT

Is there an area that is of special concern for drinking water sources or groundwater recharge within 2 miles downstream of the PA?

This includes any of the following: the source area for a surface-water drinking water source; the source area for a groundwater drinking water source; a designated Groundwater Management Area; or a designated Sole Source Aquifer area.

DESCRIPTION

This measure indicates whether the site being assessed is located in an area whose waters contribute to important drinking water sources (both surface and groundwater) or groundwater areas. This measure can be answered by evaluating several data layers, from both state and federal agencies, that monitor water quality and water use. The DEQ maintains the Surface Water Drinking Water Source Areas and the Groundwater Drinking Water Source Areas data layers, which delineate watersheds that supply drinking water to surface water intakes for public water systems, and source areas that supply drinking water to wells or springs for public water systems, respectively. DEQ also maintains the Groundwater Management Area data layer, which delineates groundwater sources that have elevated contaminant concentrations. The USEPA maintains the Sole Source Aquifer data layer, which designates drinking water supplies in areas that have few or no alternative sources to the groundwater resource. See **Appendix C** for detailed descriptions of each of these data layers.

Function Groups: Hydrology, Water Quality

Values Informed: Sub/Surface Transfer (SST), Nutrient Cycling (NR), Chemical Regulation (CR)

Model:
IF WaterSource = yes, THEN = 1.0;
IF WaterSource = no, THEN = 0.0

RATIONALE FOR INCLUSION

A stream reach that is located within a source area for drinking water is particularly valuable when its water transfer processes are functioning effectively. The ability to maintain transfer of water between surface and sub-surface sources replenishes groundwater sources and supports balance and predictability in streamflow through inflow of groundwater through the streambed and outflow to groundwater. Communities across the state are dependent on the replenishment of the surface and groundwater sources for consumptive uses.

Additionally, it is also highly valuable for a stream resource to have effective nutrient and chemical regulation processes when the water from that resource is contributing to drinking water sources and groundwater supplies. Nutrients and chemicals are introduced from a variety of point and non-point sources. Major sources of nutrient and chemical inputs include fertilizer runoff from crop fields and lawns, livestock and pet waste, effluent from manufacturing and sewage-treatment facilities, and stormwater runoff. In excess amounts, these nutrients and chemicals can have deleterious effects on water resources and, in turn, human health. Nutrient pollution can lead to increased levels of nitrate in drinking water, which can be particularly harmful to infants (Adamus *et al.,* 2016), as well as in algal blooms, which can produce toxins and bacterial growth. A stream that can transfer excess nutrients and chemicals to its riparian areas, floodplains, and nearby wetlands for storage and filtering is valuable for keeping the nutrients from reaching drinking water sources and reducing human exposure to harmful chemicals.

REFERENCES CITED

Adamus, P., Morlan, J., Verble, K., Buckley, A. (2016) Oregon Rapid Wetland Assessment Protocol (ORWAP, revised): Version 3.1 calculator spreadsheet, databases, and data forms. Oregon Department of State Lands, Salem, OR

I) Surrounding Land Cover (SurrLand)

MEASURE TEXT

What are the land cover types surrounding the PA?

Draw a 2-mile radius circle around the PA. Provide an estimate of the area within the resulting polygon that matches each land cover description. Enter 0% if none. Enter 1% if barely present. Must sum to 100%.

DESCRIPTION

This measure is an indicator of the relative distribution of natural, managed, and developed land cover types near the site. Land cover and land use is an important factor for understanding trends of habitat fragmentation and modification, habitat loss, and stressors introduced from urban and rural land use practices. These trends are known to influence habitat suitability and terrestrial and aquatic biodiversity. This measure can be answered by evaluating the National Land Cover Dataset. See **Appendix C** for a detailed description of this data layer.

Function Group: Biology

Values Informed: Maintain Biodiversity (MB), Sustain Trophic Structure (STS)

Model:
Sum of all the below:
IF unmanaged vegetation (wetland, native grassland, forest) or water; THEN = percent of area * 1.0;
IF managed vegetation (pasture, regularly watered lawn, row crops, orchards); THEN = percent of area * 0.5;
IF none of the above (bare areas [dirt, rock], roads, energy facilities, residential, commercial, industrial); THEN = percent of area * 0.0

RATIONALE FOR INCLUSION

This measure evaluates connectivity between the stream and the surrounding landscape based on the land cover. Habitat fragmentation is the division of large, continuous habitats into a greater number of smaller and more isolated habitat patches. The impacts of patch area, edge effects, isolation and landscape matrix contrasts are well-known to impact community structure and ecosystem functioning. Dominant effects include declines in population density and species richness, alterations to community composition, and reductions in the ability of populations to recover after disturbance.

m) Riparian Continuity (RipCon)

MEASURE TEXT

What is the longitudinal extent of intact riparian area that is contiguous to the PA?

Select the longest length of contiguous riparian corridor in either the upstream or downstream direction, but do not include the project area length itself.

Intact refers to a riparian area with forest or otherwise unmanaged (i.e. natural) perennial cover appropriate for the basin that is at least 15 feet wide on both sides of the channel. Contiguous means there are no gaps > 100 feet in forested cover or unmanaged perennial cover. Select the longest length of contiguous riparian corridor in either the upstream or downstream direction, but do not include the PA length itself. Unmanaged perennial cover is vegetation that includes wooded areas, native prairies, sagebrush, vegetated wetlands, as well as relatively unmanaged commercial lands in which the ground and vegetation is disturbed less than annually, such as lightly grazed pastures, timber harvest areas, and rangeland. It does not include water, pasture, row crops (e.g., vegetable, orchards, Christmas tree farms), lawns, residential areas, golf courses, recreational fields, pavement, bare soil, rock, bare sand, or gravel or dirt roads.

DESCRIPTION

This measure is an indicator of the extent of natural area buffering the stream from other land use types, providing stream shade and water quality benefits, and providing habitat connectivity for wildlife and aquatic species. Measures of buffering and connectivity can provide understanding of both the stressors that the stream resource will be exposed to (i.e., nutrient and chemical inputs, thermal loading), as well as the potential spatial influence of stream function and habitat benefits (i.e., expanded habitat corridors, refugia from stressors). This measure can be answered by evaluating aerial imagery to determine (a) if an intact riparian buffer exists at the site, and (b) the distance beyond the site that the buffer remains intact.

Function Groups: Biology, Water Quality

Values Informed: Maintain Biodiversity (MB), Create and Maintain Habitat (CMH), Sustain Trophic Structure (STS), Nutrient Cycling (NC), Chemical Regulation (CR), Thermal Regulation (TR)

Model:
IF RipCon < 100 ft, THEN=0.0;
IF RipCon = 100-500 ft, THEN=0.5;
IF RipCon > 500 ft, THEN=1.0

The inverse model (1-RipCon) is used for NC and CR.

RATIONALE FOR INCLUSION

Riparian corridors are important for improved water quality and as habitat for wildlife and aquatic habitat. Continuity along the river corridor limits solar exposure of the stream and provides increased opportunity of the stream to keep water cool. Continuity also facilitates the movement of animals upstream and downstream, increasing species resilience, and providing access to different habitats and food resources. Conversely, gaps in the corridor, either natural or man-made, may receive more inputs of nutrients and chemicals from surrounding land uses if they cannot be filtered before reaching the stream. Stream reaches that can cycle these nutrients and regulate these chemicals have higher value to downstream areas.

n) Watershed Position (Position)

MEASURE TEXT

What is the relative position of the PA in its HUC 8 watershed?

DESCRIPTION

This measure describes the landscape position of the site, which can provide a general indication of the characteristics and processes that can be supported by the stream reach. This measure can be answered by evaluating both the National Hydrography Dataset and the Watershed Boundary Dataset to determine the relative positioning of a stream reach compared to the watershed's origin, outlet, and watershed divides.

Function Groups: Geomorphology, Water Quality

Values Informed: Sediment Continuity (SC), Nutrient Cycling (NC), Chemical Regulation (CR)

Model:
IF Position = lower 1/3, THEN = 1.0;
IF Position = middle 1/3, THEN = 0.5;
IF Position = upper 1/3, THEN = 0.0

RATIONALE FOR INCLUSION

A stream's position within its watershed informs the opportunity that is has to provide important regulating functions, based on the expected characteristics, processes, and stressors associated with each position category. Streams in the upper portion of the watershed tend to be headwaters and source channels, while streams in the lower portion of the watershed likely have higher stream order and are likely to receive proportionately more sediment, nutrients, and chemicals. Streams in the lower portion of the watershed also transport water and material from greater contributing areas and may be subject to more erosive floods. All of these factors increase the value of the stream's capacity to intercept and stabilize suspended sediment, filter nutrients, and process chemicals when it is lower in the watershed. A stream that can effectively transfer, filter, and store excess sediment and nutrients is highly valued in areas that may be receiving nutrient- rich, turbid, and/or chemical-laden waters (Adamus *et al.,* 2016).

REFERENCES CITED

Adamus, P., Morlan, J., Verble, K., Buckley, A. (2016) Oregon Rapid Wetland Assessment Protocol (ORWAP, revised): Version 3.1 calculator spreadsheet, databases, and data forms. Oregon Department of State Lands, Salem, OR

o) Flow Restoration Needs (FlowRest)

MEASURE TEXT

What is the "streamflow restoration need" ranking of the watershed within which the PA is located?

Answer this question using the Flow Restoration Needs layer in the SFAM Map Viewer.

DESCRIPTION

This measure indicates whether the stream reach is located in a watershed availability basin (WAB) (a delineation used by the Oregon Water Resources Department for water availability calculations) that has been identified as a critical area for protection and restoration due to a combination of instream water deficits and a biological ranking. This measure can be answered by evaluating the Streamflow Restoration Need data layer, created by the Oregon Department of Fish and Wildlife and the Oregon Water Resources Department. Prioritization models considered (a) the number of months during which instream water rights are not met at least 50% of the time and (b) biological factors including the presence of fish resources, habitat integrity, risks to fish survival, and restoration potential. See **Appendix C** for a detailed explanation of this dataset.

Function Groups: Hydrology, Biology

Values Informed: Flow Variation (FV), Create and Maintain Habitat (CMH)

Model:
IF FlowRest = Not ranked/Low, THEN = 0.0
IF FlowRest = Moderate, THEN = 0.5
IF FlowRest = High/Highest, THEN = 1.0

The inverse model (1-RipCon) is used for CMH.

RATIONALE FOR INCLUSION

This existing dataset identifies areas where streamflow restoration would be valuable due to the instream benefits that wildlife, specifically fish, would likely realize. A stream reach that provides for additional flow in a WAB where streamflow restoration is prioritized is therefore more valuable. Conversely, restricted availability of water limits the opportunity of the stream reach to support the habitat needs of species.

p) Unique Habitat Features (HabFeat, SubFeat, ThermFeat)

MEASURE TEXT

Are there rare aquatic habitat features within the EAA that are not common to the rest of the contributing basin?

DESCRIPTION

This measure indicates whether there are any rare features within close proximity of the project area that provide disproportionate value to the resource. Rare features include large log jams (spanning 25% or more of the active channel width), braided channels (or otherwise multiple channels that result in islands), large spatial extent (> 30%) of wetlands in the floodplain, or seeps, springs, or tributaries that contribute colder water to the project area. While some of these features can be identified using aerial imagery or screened using data layers in the SFAM Map Viewer as described in the User Manual, this measure must be evaluated and verified in the field. All of the listed feature types are considered in the overall measure score, which factors into the value scores for two biological functions. There are two sub-models, specific to the value scores for Substrate Mobility and Thermal Regulation, that consider only those features that are relevant to the respective functions.

Function Groups: Geomorphology, Biology

Values Informed: Substrate Mobility (SM), Maintain Biodiversity (MB), Create and Maintain Habitat (CMH), Sustain Trophic Structure (STS), Thermal Regulation (TR)

Model:
IF HabFeat= none, THEN=0.0;
IF HabFeat= any one of the options, THEN=0.5;
IF HabFeat= any two or more of the options, THEN=1.0

Substrate submeasure model (looking ONLY to braided channels and multiple channels):
IF HabFeat = no, THEN = 0.0;
IF HabFeat = yes, THEN = 1.0

Thermal submeasure model (looking ONLY to wetland and cool water input features):
IF HabFeat= none, THEN=0.0;
IF HabFeat= any one of the options, THEN=0.5;
IF HabFeat= any two or more of the options, THEN=1.0

RATIONALE FOR INCLUSION

Stream reaches where rare features occur are more significant because scarcity typically increases value. Larger log jams are rare in many streams because large woody debris is often removed due to potential damages to bridges and other crossings, dangers for boaters, and drainage issues. Natural sources of large wood have decreased due to logging and reduced connectivity to source areas (e.g. reduced delivery to the stream through landslides), although man-made log structures may have been added for stream restoration. Braided or multiple channels, and a large spatial extent of wetlands in the floodplain are often rare because many lowland streams have been straightened, confined into a single, deeper channel to promote other land uses. Many of Oregon’s streams are too warm for some beneficial uses so seeps, springs, and tributaries that can provide cooler water into a stream reach are valuable for moderating water temperatures.

4.4 Context Measures

This section describes measures which provide landscape or physical context about the subject stream site and how they are used in SFAM.

a) Stream Type and Classifications

MEASURE DESCRIPTION

The Oregon Stream Classification (Nadeau *et al.,* 2012) is one of the data layers made available through the SFAM Map Viewer (**Section 2.6**). Below are descriptions of the context measures generated from the Oregon Stream Classification that are used as SFAM inputs to inform SFAM outputs. This information is available on the site-specific SFAM Report generated in the SFAM Map Viewer.

Stream Classification

The USEPA developed a stream/watershed classification system using 11 local scale and nine watershed scale parameters that describe hydrologic and physical characteristics of streams, as described in **Section 2.2** of this document. To provide a limited number of classes for easier comparison, stream classes were further grouped into 17 stream types based upon a subset of landscape position, water budget, and seasonal hydrology parameters. This subset of parameters (see **Appendix B**, Exclusionary Rules for 17 Stream Types) is the basis of the naming convention used in the Stream Classification options available from the dropdown menu of the Cover Page of the SFAM Workbook.

Function Group: Hydrology

Value Informed: Surface Water Storage (SWS)

Model:

IF DomStreamType = Not Classified, Then = NA;

Low Water Availability:
IF DomStreamType = Mountain Dry, Valley Dry, Transitional Dry, or Mountain Dry/ Valley Dry, THEN = 0;

Moderate Water Availability:
IF DomStreamType = Mountain Wet Rain/Valley Dry, Mountain Wet Snow/Valley Dry, Mountain Wet/Locally Mountain Dry, and the Gradient = <2% OR 2-6%, THEN = 0.25;

IF DomStreamType = Mountain Wet Rain/Valley Dry, Mountain Wet Snow/Valley Dry, Mountain Wet/Locally Mountain Dry, and the Gradient = >6%, THEN = 0.5;

Higher Water Availability:
IF DomStreamType = Mountain Wet Rain Low Permeability, Mountain Wet Rain High Permeability, Mountain Wet Snow Low Permeability, Mountain Wet Snow High Permeability, Valley Wet, Transitional Wet Rain High Permeability, Transitional Wet Rain Low Permeability, Transitional Wet Snow High Permeability, Mountain Wet Rain/Valley Wet, Mountain Wet Snow/Valley Wet, and the Gradient = < 2% or 2-6%, THEN = 0.75;

IF DomStreamType = Mountain Wet Rain Low Permeability, Mountain Wet Rain High Permeability, Mountain Wet Snow Low Permeability, Mountain Wet Snow High Permeability, Valley Wet, Transitional Wet Rain High Permeability, Transitional Wet Rain Low Permeability, Transitional Wet Snow High Permeability, Mountain Wet Rain/Valley Wet, Mountain Wet Snow/Valley Wet, and the Gradient = >6%, THEN = 1

Aquifer Permeability (local)

The aquifer permeability output from the Oregon Stream Classification was determined by assessing the percent of permeable bedrock based on literature values of estimated hydraulic conductivity. A rating of "Low" was assigned to areas where estimated hydraulic conductivity is < 0.0847 meters per day and a rating of "High" was assigned to areas where estimated hydraulic conductivity is ≥ 0.0847 meters per day. The entire local-scale unit was then assigned the permeability class (Low, High) with the highest percent within that unit area.

Function Group: Hydrology

Values Informed: Sub/Surface Transfer (SST), Flow Variation (FV)

Model:
IF AqPerm = High; THEN = 0.0;
IF AqPerm = Low; THEN = 1.0

Soil Permeability (local)

The soil permeability output from the Oregon Stream Classification represents the potential for infiltration and shallow water movement. Permeability of the soil was determined by assessing soils data from STATSGO and calculating the average hydraulic conductivity (in µm/s) of the top two 5-cm layers. A rating of "Low" was assigned to areas where calculated hydraulic conductivity was ≤ 4.23 µm/s and a rating of "High" was assigned to areas where calculated hydraulic conductivity was > 4.23 µm/s. The entire local-scale unit was then assigned the permeability class (Low, High) with the highest percent coverage.

Function Group: Hydrology

Values Informed: Sub/Surface Transfer (SST), Flow Variation (FV)

Model:
IF SoilPerm = High; THEN = 0.0;
IF SoilPerm = Low; THEN = 1.0

Erodibility (local)

The erodibility output from the Oregon Stream Classification was determined by assessing the percent erodible geology based on the state bedrock geology map created by the National Oceanic and Atmospheric Administration. The percentage of each erodibility class (Easily Erodible, Moderately Erodible, Difficult to Erode) was calculated and the class with the highest percentage area was assigned to the local-scale unit.

Function Group: Geomorphology

Value Informed: Sediment Continuity (SC)

Model:
IF Erode = Moderately Erodible; THEN = 0.0
IF Erode = Difficult to Erode; THEN = 0.75
IF Erode = Easily Erodible; THEN = 1.0

Gradient (local)

The gradient output from the Oregon Stream Classification was determined by assessing stream segments in each local-scale unit on the 30-meter Digital Elevation Model. The percent slope (rise/run*100) was calculated between the minimum and maximum elevation cells (rise) over the length of the highest order stream segments (run) in the local-scale unit. A rating of "Low" was assigned to segments if percent slope < 2%, "Moderate" if percent slope ≥ 2% and ≤ 6%, and "High" if percent slope is > 6%.

Function Group: Hydrology

Value Informed: Surface Water Storage (SWS)

Model: See the model for Stream Classification (Gradient is used only in combination with dominant stream type (DomStreamType))

REFERENCES CITED

Nadeau, T-L., Wigington Jr., P.J., Comeleo, R.L., Leibowitz, S.G., Brooks, R.J., Patil, S., Sobota, D.J. (2012) A dualistic stream classification system for Oregon: in support of a stream compensatory mitigation framework. American Geophysical Union, Winter Conference, San Francisco, CA

b) Flow Duration or Permanence Class

MEASURE DESCRIPTION

The flow permanence class of a channel—whether it is perennial, intermittent, or ephemeral— may be provided by the Flowline layer within the NHD (U.S. Geological Survey), which is one of the data layers available through the SFAM Map Viewer. If there is no NHD information available about the subject stream reach, or there is disagreement with the NHD designation, and other information is available it can be used to support a flow permanence class designation. If there is no information available, the Streamflow Duration Assessment Method for the Pacific Northwest (Nadeau, 2015; Nadeau *et al.,* 2015) can be applied to determine whether the subject stream reach is perennial, intermittent, or ephemeral. While flow permanence class does not directly inform SFAM function or value measures, it does provide site-specific context and is used by the agencies in determining whether a proposed mitigation site would be eligible to offset the proposed impacts at the subject stream site. For these reasons, this information is made available as part of an SFAM assessment.

REFERENCES CITED

Nadeau, T-L. (2015) Streamflow Duration Assessment Method for the Pacific Northwest. EPA/910/K-14/001, U.S. Environmental Protection Agency, Region 10, Seattle, WA

Nadeau, T-L., S.G. Leibowitz, P.J. Wigington Jr, J.L. Ebersole, K.M. Fritz, R. Coulombe, R. L. Comeleo, Blocksom, K.A. (2015) Validation of rapid assessment methods to determine streamflow duration classes in the Pacific Northwest, USA. Environmental Management 56 (1):34-53

c) Level III Ecoregion

MEASURE DESCRIPTION

Ecoregions denote areas of similarity in the mosaic of biotic, abiotic, terrestrial, and aquatic ecosystem components with humans being considered as part of the biota. Ecoregions are identified by analyzing the patterns and composition of biotic and abiotic phenomena that affect or reflect differences in ecosystem quality and integrity (Omernik, 1987, 1995). These phenomena include geology, landforms, soils, vegetation, climate, land use, wildlife, and hydrology. The USEPA ecoregion framework is derived from Omernik (1987) and from mapping done in collaboration with USEPA regional offices, other federal agencies, state resource management agencies, and neighboring North American countries. Available through the SFAM Map Viewer, Level III Ecoregion information ("Western Mountains" versus "Xeric") is used to set performance expectations for several function measures.

REFERENCES CITED

Omernik, J.M. (1987) Ecoregions of the conterminous United States. Map (scale 1:7,500,000). Annals of the Association of American Geographers 77 (1):118-125

Omernik, J.M. (1995) Ecoregions: A spatial framework for environmental management. In: Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making. Davis, W.S. and T.P. Simon (eds.), Lewis Publishers, Boca Raton, FL. pp 49-62

d) Average Stream Width

Whether the Average Stream Width is greater than or less than 50 feet is input provided directly by the SFAM user. This information is used to set performance expectations for several function measures.

e) 2-Year Peak Flow

MEASURE DESCRIPTION

The 2-Year Peak Flow is provided by the StreamStats Report (U.S. Geological Survey) that is generated as part of completing the Office Component of SFAM. It is an estimate of the magnitude of peak streamflow at or near bankfull discharge or effective discharge for the 2-year recurrence interval. While the 2-Year Peak Flow does not directly inform SFAM function or value measures, it does provide site-specific context to SFAM users and reviewers of SFAM assessments. For this reason, members of the Technical Working Group and reviewers requested that this information be made available as part of an SFAM assessment.

f) Drainage Area

MEASURE DESCRIPTION

Drainage Area (the total basin areas flowing into the project area) is provided by the StreamStats Report (U.S. Geological Survey) that is generated as part of completing the Office Component of SFAM. Note that the StreamStats method for calculating drainage area is based upon a natural landscape, and if the stream is primarily fed by piped streams and waterways, modeled data will not necessarily be accurate. While Drainage Area does not directly inform SFAM function or value measures, it does provide site-specific context to SFAM users and reviewers of SFAM assessments. For this reason, members of the

Technical Working Group and reviewers requested that this information be made available as part of an SFAM assessment.

5.0 Measures Removed or Not Included

This section provides a brief description of function measures that were initially included in SFAM, but were removed, as noted in **Table 2.1**, for various reasons summarized below. Changes that were made to improve current SFAM function measures are summarized in the Measure Development subsection of descriptions of individual function measures (**Section 4.2 (a)-(q)**).

5.1 Removed Measures

a) Richards-Baker Flashiness Index

MEASURE TEXT

What is the Richards-Baker Flashiness Index?

R-B Index is based on mean daily flow and the relative size of the watershed. Flashy streams tend to have either urbanized environments or may be associated with arid, rocky environments. Stable streams tend to be groundwater driven.

MEASURE DESCRIPTION

Purpose: characterize streamflow, especially whether or not the stream reach is stable, average, or flashy

Function Group: Hydrology

Function Informed: Flow Variation (FV)

Model (categorical):
Based on watershed area, is the R-B Index considered stable, average, or flashy:

	Stable	Mean	Flashy
< 30 mi^2	< 0.2	0.2 - 0.35	> 0.35
> 30 mi^2	< 0.1	0.1 - 0.25	> 0.25
Score	0.5	1.0	0.5

WHY THIS MEASURE WAS REMOVED and ALTERNATIVES CONSIDERED

If there are no gage data, this question cannot be answered. Gage data are frequently unavailable. Statistical and reviewer analysis indicated that this measure performed poorly across all evaluative criteria.

It proved challenging to find an alternative measure for quantifying base flow that can be easily obtained. As the method evolved, and considering input from reviewers, it became clear that this attribute could more appropriately be addressed as a value measure—the opportunity to provide variability in flow, and the significance of the benefits that flow variation provides at that site. These are captured through the Impervious Area, Flow Modification, and Impoundment value measures.

b) Non-native Aquatic Species

MEASURE TEXT

Are there non-native aquatic animal species present?

Presence of individuals of observed or likely reproducing population of non-native aquatic animal species (vertebrate or invertebrate) at or near the PA. From spatial database of known presence.

MEASURE DESCRIPTION

Purpose: direct measure of impact to biodiversity

Function Group: Biology

Function Informed: Maintain Biodiversity (MB)

Model (categorical):
IF NNAquSpp=>1; THEN=0;
IF NNAquSpp=1, THEN=0.5;
IF NNAquSpp=none, THEN=1;
IF 'not known' THEN= blank

WHY THIS MEASURE WAS REMOVED

Ranked moderately by the Technical Working Group, this measure was originally considered a potential indicator of aquatic species structure and composition, water quality, and water temperature. Reviewers raised several concerns about this measure, including that presence or absence did not really address whether a non-native was relatively innocuous, or a true invasive species of concern. Additionally, the DEQ's database does not cover all locations across the state, and without existing information, it could require intensive sampling to collect and identify invertebrates, electrofishing to collect fish, and amphibian sampling. Furthermore, it was difficult to clarify what level of effort was needed to distinguish between 'none' and 'not known'. Statistical and reviewer analysis indicated that this measure performed poorly across most evaluative criteria.

c) Benthic Index of Biotic Integrity (BIBI)

MEASURE TEXT

What is the BIBI family score?

Only answer if BIBI score is available from other data sources--you do not need to calculate the BIBI score for this assessment.

MEASURE DESCRIPTION

Purpose: direct or semi-direct measure of aquatic invertebrate communities and an indirect measure of overall aquatic ecosystem function

Function Group: Water Quality

Functions Informed: Nutrient Cycling (NC), Chemical Regulation (CR), Thermal Regulation (TR)

Model (categorical):
IF BIBI=0–13; THEN=0;
IF BIBI=14–19, THEN=0.5;
IF BIBI=>19, THEN=1;
IF BIBI not available, THEN=blank

WHY THIS MEASURE WAS REMOVED and ALTERNATIVES CONSIDERED

Ranked moderately by the Technical Working Group, this information is rarely available in Oregon and when not available, would be difficult or time consuming to calculate. Reviewers remarked that even where data are available, it is difficult to determine the cause of low BIBI scores or make assumptions about specific indirect functions without additional data that directly relate to the functions. There were not enough data (inputs) available from SFAM field study sites to include in statistical analysis, and this measure performed poorly across most evaluative criteria.

The DEQ, as part of USEPA's 2008 NRSA survey, produced a summary score of biotic health from a number of sites, using their PREDATOR O/E model (River Invertebrate Prediction and Classification System based). However, stream conditions have changed and there are no comprehensive state-wide surveys, so this was ruled out as a practicable option as it does not meet measure inclusion criteria.

d) Temperature Exceedance

MEASURE TEXT

What is the mean August stream temperature?

Use NorWeST modeled values unless more accurate local data are available.

MEASURE DESCRIPTION

Purpose: indicator of stream temperature

Function Group: Water Quality

Function Informed: Thermal Regulation (TR)

Model (categorical):
IF TempEx=<16 degrees C; THEN=1;
IF TempEx =16–20 degrees C, THEN=0.3;
IF TempEx =≥20 degrees C, THEN=0;
IF TempEx not available, THEN=blank

WHY THIS MEASURE WAS REMOVED

This measure relied on the U.S. Forest Service's NorWeST model, which aggregates stream temperature data from the Northwestern U.S. into a stream temperature database and uses the data to develop stream temperature models. It was not ranked highly by the Technical Working Group because the data derive from relatively new sources, have not been extensively vetted for use as proposed in SFAM, are not available for smaller streams, and the NorWeST tool provides modeled average data and thus no change is expected for site-level actions.

e) Native Coniferous Trees

MEASURE TEXT

What is the plant composition within the PAA?

What is the percent cover within the PAA of the following vegetation types: invasive plants, native woody vegetation, large trees, and native coniferous trees?*

*Note, in the initial SFAM model, plant composition had four submeasures as noted above; Invasive Vegetation, Native Woody Vegetation, and Large Trees have been maintained as individual plant composition measures in the current SFAM model.

MEASURE DESCRIPTION

Purpose: habitat availability, diversity and food resource availability

Function Group: Biology

Functions Informed: Maintain Biodiversity (MB), Create and Maintain Habitat (CMH), Sustain Tropic Structure (STS)

Model (Categorical):
IF Conifer=>20%, THEN=1;
IF Conifer=>10–20%, THEN=0.5;
IF Conifer=0-10%, THEN=0

WHY THIS MEASURE WAS REMOVED and ALTERNATIVES CONSIDERED

The Native Coniferous Trees measure was removed as a stand-alone measure, because it is captured in either the Native Woody Vegetation or the Large Trees measures, and analysis indicated it was being overemphasized in the MB, CMH, and STS function calculations. In our best fit analyses, removing Native Coniferous Trees improved the model fit.

f) Geomorphic Successional Stage

MEASURE TEXT

What is the geomorphic successional stage?

See diagrams provided [*Cluer and Thorne (2013), Table I, Table II and Figure 4*] for more detail and select the most appropriate successional stage.

MEASURE DESCRIPTION

Purpose: sediment availability is in balance

Function Group: Geomorphology

Function Informed: Sediment Continuity (SC)

Model (categorical):
IF reach considered stable (no net aggradation or erosion of sediment), Stream Evolution Model (SEM) stages 0, 1, 2, 3s, 6 or 8; THEN GeoSuc=1;
IF reach experiences moderate net aggradation or erosion of sediment, SEM stages 3 or 7; THEN GeoSuc=0.5;
IF reach experiences significant net aggradation or erosion of sediment, SEM stages 4 or 5; THEN GeoSuc=0

WHY THIS MEASURE WAS REMOVED and ALTERNATIVES CONSIDERED

This measure was added prior to SFAM field testing. Reviewers highlighted concerns with this measure including: 1) that it is hard to capture a trend (geomorphic successional trajectory) and challenging to determine a successional stage using site conditions, 2) that it applies only to alluvial channels, and 3) that the proposed categorical scoring may not be appropriate. There were additional concerns that the measure is qualitative and subjective, and it is questionable whether a defensible standard performance index for scoring could be generated.

Reviewers also questioned whether there was redundancy with the Incision measure, and recommended that the field evaluation consider other measures of net aggradation or erosion. In the current SFAM model, the Incision, Erosion, and Lateral Migration measures inform the Sediment Continuity function.

REFERENCES CITED

Cluer, B. and Thorne, C. (2013) Stream evolution model integrating habitat and ecosystem benefits. River Research and Applications. doi: 10.1002/rra.2631

g) Vegetation on Bars

MEASURE TEXT

Is the channel dynamic?

To what extent is early successional woody riparian vegetation (willows, alders, cottonwoods, etc.) of age class 1–10 years present on alluvial channel bars within or at the boundaries of the active channel within the EAA?

MEASURE DESCRIPTION

Purpose: sediment available to form bars; diversity of habitat

Function Groups: Geomorphology, Biology

Functions Informed: Substrate Mobility (SM), Create and Maintain Habitat (CMH)

Model (categorical):
IF BarVeg=>20%, THEN=1;
IF BarVeg=<20%, THEN=0.6;
IF no bars are present, THEN=0

WHY THIS MEASURE WAS REMOVED and ALTERNATIVES CONSIDERED

This measure received a low ranking from the Technical Working Group, but it was retained in the initial SFAM as it was considered easy to assess and a potential indicator of bed mobility and successional process (Beechie *et al.,* 2006). Using the presence/absence of un-vegetated channel bars was also considered. Several problems were identified however, including 1) that the measure is only useful if bars are developed in the reach, 2) that significance and correlation with specific functions may vary based on location of bars (e.g. mid-channel versus lateral bars), and 3) it would be difficult to measure a percent change.

Reviewers also observed that as an indicator of the Maintain Biodiversity function, some bare substrate on gravel bars is important to support certain nesting birds and, in higher areas of bars, nesting turtles, indicating the intermediate condition should score highest.

Pebble counts were explored as a more direct measure of channel dynamics but given how time-intensive the standard protocols are for collecting those data, an Embeddedness measure (**Section 4.2(p)**) was developed to provide information about a stream's sediment regime.

REFERENCES CITED

Beechie, T.J., Liermann, M., Pollock, M.M., Baker, S., Davies, J. (2006) Channel pattern and river floodplain dynamics in forested mountain river systems. Geomorphology 78 (1):124-141

h) Beaver

MEASURE TEXT

Is there beaver activity?

Evidence may include actively maintained beaver dams or beaver lodges within the active channel including the main channel and side channels. Consider the EAA.

MEASURE DESCRIPTION

Purpose: habitat complexity; potential for water storage and replenishment of groundwater

Function Groups: Biology, Hydrology

Functions Informed: Surface Water Storage (SWS), Sub/Surface Transfer (SST), Create and Maintain Habitat (CMH)

Model (categorical):
IF there are one or more active dams or lodges within the active channel, THEN=1;
IF there are one or more dams or lodges within the active channel that appear inactive or are in disrepair, THEN=0.5;
IF there is no evidence of beaver activity; or they are present but only as bank-lodge dwellers or for feeding and material recruitment purposes as evidenced by downed trees, THEN=0

WHY THIS MEASURE WAS REMOVED

This measure was moderately ranked by the Technical Working Group, as it was considered easy to assess and an informative measure of hydrologic control, and likely to be responsive to action (impacts or restoration). However, reviewers indicated this was not a stable measure, that it assumed that beavers should be everywhere, and that sometimes beavers may only occupy a reach for a relatively short period of time. It ranked poorly (statistically) in terms of importance, and the stream functions proposed to be informed by the Beaver measure are better captured by other function measures.

5.2 Measures Considered but Not Included

While exploring measures as indicators of attributes of stream function, several were considered but ultimately rejected because they were not practicable for a rapid assessment method, or did not meet the other inclusion criteria described in **Section 2.1**. These included base flow, hyporheic flow, groundwater flux, bankfull flow duration and frequency, as well as biological indicators such as channel/floodplain habitat complexity, fish population structure and composition, macroinvertebrate and macrophyte structure and composition, and tropic level balance and composition.

As rapid protocols for assessing these aspects of stream process become more widely available, it may be that they can be integrated into future versions of the SFAM model.

Appendix A. Scientific and Technical Support: Acknowledgements

With thanks to the many people who provided critical input, technical review, and otherwise collaborated with us during the several phases of SFAM development (see **Figure 2.1**). We are grateful for their expertise and engagement.

Technical Working Session (2010)

Peter Skidmore (Skidmore Restoration Consulting)*

Greg Koonce (Inter-fluve)*

Janine Castro (U.S. Fish and Wildlife Service)

Bobby Cochran (Willamette Partnership)

Ed Emrick (City of Salem)

Jess Jordan (U.S. Army Corps of Engineers, Seattle District)

Bill Kirchner (U.S. Fish and Wildlife Service)

Marc Liverman (National Oceanographic and Atmospheric Administration - Fisheries)

Ranei Nomura (Oregon Department of Environmental Quality)

Chester Novak (Bureau of Land Management)

Clay Penhollow (Confederated Tribes of Warm Springs)

Mike Reed (City of Portland, Bureau of Environmental Services)

Joe Sheahan (Oregon Department of Fish and Wildlife)

Kristina Tong (U.S. Army Corps of Engineers, Seattle District)

Mike Turaski (U.S. Army Corps of Engineers, Portland District)

Yvonne Vallette (U.S. Environmental Protection Agency)

Joy Vaughn (Oregon Department of State Lands)

Deborah Virgovic (Natural Resources Conservation Service)

Draft Functional Assessment Framework (2010)

Peter Skidmore (Skidmore Restoration Consulting)*

Greg Koonce (Inter-fluve)* Andy Selle (Inter-fluve)*

Oregon Stream Classification System (2011 – 2013)

USEPA’s Oregon Stream Classification System (**Section 2.2**) evolved from a conceptual stream classification system we developed with support from NatureServe, which included input from the following people via a series of interviews and an expert panel:

Gwen Kittle (NatureServe)*

Sara Howard (NatureServe)*

Peter Skidmore (Skidmore Restoration Consulting)*

Jimmy Kagan (Institute for Natural Resources, Portland State University)*

Alison Aldous (The Nature Conservancy)

Leslie Bach (The Nature Conservancy)

Bob Bilby (Weyerhaeuser)

Pete Bisson (U.S. Forest Service)

Janine Castro (U.S. Fish and Wildlife Service/ NOAA- Fisheries)

Dana Hicks (Oregon Department of State Lands)**

Sherri Johnson (U.S. Forest Service)

Chris Jordan (National Oceanographic and Atmospheric Administration - Fisheries)

Judy Linton (U.S. Army Corps of Engineers, Portland District)

Kelly Moore (Oregon Department of Fish and Wildlife)

Michael Schindel (The Nature Conservancy)

David Stagliano (Montana Heritage Program)

Jim Wigington (U.S. Environmental Protection Agency)

Stream Technical Working Group (2012 – 2014)

The following people participated in extended technical working group meetings held in 2012 and 2013, and/or contributed review and input during the development of the draft Stream Function Assessment Method.

Peter Skidmore (Skidmore Restoration Consulting)*

Bobby Cochran (Willamette Partnership)**

Nicole Maness (Willamette Partnership)**

Nicole Czarnomski (Environmental Science Associates)*

Marjorie Wolfe (Environmental Science Associates)*

Heidi Berg (City of Portland)

Bob Bilby (Weyerhaeuser)

Jeff Brandt (Oregon Department of Forestry)

Janine Castro (U.S. Fish and Wildlife Service/ NOAA- Fisheries)

Jaimee Davis (U.S. Army Corps of Engineers, Portland District)

Lauren Driscoll (Washington Department of Ecology)

Ed Emrick (City of Salem)

Sherri Johnson (U.S. Forest Service)

Jess Jordan (U.S. Army Corps of Engineers, Seattle District)

Greg Koonce (Inter-fluve)

Scott Lightcap (Bureau of Land Management)

Judy Linton (U.S. Army Corps of Engineers, Portland District)

Brad Livingston (Oregon Department of Transportation)

Christy Meyer (Freshwater Trust)

Carrie Sanneman (Willamette Partnership)

Cecilia Seiter (Oregon Department of State Lands, Hatfield Fellow)

Joe Sheahan (Oregon Department of Fish and Wildlife)

Kendra Smith (Bonneville Environmental Foundation)

Ron Smith (Natural Resources Conservation Service)

Randi Thurston (Washington Department of Ecology)

Jim Turner (National Oceanographic and Atmospheric Administration - Fisheries)

Jim Wigington (U.S. Environmental Protection Agency)

Initial Draft SFAM (2012 -2013)

Nicole Czarnomski (Environmental Science Associates)*

Rob Coulombe (CSS-Dynamac)*

Nicole Maness (Willamette Partnership)**

Field Testing (2013 – 2014)

Rob Coulombe, Howard Bruner (CSS-Dynamac)*

Nicole Maness (Willamette Partnership)**

Oregon Watershed Enhancement Board – with thanks for partial funding in support of the field testing

Andrea Wagner (U.S. Army Corps of Engineers, Portland District)

Statistical Analysis (2015 – 2017)

Phase I

Dalton Hance, Kara Hitchko, Josh Murauskas (Anchor QEA)*

Rob Coulombe (CSS-Dynamac)*

Phase II

Alex Caillat, Larissa Rohrbach, Josh Murauskas (Anchor QEA)*

Rob Coulombe (CSS-Dynamac)*

Reviewers (2015-2018)

Phase I

Bruce Pruitt (U.S. Army Corps of Engineers, Engineer Research and Development Center)

Brian Topping (U.S. Environmental Protection Agency)

John van Staveren, Gregg Lomnicky, Craig Tumer, Dale Groff (Pacific Habitat Services, Inc.)*

Will Harman (Stream Mechanics)*

Bob Hughes, Lawrence Willis (AOI)*

Final

Bruce Pruitt (U.S. Army Corps of Engineers, Engineer Research and Development Center)

Brian Topping, Tracy Peak, Charissa Bujak, Joe Morgan, Melissa Scianni, Rob Leidy, Megan Fitzgerald (U.S. Environmental Protection Agency)

Will Harman (Stream Mechanics)*

Nicole Czarnomski (Washington Department of Fish and Wildlife)

Standard Performance Index Development (2017-2018)

Larissa Rohrbach, Sydney Gonsalves, Josh Murauskas (Anchor QEA)*

Rob Coulombe, Gregg Lomnicky (CSS-Dynamac)*

Will Harman (Stream Mechanics)*

Pilot Testing (2018)

Brad Livingston, Ron Francis, Allison Cowie, Ken Sargent, Daniel Ohrn, Julie Worsley, Pete Baki, Doug Sharp, Eric Osborne (Oregon Department of Transportation)

Mike DeBlasi, Dan Cary, Melody Rudenko, Peter Ryan (Oregon Department of State Lands)

Trevan Cornwell, Staci Stein (Oregon Department of Fish and Wildlife)

Andrea Wagner, Carrie Bond (U.S. Army Corps of Engineers, Portland District)

* *Contracted support*

** *Cooperative agreements through the USEPA Wetland Program Development Grants program to Oregon Department of State Lands and Clean Water Services*

Appendix B. Oregon Stream Classification System

Stream Classification Parameters

General Information

- Developed by USEPA
- Local units are aggregates of NHDPlusV21 catchments. The target size for the grouped catchments was 80 km^2. Actual mean assessment unit size was 59 km^2 due to many small isolated, or sink, networks.
- Local-Scale (L_*) parameters are calculated for each grouped catchment or local unit
- Watershed-Scale (W_*) parameters are calculated for the area composed of each local- scale unit and all upstream grouped catchments or units
- Upstream units were identified by accumulating all grouped catchments upstream of and including the local-scale grouped catchment unit
- There are 4,048 grouped catchment units in Oregon
- 90 watersheds have greater than 10% of their drainage area outside of the Oregon, Washington, and Idaho data area, the three-state area for which watershed-scale parameters were available. Watershed-scale parameters were not calculated for these local units.
- 1388 local units have no or unconnected stream segments associated with them and are defined as ‘Sinks’ in NHDPlusV21. However, 521 of these are “false sinks” (artefacts of NHD) and watershed parameters *were* calculated for these 521.

Local-Scale Parameters

UNIT_ID

- the ID for the unit. Same as the NHDPlusV21 FID

L_STREAMORDER

- the highest Strahler stream order in each local unit
- stream order calculated (StreamCalc) using the NHDPlusV2.1 Strahler Calculator
- ftp://ftp.horizon-systems.com/nhdplus/NHDPlusV1/NHDPlusExtensions/SOSC/SOSC_technical_paper.pdf

L_AREA_KM

- area of the local unit in square kilometers

L_CLIMATE (HL metric)

- Feddema average annual moisture index (I_m)
- index value ranges from -1.0 to 1.0
- calculate average cell value of I_m for each local watershed
- assign ‘Very Wet’ to segment if average I_m is ≥ 0.66
- assign ‘Wet’ to segment if average I_m is < 0.66 and ≥ 0.33
- assign ‘Moist’ to segment if average I_m is < 0.33 and ≥ 0
- assign ‘Dry’ to segment if average I_m is < 0 and ≥ -0.33
- assign ‘Semiarid’ to segment if average I_m is < -0.33 and ≥ -0.66
- assign ‘Arid’ to segment if average I_m is < -0.66

L_SEASONALITY (HL metric)

- season of maximum 30-year average annual snowmelt-adjusted surplus using parameters from a Columbia Basin regional snowmelt model
- deficit areas are set to zero (deficit areas cannot reduce overall watershed surplus)
- calculate mean monthly surplus (S) as P – PET
- add monthly snowmelt (+)/snowpack (-) to monthly surplus to create snowmelt-adjusted S, or S'
- sum three months of snowmelt-adjusted S for each season
- calculate average cell value of snowmelt-adjusted S for each season
- assign 'Fall or Winter' if fall or winter season has highest average snowmelt-adjusted S
- assign 'Spring' if spring season has highest average snowmelt-adjusted S
- assign 'Summer' if summer season has highest average snowmelt-adjusted S

L_AQUIFER_PERM (HL metric)

- % permeable bedrock based on literature values of estimated hydraulic conductivity in m/ day
- assign 'Low' permeability if estimated hydraulic conductivity < 0.0847 m/d
- assign 'High' permeability if estimated hydraulic conductivity ≥ 0.0847 m/d
- calculate the % of each aquifer permeability class (High, Low) in each local watershed
- assign the permeability class (High, Low) with the highest % in the local watershed

L_TERRAIN (HL metric)

- terrain class for the local watershed
- relief = maximum elevation in the local watershed – minimum elevation in the local watershed
- % flatland = the % of the local watershed with slope < 1%
- assign 'Mountain' to the local watershed if % flatland < 10 and relief > 300 m
- assign 'Flat' to the local watershed if % flatland > 50
- assign 'Transitional' to all remaining local watersheds

L_SOIL-PERM (HL metric)

- % permeable soil based on hydraulic conductivity in µm/s
- STATSGO-based, 1 km cell size grid from Penn State Soil Information for Environmental Modeling and Ecosystem Management
- used the average of the top two 5-cm layers
- calculate the % of each permeability class (Low 0-4.23 µm/s, High > 4.23 µm/s) in each local watershed
- permeability class with the highest % in the local watershed is assigned to the segment

L_HL_CLASS

- Oregon Hydrologic Landscapes class based on L_CLIMATE, L_SEASONALITY, L_ AQUIFER_ PERM, L_TERRAIN, and L_SOIL_PERM, as described above.

L_ERODE_CLASS

- % erodible geology based on erodibility classes interpreted from state bedrock geology map by the National Oceanic and Atmospheric Administration
- calculate the % of each erodibility class (Easily Erodible, Moderately Erodible, Difficult to Erode) in each local watershed
- class with the highest % in the local watershed is assigned to the stream segment

L_GRADIENT

- % slope (rise/run*100) of the highest order stream segments in each local unit
- % slope based on overlay of the highest order stream segments in each local unit on 30-meter DEM
- % slope = (rise/run)*100
- calculate the % slope between the min and max elevation cells (rise) over the length of the highest order stream segments (run) in the local unit
- assign 'Low' to the segment if % slope < 2%
- assign 'Moderate' to the segment if % slope ≥ 2% and ≤ 6%
- assign 'High' to the segment if % slope > 6%

L_FLOODPLAIN

- floodplain influence at the local watershed scale
- % flatland in lowlands
- % flatland = the % of the local watershed with slope < 1%
- lowlands = area less than the midpoint elevation
- midpoint elevation = relief / 2
- assign 'Yes' if % flatland in lowlands > 5%
- assign 'No' if % flatland in lowlands ≤ 5%

Watershed-Scale Parameters

W_PC_OUTSIDE

- the % of the watershed outside of the OR, WA, ID region (i.e. % NODATA)

W_WSHED_FLAG

- flags watersheds with > 10% NODATA as OUT and watersheds with ≤ 10% NODATA as IN

W_AREA_KM

- drainage area of the local-scale unit and all upstream units in square kilometers

W_TERRAIN

- terrain class for the area above the downstream node of each stream segment
- metric calculated at the local scale and evaluated at the watershed scale
- relief = maximum elevation – minimum elevation in the local watershed
- % flatland = the % of the local watershed with slope < 1%
- assign 'Mountain' to the local watershed if % flatland < 10 and relief > 300 m
- assign 'Flat' to the local watershed if % flatland > 50
- assign 'Transitional' to all remaining local watersheds
- assign dominant class to terrain class for the segment drainage area

W_FLOODPLAIN

- floodplain influence at the watershed scale
- % flatland in lowlands
- % flatland = the % of the local watershed with slope < 1%
- lowlands = area less than the midpoint elevation
- midpoint elevation = relief / 2
- assign 'Yes' if % flatland in lowlands > 5%
- assign 'No' if % flatland in lowlands ≤ 5%

W_SURPLUS

- % of watershed land area that is in surplus
- assign 'None' if % average annual water surplus is < 5%
- assign 'Limited' if % average annual water surplus is ≥ 5% and < 34 %
- assign 'Moderate' if % average annual water surplus is ≥ 34% and < 67 %
- assign 'Extensive' if % average annual water surplus is ≥ 67%

W_VOL_SURPLUS

- 30-year average annual watershed surplus volume in cubic meters
- deficit areas are set to zero (deficit areas cannot reduce overall watershed surplus)
- surplus depth in mm converted to surplus volume in cubic meters on a cell-by-cell basis then summed over the entire watershed

W_SEASONALITY

- season of maximum 30-year average annual snowmelt-adjusted surplus using parameters from a Columbia Basin regional snowmelt model
- deficit areas are set to zero (deficit areas cannot reduce overall watershed surplus)
- calculate mean monthly surplus (S) as P – PET
- add monthly snowmelt (+)/snowpack (-) to monthly surplus to create snowmelt-adjusted
- S, or S'
- sum six months of snowmelt-adjusted S for each season
- calculate average cell value of snowmelt-adjusted S for each season
- assign 'Fall Winter' if fall or winter season has highest average snowmelt-adjusted S
- assign 'Spring Summer' if fall or winter season has highest average snowmelt-adjusted S

W_PC_L_PERM

- % permeable bedrock based on literature values of estimated hydraulic conductivity in m/ day
- calculate the % of low aquifer permeability class (< 0.0847 m/d) in each watershed

W_PC_H_PERM

- % permeable bedrock based on hydraulic conductivity in ft/day
- calculate the % of high aquifer permeability class (≥ 0.0847 m/d) in each watershed

Exclusionary Rules (Rule Set) for Seventeen Stream Types

Using a subset of the stream classification parameters, a rule set was developed for distinguishing the stream type of a given local unit. Included watershed parameters were key in defining regional differences, and local parameters were used to help make further distinctions:

W_TERRAIN – ***Mountain, Transitional, Flat***
W_SURPLUS – *Dry****: None, Low;*** *Wet****: Moderate, Extensive***
W_SEASONAL – ***Fall Winter, Spring Summer***
W_PC_L_PERM – ***Low Permeability***
W_PC_H_PERM – ***High Permeability***
L_CLIMATE – *Dry****: Dry, Semiarid, Arid;*** *Wet****: Moist, Wet, Very Wet***
L_TERRAIN – ***Mountain, Transitional, Flat***

The seventeen stream types are as follows:

1. Mountain Dry

Brief description: Primarily low order streams in high relief terrain and dry local climate.

e.g. Steens, Ochoco and Strawberry Mountains

Rule Set:

1. W_TERRAIN: Mountain
2. L_TERRAIN: Mountain
3. W_SURPLUS: None, Limited

2. Mountain Wet Rain Low Permeability

Brief description: Primarily low order streams in high relief terrain and wet local climate.

e.g. Coast Range or western Cascades, Siskiyous, Ochocos, Blue Mountains

Rule Set:

1. W_TERRAIN: Mountain
2. L_TERRAIN: Mountain
3. W_SURPLUS: Moderate, Extensive
4. W_SEASONAL: Fall Winter
5. L_CLIMATE (HL metric): Moist, Wet, Very Wet
6. W_PC_L_PERM

3. Mountain Wet Rain High Permeability

Brief description: Primarily low order streams in high relief terrain and wet local climate.

e.g. Coast Range or western Cascades, Siskiyous, Ochocos, Blue Mountains

Rule Set:

1. W_TERRAIN: Mountain
2. L_TERRAIN: Mountain
3. W_SURPLUS: Moderate, Extensive
4. W_SEASONAL: Fall Winter
5. L_CLIMATE (HL metric): Moist, Wet, Very Wet
6. W_PC_H_PERM

4. Mountain Wet Snow Low Permeability

Brief description: Primarily low order streams in high relief terrain and mid to high elevation, nonvolcanic geology with a wet local climate.

e.g. Wallowas, Elkhorn Mountains

Rule Set:

1. W_TERRAIN: Mountain
2. L_TERRAIN: Mountain
3. W_SURPLUS: Moderate, Extensive
4. W_SEASONAL: Spring Summer
5. L_CLIMATE (HL metric): Moist, Wet, Very Wet
6. W_PC_L_PERM

5. Mountain Wet Snow High Permeability

Brief description: Primarily low order streams in high relief terrain and high elevation, volcanic geology with a wet local climate.

e.g. High Cascades, Wallowas, Strawberry Mountains, Steens Mountain

Rule Set:

1. W_TERRAIN: Mountain
2. L_TERRAIN: Mountain
3. W_SURPLUS: Moderate, Extensive
4. W_SEASONAL: Spring Summer
5. L_CLIMATE (HL metric): Moist, Wet, Very Wet
6. W_PC_H_PERM

6. Mountain Wet / Locally Mountain Dry

Brief description: Primarily low order streams in high relief terrain with a dry local climate

e.g. Ochoco and Strawberry Mountains, Steens/Lake Abert area

Rule Set:

1. W_TERRAIN: Mountain
2. L_TERRAIN: Mountain
3. W_SURPLUS: Moderate, Extensive
4. L_CLIMATE (HL metric): Dry, Semiarid, Arid

7. Valley Wet

Brief description: Primarily low order streams in low relief terrain and wet local climate.

e.g. Willamette Valley, coast, Klamath region

Rule Set:

1. W_TERRAIN: Flat, Transitional
2. L_TERRAIN: Flat
3. W_SURPLUS: Moderate, Extensive

8. Valley Dry

Brief description: Primarily low order streams in low relief terrain and dry local climate.

e.g. Deschutes basin, Burns area, Steens/Alvord Desert

Rule Set:

1. W_TERRAIN: Flat, Transitional
2. L_TERRAIN: Flat
3. W_SURPLUS: None and Limited

9. Transitional Wet Rain Low Permeability

Rule Set:

1. W_TERRAIN: Flat, Transitional
2. L_TERRAIN: Transitional, Mountain
3. W_SURPLUS: Moderate, Extensive
4. W_SEASONAL: Fall Winter
5. W_PC_L_PERM

10. Transitional Wet Rain High Permeability

Rule Set:

1. W_TERRAIN: Flat, Transitional
2. L_TERRAIN: Transitional, Mountain
3. W_SURPLUS: Moderate, Extensive
4. W_SEASONAL: Fall Winter
5. W_PC_H_PERM

11. Transitional Wet Snow High Permeability

Rule Set:

1. W_TERRAIN: Flat, Transitional
2. L_TERRAIN: Transitional, Mountain
3. W_SURPLUS: Moderate, Extensive
4. W_SEASONAL: Spring Summer
5. W_PC_H_PERM

12. Transitional Dry

Brief description: Primarily low to mid-order streams in low relief terrain and dry local climate.

e.g. Burns area, Steens/Alvord Desert

Rule Set:

1. W_TERRAIN: Transitional
2. L_TERRAIN: Transitional, Mountain
3. W_SURPLUS: None, Limited

13. Mountain Wet Rain / Valley Wet

Brief description: Higher percentage of high order streams located in low relief terrain downstream of a watershed containing a significant percentage of higher relief terrain, and a wet local climate.

e.g. coast, low elevation western Cascades, western Cascades foothills

Rule Set:

1. W_TERRAIN: Mountain
2. L_TERRAIN: Flat, Transitional
3. W_SURPLUS: Moderate, Extensive
4. W_SEASONAL: Fall Winter
5. L_CLIMATE: Moist, Wet, Very Wet

14. Mountain Wet Snow / Valley Wet

Brief description: Higher percentage of high order streams located in low relief terrain downstream of a watershed containing a significant percentage of higher relief terrain at mid to high elevation; with a wet local climate.

e.g. Upper Deschutes

Rule Set:

1. W_TERRAIN: Mountain
2. L_TERRAIN: Flat, Transitional
3. W_SURPLUS: Moderate, Extensive
4. W_SEASONAL: Spring Summer
5. L_CLIMATE: Moist, Wet, Very Wet

15. Mountain Wet Rain / Valley Dry

Brief description: Higher percentage of high order streams located in low relief terrain downstream of a watershed containing a significant percentage of higher relief terrain, and a dry local climate.

e.g. Siskiyou foothills, Klamath foothills, high valleys on eastern Cascades

Rule Set:

1. W_TERRAIN: Mountain
2. L_TERRAIN: Flat, Transitional
3. W_SURPLUS: Extensive, Moderate
4. W_SEASONAL: Fall Winter
5. L_CLIMATE: Dry, Semiarid, Arid

16. Mountain Wet Snow / Valley Dry

Brief description: Higher percentage of high order streams located in low relief terrain downstream of a watershed containing a significant percentage of higher relief terrain at mid to high elevation; with a dry local climate.

e.g. Wallowas

Rule Set:

1. W_TERRAIN: Mountain
2. L_TERRAIN: Flat, Transitional
3. W_SURPLUS: Extensive, Moderate
4. L_CLIMATE: Dry, Semiarid, Arid
5. W_SEASONAL: Spring Summer

17. Mountain Dry / Valley Dry

Brief description: Higher percentage of high order streams located in low relief terrain downstream of a watershed containing a significant percentage of higher relief terrain, and a dry local climate.

e.g. John Day, Alvord Desert basins

Rule Set:

W_TERRAIN: Mountain
L_TERRAIN: Flat, Transitional
W_SURPLUS: Limited, None

Appendix C. SFAM Relevant Map Layers in the ORWAP and SFAM Map Viewer[9]

Oregon Wetlands Cover

Data source: Oregon Institute for Natural Resources

Description updated from: http://oe.oregonexplorer.info/metadata/wetlands_or.htm

This coverage is a compilation of polygon data from numerous sources to represent the location, type, and extent of the state's wetlands. It was produced in 2009 by the Oregon Natural Heritage Information Center and The Wetlands Conservancy. It uses as a base all available digital data from the National Wetlands Inventory (NWI) (U.S. Fish and Wildlife Service, USFWS), to which was added draft NWI mapping, Local Wetlands Inventories (LWI) (DSL), wetlands along state highways (Oregon Department of Transportation), Wetland Reserve Program sites (Natural Resources Conservation Service), wetland mitigation banks (DSL), and mapping of individual sites by a variety of federal, state, academic, and nonprofit sources. Despite the contributions from many sources, large numbers of jurisdictional wetlands are not shown in this coverage and new information may be available (e.g. new LWIs and mitigation banks). As noted on the website, the wetland maps shown in the Oregon Wetlands Cover must not be used to represent jurisdictional wetlands or jurisdictional wetland boundaries.

National Hydrography Dataset

Data source: U.S. Geological Survey (USGS)

Description excerpted from: https://nhd.usgs.gov/NHD_High_Resolution.html

The National Hydrography Dataset (NHD) represents the nation's drainage networks and related features, including rivers, streams, canals, lakes, ponds, glaciers, coastlines, dams, and stream gages. The NHD High Resolution, at 1:24,000 scale or better, is the most up-to-date and detailed hydrography dataset for the nation.

Watershed Boundary Dataset

Data source: USGS

Description excerpted from: https://nhd.usgs.gov/wbd.html

The Watershed Boundary Dataset (WBD) defines the areal extent of surface water drainage to a point, accounting for all land and surface areas. Watershed boundaries are determined solely upon science-based hydrologic principles, not favoring any administrative boundaries or special projects, nor any particular program or agency. The intent of defining Hydrologic Units (HU) for the WBD is to establish a baseline drainage boundary framework, accounting for all land and surface areas. At a minimum, the WBD is being delineated and georeferenced to the USGS 1:24,000 scale topographic base map meeting National Map Accuracy Standards. HUs are given a Hydrologic Unit Code.

An HU is a drainage area delineated to nest in a multi-level, hierarchical drainage system. Its boundaries are defined by hydrographic and topographic criteria that delineate an area of land upstream from a specific point on a river, stream, or on similar surface waters. An HU can accept surface water directly from upstream drainage areas, and indirectly from associated surface areas such as remnant, non-contributing, and diversions to form a drainage area with single or multiple outlet points. HUs are only

9 Note that only layers used to complete an SFAM assessment are described in Appendix C.

synonymous with classic watersheds when their boundaries include all the source area contributing surface water to a single defined outlet point.

Oregon Stream Classification

Data source: USEPA

Description excerpted from: Section 2.2 of this document

USEPA (Region 10 and Office of Research and Development, Western Ecology Division) developed a stream/watershed classification system for streams and rivers of various sizes (Nadeau *et al.,* 2012) based in part on a hydrologic landscape classification system, addressing local assessment units, previously developed for Oregon (Wigington *et al.,* 2013). The current stream classification system, available through the Map Viewer, reflects recent revisions to the hydrologic landscape classification system that informs several of the included classification parameters. Specific changes from that initial classification system (Nadeau *et al.,* 2012) include the use of local assessment units based on National Hydrography Dataset Plus V2 to promote compatibility with geospatial data that are more broadly available with the United States, and aquifer and soil permeability classes based on uniform criteria (Comeleo *et al.,* 2014; Leibowitz *et al.,* 2016).

The stream classification system can be used to identify stream types that exhibit similar functional characteristics. Each stream type (associated with the local assessment unit) is defined by basic hydrologic and physical characteristics and determinants of flow regime, and reflects broad functional expectations. The classification system covers both watershed and local scale hydrologic and geologic characteristics that are drivers of many stream functions. The classification system is hierarchical, expandable, and dualistic—providing information at both the local (assessment unit) and watershed (integrative) scales.

References Cited

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Nadeau, T-L., Wigington Jr., P.J., Comeleo, R.L., Leibowitz, S.G., Brooks, R.J., Patil, S., Sobota, D.J. (2012) A dualistic stream classification system for Oregon: in support of a stream compensatory mitigation framework. American Geophysical Union, Winter Conference, San Francisco, CA

Wigington, P.J., Jr., Leibowitz, S.G., Comeleo, R.L., Ebersole, J.L. (2013) Oregon hydrologic landscapes: a classification framework. Journal of the American Water Resources Association 49:163-182

Water Quality (Lakes & Streams)

Data source: Oregon Department of Environmental Quality (DEQ)

Description excerpted from: http://www.deq.state.or.us/wq/assessment/rpt2012/search.asp

This feature contains a spatial representation of streams and stream segments with water quality information from Oregon's 2012 Integrated Report Assessment Database and 303(d) List. The Integrated Report Assessment Database contains information on water quality in Oregon's surface waters and includes waters identified as water quality limited that need Total Maximum Daily Loads (Category 5: Section 303(d) List). A water body may have assessment information for multiple pollutants or conditions, and may have multiple data records associated with the spatial representation of the water body or segment of the water body. Oregon's 2012 Integrated Report Assessment Database and 303(d) List are available online at http://www.deq.state.or.us/ wq/assessment/rpt2012/search.asp. The on-line searchable database is the reference source to verify all attribute information about water quality and to obtain assessment information about water bodies that do not have georeferenced locations.

Surface Water & Groundwater Drinking Water Source Areas

Data source: DEQ; Oregon Health Authority (OHA)

Description excerpted from: http://spatialdata.oregonexplorer.info/osdl-geoportal/rest/document?id=%7BBD6FD933-A183-4A4C-8314-AF1FC4613CB7%7D and http://spatialdata.oregonexplorer.info/osdl-geoportal/rest/document?id=%7B6A1EC8DD-8B68-4483-8CC5-01C57B6A2C27%7D

Surface Water: This map includes DEQ and OHA Drinking Water Program Source Water Assessment results for community and non-transient non-community public water systems for surface water systems that were active in June 1999 (when Oregon's Source Water Assessment Plan was approved by USEPA). Subsequently, post-1999 systems have been added including some non-community systems. This layer was developed in order to spatially reference the watersheds that supply drinking water to surface water intakes for Public Water Systems (PWS) within the state of Oregon. Source water assessments were completed for these PWSs in accordance with the 1996 Amendments to the Safe Drinking Water Act and Oregon's 1999 Source Water Assessment Plan. The original list of PWSs was generated in 1999, however additional PWSs may be added in the future. These source areas should be used in conjunction with the locations of potential contaminant source threats as well as mapped sensitive areas to provide an overall picture of the susceptibility of the drinking water system.

These data are for community (C) and non-transient non-community (NTNC) public water systems only. Data were compiled in a cooperative effort between DEQ/Water Quality Division, Drinking Water Protection Program and OHA/Drinking Water Program. A community PWS regularly serves at least 25 year-round residents or serves at least 15 service connections used by year-round residents. A non-transient non-community PWS is not a community PWS and regularly serves at least 25 of the same people over 6 months per year (for example, work sites and schools). Source Water Assessment results for 1100 public water systems serving approximately 2,360,000 Oregonians are included in this data set. Source Water Assessment results for transient non-community systems (NC) (a PWS that does not regularly serve at least 25 of the same people over 6 months per year (i.e., rest areas, campgrounds) are not included in these data. Information on private water supplies was not collected as part of the Source Water Assessment project. For surface water, the drinking water source area is defined as the geographic area (watershed) that supplies the water body where the intake is located. Surface water source areas were delineated intake to intake. For watersheds with more than one intake, Oregon reported source water assessments results by watershed segment representing the area from the public water system's intake to the next intake upstream. All source areas upstream of a specific water system's intake are included in the drinking water source area for that water system and PWSs are encouraged to work with other water providers and other entities within the subbasin as they move forward with developing protection strategies.

Groundwater: These polygons were developed to spatially reference source areas that supply drinking water to groundwater wells or springs for PWSs within the state of Oregon. Source water assessments were completed for these PWSs in accordance with the 1996 Amendments to the Safe Drinking Water Act and Oregon's 1999 Source Water Assessment Plan. The original list of PWSs was generated in 1999, however additional PWSs will be added in the future. PWSs whose status changed to community or non-transient non-community since the 1999 list was generated may not be included or may be added as updates are performed; PWSs that have become inactive may be deleted. These source areas are to be used in conjunction with the locations of potential contaminant source threats as well as mapped sensitive areas to provide an overall picture of the susceptibility of the drinking water system.

Streamflow Restoration Needs

Data source: Oregon Water Resources Department (WRD) and Oregon Department of Fish and Wildlife (ODFW)

Description excerpted from: http://www.oregon.gov/owrd/pubs/docs/reports/summary.pdf

The WRD and the ODFW jointly identified priority areas for streamflow restoration in basins throughout the state. These priority areas represent watersheds in which there is a combination of need and opportunity for flow restoration to support fish recovery efforts under the Oregon Plan for Salmon and Watersheds. To determine need, ODFW used a process based on the Bradbury Prioritization Model[10] to identify the critical areas for protection and restoration. In applying the process, ODFW district biologists gathered information on the presence of fish resources, habitat integrity, risks to fish survival, and restoration potential for each water availability basin (WAB). These factors were combined to produce a biological rank by season for each water availability basin. Appendix 2 of the document, Factors Included in Biological Rank, provides a detailed list of the factors included in the biological ranking. WRD used the water availability model to determine the number of months during which instream water rights are not met at least 50 percent of the time. As staff began the prioritization process, they concluded that, in addition to instream water right deficits, the percentage of natural flow consumed by water uses in each water availability basin would provide an indicator of the extent to which fish were negatively affected by reductions in streamflow. WRD also used the water availability model to develop and to provide ODFW with these data. The combination of the biological ranking, data on instream deficits and water use, and biologists' judgments of the potential for fish recovery if water was restored yielded a value reflecting the need for flow restoration during each season in each WAB. These values were divided into the following four classes: Low, Moderate, High and Highest.

Sole Source Aquifers

Data source: USEPA

Description excerpted from: https://catalog.data.gov/harvest/object/05efabd4-ee92-43b2-b51f-f45d666cba4b/html

This coverage displays sole source aquifers in Oregon, as designated under the National Environmental Policy Act as of October 2016. The Sole Source Aquifer protection program is authorized by section 1424(e) of the Safe Drinking Water Act of 1974 (Public Law 93-523, 42 U.S.C. 300 et seq.). This program is designed to protect drinking water supplies in areas with few or no alternative sources to the ground water resource, and where, if contamination occurred, using an alternative source would be extremely expensive. USEPA defines a sole or principal source aquifer as an aquifer that supplies

10 The model was developed by a team of scientists to provide a framework for prioritizing restoration work. The team was coordinated by the Pacific Rivers Council at the request of Senate President Bill Bradbury.

at least 50 percent of the drinking water consumed in the area overlying the aquifer. These areas may have no alternative drinking water source(s) that could physically, legally and economically supply all those who depend on the aquifer for drinking water. For convenience, all designated sole or principal source aquifers are referred to as “sole source aquifers.” The designation protects an area’s ground water resource by requiring USEPA to review certain proposed projects within the designated area.

DEQ Groundwater Management Areas

Data source: DEQ

Description excerpted from: http://www.oregon.gov/deq/wq/programs/Pages/GWP-Management-Areas.aspx

This coverage displays groundwater management areas (GWMA) in Oregon, as designated by DEQ as of June 2018. GWMAs are designated when groundwater in an area has elevated contaminant concentrations resulting, at least in part, from nonpoint sources. Once the GWMA is declared, a local groundwater management committee comprised of affected and interested parties is formed. The committee then works with and advises the state agencies that are required to develop an action plan that will reduce groundwater contamination in the area. Oregon has designated three GWMAs because of elevated nitrate concentrations in groundwater. These include the Lower Umatilla Basin GWMA, the Northern Malheur County GWMA, and the Southern Willamette Valley GWMA. Each one has developed a voluntary action plan to reduce nitrate concentrations in groundwater.

100-Year Floodplain

Data source: Oregon Spatial Data Library

Description excerpted from: http://spatialdata.oregonexplorer.info/geoportal/details;id=f2cc36de1f0a42d29b8dfdd71721a7d3

This coverage uses a feature class called the Federal Emergency Management Agency (FEMA) Flood Insurance Study inundation zones, which were derived from Digital Flood Insurance Rate Maps and georeferenced paper Flood Insurance Rate Maps. The originator of the data for Oregon is the Oregon Department of Land Conservation and Development and Oregon Department of Geology and Mineral Industries.

National Land Cover Dataset

Data source: USGS

Description excerpted from: https://www.mrlc.gov/nlcd2011.php

The National Land Cover Database (NLCD) serves as the definitive Landsat-based, 30-meter resolution, land cover database for the nation. NLCD provides spatial reference and descriptive data for characteristics of the land surface such as thematic class (for example, urban, agriculture, and forest), percent impervious surface, and percent tree canopy cover. NLCD supports a wide variety of federal, state, local, and nongovernmental applications that seek to assess ecosystem status and health, understand the spatial patterns of biodiversity, predict effects of climate change, and develop land management policy. NLCD products are created by the Multi- Resolution Land Characteristics (MRLC) Consortium, a partnership of federal agencies led by the USGS. National Land Cover Database 2011 (NLCD 2011) is the most recent national land cover product created by the MRLC Consortium.

Level III Ecoregions

Data source: USEPA

Description excerpted from: https://www.epa.gov/eco-research/ecoregions

Ecoregions are areas where ecosystems (and the type, quality, and quantity of environmental resources) are generally similar. The Level III Ecoregions framework is derived from Omernik (1987) and from mapping done in collaboration with USEPA regional offices, other federal agencies, state resource management agencies, and neighboring North American countries. Designed to serve as a spatial framework for the research, assessment, and monitoring of ecosystems and ecosystem components, ecoregions denote areas of similarity in the mosaic of biotic, abiotic, terrestrial, and aquatic ecosystem components with humans being considered as part of the biota. These regions are critical for structuring and implementing ecosystem management strategies across federal agencies, state agencies, and nongovernmental organizations that are responsible for different types of resources within the same geographic areas (McMahon *et al.,* 2001; Omernik and Griffith, 2014).

Ecoregions are identified by analyzing the patterns and composition of biotic and abiotic phenomena that affect or reflect differences in ecosystem quality and integrity (Omernik, 1987; 1995). These phenomena include geology, landforms, soils, vegetation, climate, land use, wildlife, and hydrology. The relative importance of each characteristic varies from one ecological region to another regardless of the hierarchical level.

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Zoning

Data source: Oregon Department of Land Conservation and Development (DLCD)

Description excerpted from: http://spatialdata.oregonexplorer.info/geoportal/details;id=9966f34d71e74bd5a91e0d2757c91ebf

As of April 28, 2017, this feature class contains zoning data from 198 local jurisdictions. DLCD plans to continue adding to and updating this statewide zoning dataset as they receive zoning information from the local jurisdictions. Jurisdictions included in the latest version of the statewide zoning geodatabase:

Cities: Adams, Adrian, Albany, Amity, Antelope, Ashland, Astoria, Athena, Banks, Barlow, Bay City, Beaverton, Bend, Bonanza, Brookings, Brownsville, Burns, Butte Falls, Canby, Cannon Beach, Carlton, Cascade Locks, Cave Junction, Central Point, Chiloquin, Coburg, Columbia City, Coos Bay, Cornelius, Corvallis, Cottage Grove, Creswell, Culver, Damascus, Dayton, Detroit, Donald, Dufur, Dundee, Dunes City, Eagle Point, Echo, Estacada, Eugene, Fairview, Falls City, Florence, Forest Grove, Garibaldi, Gates, Gearhart, Gervais, Gladstone, Gold Beach, Gold Hill, Grants Pass, Grass Valley, Halsey, Happy

Valley, Harrisburg, Helix, Hermiston, Hillsboro, Hines, Hood River, Hubbard, Idanha, Independence, Jacksonville, Jefferson, Johnson City, Jordan Valley, Junction City, Keizer, King City, Klamath Falls, La Pine, Lafayette, Lake Oswego, Lebanon, Lincoln City, Lowell, Lyons, Madras, Malin, Manzanita, Maupin, Maywood Park, McMinnville, Medford, Merrill, Metolius, Mill City, Millersburg, Milton-Freewater, Milwaukie, Molalla, Monmouth, Moro, Mosier, Mt. Angel, Myrtle Creek, Nehalem, Newberg, Newport, North Bend, North Plains, Nyssa, Oakridge, Ontario, Oregon City, Philomath, Phoenix, Pilot Rock, Portland, Port Orford, Prineville, Redmond, Reedsport, Rivergrove, Rockaway Beach, Rogue River, Rufus, Salem, Scappoose, Scio, Scotts Mills, Seaside, Shady Cove, Shaniko, Sheridan, Sherwood, Silverton, Sisters, Sodaville, Springfield, Stanfield, St. Helens, Stayton, Sublimity, Sweet Home, Talent, Tangent, The Dalles, Tigard, Tillamook, Troutdale, Tualatin, Turner, Ukiha, Umatilla, Vale, Veneta, Vernonia, Warrenton, Wasco, Waterloo, West Linn, Westfir, Weston, Wheeler, Willamina, Wilsonville, Winston, Wood Village, Woodburn, Yamhill.

Counties: Baker County, Benton County, Clackamas County, Clatsop County, Columbia County, Coos County, Crook County, Curry County, Deschutes County, Douglas County, Harney County, Hood River County, Jackson County, Jefferson County, Josephine County, Klamath County, Lane County, Lincoln County, Linn County, Malheur County, Marion County, Multnomah County, Polk County, Sherman County, Tillamook County, Umatilla County, Union County, Wasco County, Washington County, Wheeler County, Yamhill County.

Essential Salmonid Habitat

Data source: DSL

Description excerpted from: http://chetco-new.dsl.state.or.us/esh2017/

Essential salmonid habitat is defined as the habitat necessary to prevent the depletion of native salmon species (chum, sockeye, Chinook and coho salmon, and steelhead and cutthroat trout) during their life history stages of spawning and rearing. The designation applies only to those species that have been listed as “Sensitive, Threatened, or Endangered” by a state or federal authority. The DSL, in consultation with the ODFW, designates essential salmonid habitat areas based on field surveys and/or the professional judgment of ODFW´s district biologists, and is the source of this coverage. Designations are periodically reviewed and updated. The last update was in 2015. Stream reaches used only by non-native salmonids, or used only as passageways, are not included.

Fish Passage Barriers

Data source: ODFW

Description excerpted from: https://nrimp.dfw.state.or.us/DataClearinghouse/default.aspx?p=202&XMLname=44.xml

The OFPBDS dataset contains the locations of barriers to fish passage in Oregon watercourses. Barriers include the following types of natural or artificial structures: bridges, cascades, culverts, dams, debris jams, fords, natural falls, tide gates, and weirs. The OFPBDS dataset does not include structures which are not associated with in- stream features (such as dikes, levees or berms). Barriers are structures which do, or potentially may, impede fish movement and migration. Barriers can be known to cause complete or partial blockage to fish passage, or they can be completely passable, or they may have an unknown passage status. The OFPBDS dataset now contains over 40,000 barrier features from 19 separate sources including: ODFW, Oregon Department of Transportation, Oregon Department of Water Resources, Oregon Department of Forestry, Oregon Watershed Enhancement Board , Oregon Department of Land Conservation and Development, U.S. Bureau of Land Management, U.S. Forest Service, Nez Perce Tribe, Benton Soil and Water Conservation District, Washington County, Lower Columbia River Estuary Partnership and watershed councils representing the Rogue, Umpqua, Siuslaw, Santiam, Calapooia, Clackamas and Scappoose basins.

The OFPBDS database is the most comprehensive compilation of fish passage barrier information in Oregon however, it does NOT represent a complete and current record of every fish passage barrier within the state. Efforts to address deficiencies in data currency, completeness and accuracy are ongoing and are often limited by lack of sufficient resources. Attributes (including key attributes such as fish passage status) are often unknown or incomplete. Consistency in attribution also varies among data originators. Field verification of barrier features and their attributes will be an important component to making this dataset current, comprehensive and accurate. Fish passage status is a key attribute. Many barrier features have an unknown passage status.

Important Bird Areas

Data source: Audubon Society of Portland

Description excerpted from: http://audubonportland.org/local-birding/iba and http://oe.oregonexplorer.info/ExternalContent/ORWAP/metadata/IBA_2013_metadata.xml

This coverage contains boundaries and associated attributes for Important Bird Areas (IBA) identified as of May 2013. An IBA is a site that has been selected for its outstanding habitat value and imperative role it plays in hosting birds, whether for breeding, migrating, or over- wintering. The IBA designation is internationally-recognized. State-level IBAs are nominated through a public process and reviewed by a Technical Advisory Committee. The boundaries should not be perceived as absolute, definitive boundaries. Rather, the boundaries should be considered approximates of the critical habitat areas. There are four specific scientific criteria to be considered as a guideline for the IBA program (in-depth descriptions can be found at http:// audubonportland.org/local-birding/iba/selection-criteria):

1. Sites important to endangered/threatened species or species of special concern.
2. Sites important to species of high conservation priority (which includes species identified as high conservation priorities by Partners in Flight and identified in any bird conservation plan or agency list relative to the area in question).
3. Sites that are representative of rare or threatened natural communities.
4. Sites where significant numbers of birds concentrate for breeding, during migration, or in the non-breeding season.

Cold Water Habitat

Data source: DEQ

Descriptions excerpted from: https://oe.oregonexplorer.info/externalcontent/metadata/cold_water_refuges.html and https://oe.oregonexplorer.info/externalcontent/metadata/core_cold_bt_fishuse.html

Lower Willamette River Cold Water Refugia: This coverage displays cold water refuges that the Oregon Department of Environmental Quality has identified in the lower Willamette River. Cold Water Refuges are those portions of a water body where at times during the diel temperature cycle the water temperature is at least 2°C (3.6°F) colder than the daily maximum temperature of the adjacent well mixed flow of the water body (OAR 340-041-0002 [10]). Cold water refuges function to provide access to colder water relative to the main flow of the river in waters classified as “salmon and steelhead migration corridors” and are primarily colder water tributaries designated as “salmon and trout rearing and migration” use. Some off-channel features also provide cold water refuge.

Cold Water Fish Use Designations: This coverage is a derived product of the Oregon Department of Environmental Quality’s designated aquatic life fish use maps in OAR 340-041-1 to -340 and is for Clean Water Act purposes. The dataset includes two sublayers:

Core Cold Water Habitat are waters expected to maintain temperatures within the range generally considered optimal for salmon and steelhead rearing, or that are suitable for bull trout migration, foraging and sub-adult rearing that occurs during the summer (OAR 340-041-0002 [13]). The biologically based temperature goal for waters designated as Core Cold Water Habitat is a seven-day Average Maximum temperature ≤16°C (~61°F). Waters designated as Core Cold Water Habitat have been mapped by DEQ.

Bull Trout Spawning and Juvenile Rearing Habitat are waters expected to maintain temperatures optimal for juvenile bull trout rearing in the summer and for bull trout spawning and egg development from fall through spring. The biologically based temperature goal for waters designated as bull trout spawning and rearing habitat is a seven-day Average Maximum temperature ≤12°C (~54°F).