

# A Function-Based Framework for Stream Assessment & Restoration Projects

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The findings and conclusions in this document are those of the authors and do not necessarily represent the views of the US Fish and Wildlife Service (FWS) or the US Environmental Protection Agency (EPA).

**Authors' Note:**

This document provides a new framework for approaching stream assessment and restoration from a function-based perspective; as such, it will benefit from review, comments, and example experiences and applications. Please share these with the authors so the concepts, examples and templates can be revised and expanded. Contact any one of the following: Will Harman, lead author ([wharman@stream-mechanics.com](mailto:wharman@stream-mechanics.com), 919-747-9448), Brian Topping, EPA project sponsor ([topping.brian@epa.gov](mailto:topping.brian@epa.gov), 202-566-5680) or Rich Starr, FWS project sponsor ([rich\\_starr@fws.gov](mailto:rich_starr@fws.gov), 410-573-4583).

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The Framework presented in this document was tested through a pilot workshop at the FWS National Conservation Training Center in the summer of 2010. EPA staff from around the country attended the workshop and provided comments on how to improve the Framework and workshop. They also provided real-world examples of stream impacts and restoration needs from various regions that could be used to develop case studies. These scientists and managers included: Eric Somerville, Ed Reiner, Robert Montgomerie, Stephanie Chin, Carol Petrow, David Rider, Bill Ainslie, Mara Lindsley, Sue Elston, Melissa Gebien, Melanie Haveman, Scott McWhorter, Catherine Holston, Jason Daniels, Richard Clark, Toney Ott, Tracie Nadeau, Linda Storm, Brent Johnson, Greg Pond, Joy Gillespie, Brian Topping and Palmer Hough.

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# Chapter 4

## The Stream Functions Pyramid

The Stream Functions Pyramid, developed by Harman (2009), provides a framework that organizes stream functions in a pyramid form. The Stream Functions Pyramid illustrates that stream functions are supported by lower-level functions in a hierarchical structure. The Pyramid is a useful tool in goal setting, developing and reviewing stream assessment methodologies, and creating standard operating procedures (SOPs) for regulatory and non-regulatory stream restoration programs. This chapter provides a detailed overview of the Stream Functions Pyramid along with simple examples of how it can be applied. Detailed applications are provided in Chapter 11.

### 4.1 » FUNCTIONAL OBJECTIVES FOR STREAM RESTORATION

A stream functions framework was created by the US Army Corp of Engineers (USACE) for determining and evaluating objectives for stream restoration projects (Fischenich, 2006). This framework provided the foundation for development of the Stream Functions Pyramid. It identifies a suite of 15 functions critical to the health of stream and riparian ecosystems. These functions are summarized in Table 4.1. The USACE functional framework is appealing since it has a scientific basis in stream functions, is based on processes, and attempts to describe the interactions between identified functions.

**TABLE 4.1** FUNCTIONS CRITICAL TO STREAM AND RIPARIAN ECOSYSTEM HEALTH (Fischenich 2006)

FUNCTION	DESCRIPTION
1. Maintain Stream Evolution Processes	Maintains appropriate energy levels; promotes diversity and variability of biotic communities.
2. Energy Management Processes	Allows for conversion between potential and kinetic energy through changes in the system.
3. Provide for Riparian Succession	Changes in vegetation structure promote diversity and ecological vigor, vegetation necessary for system stability and nutrient cycling.
4. Surface Water Storage Processes	Provides temporary water storage during high flows, regulates soil moisture, provides pathway for aquatic organism movement, and provides contact time for biogeochemical processes.

## Chapter 4: The Stream Functions Pyramid

**TABLE 4.1** FUNCTIONS CRITICAL TO STREAM AND RIPARIAN ECOSYSTEM HEALTH  
(Fischenich 2006)

FUNCTION	DESCRIPTION
5. Maintain Surface/ Subsurface Water Connections and Processes	Provides bi-directional exchange from open channel to subsurface soils; allows exchange of chemicals, nutrients and water.
6. General Hydrodynamic Balance	Provides proper flow conditions at the appropriate seasons for support of the biotic community.
7. Sediment Continuity	Provides for appropriate erosion, transport and deposition processes.
8. Maintain Substrate and Structural Processes	Provides substrate and structural architecture to support diverse habitats and biotic communities.
9. Quality and Quantity of Sediments	Determines the physical character of the system relative to the primary variables: sediment yield and character.
10. Support Biological Communities and Processes	Provides diverse assemblages of native species.
11. Provide Necessary Habitats	Produces and sustains habitats to support vigorous aquatic and riparian biotic communities.
12. Maintain Trophic Structures and Processes	Promotes growth and reproduction of biotic communities across trophic levels.
13. Maintain Water and Soil Quality	Promotes favorable conditions for riparian communities that trap, retain and remove particulate and dissolved constituents from surface and overland flow.
14. Maintain Chemical Processes and Nutrient Cycles	Provides for complex reactions to maintain equilibrium and supply required elements to biota.
15. Maintain Landscape Pathways	Maintains connectivity to allow for biotic and abiotic energy process pathways.

The functions characterized by Fischenich (2006) are ordered into a hierarchy of functions, where the relative significance of each function is inferred by assessing the interrelations among functions. Functions that affect the greatest number of other functions are ranked highest, while functions that have the least effect on other functions are ranked lower (Table 4.2). For example, the General Hydrodynamic Balance function (1), which describes a system's flow characteristics, supports directly or indirectly all other functions listed in the Framework, such as sediment transport, energy, biotic and chemical functions. In contrast, the Provide Necessary Habitats function (15) directly affects three other functions, which are all related to the biological systems that are supported by streams.

## Chapter 4: The Stream Functions Pyramid

**TABLE 4.2** RANKINGS OF FUNCTIONS PROPOSED BY FISCHENICH (2006)

FUNCTION	FUNCTIONS DIRECTLY AFFECTED	FUNCTIONS INDIRECTLY AFFECTED
1. General Hydrodynamic Balance	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14, 15	13
2. Maintain Stream Evolution Processes	1, 3, 4, 5, 6, 7, 8, 10, 11, 12, 14, 15	9, 13
3. Surface Water Storage Processes	1, 4, 6, 10, 11, 12, 14, 15	2, 5, 7, 8, 9, 13
4. Sediment Continuity	3, 5, 6, 7, 8, 9, 11, 15	1, 13, 14
5. Provide for Riparian Succession	1, 2, 3, 4, 6, 12, 14, 15	9, 13
6. Energy Management Processes	1, 2, 3, 4, 5, 7, 8, 15	--
7. Maintain Substrate and Structural Processes	1, 2, 4, 6, 7, 10, 15	5, 9, 11, 13
8. Quality and Quantity of Sediments	2, 4, 5, 6, 7, 10, 15	1, 9, 11, 14
9. Support Biological Communities and Processes	5, 11, 13, 14, 15	1, 2, 3, 7, 8, 10, 12
10. Maintain Surface/Subsurface Water Connections and Processes	1, 5, 11, 15	3, 9, 12, 13
11. Maintain Water and Soil Quality	8, 9, 13, 14	5
12. Maintain Landscape Pathways	9, 13, 14, 15	6
13. Maintain Trophic Structures and Processes	9, 11, 14	8
14. Maintain Chemical Processes and Nutrient Cycles	8, 9, 13	6
15. Provide Necessary Habitats	9, 12, 13	–

Fischenich (2006) notes that efforts to restore streams are often ineffective because they fail to address the underlying processes that create and maintain the biological functions. The purpose of this hierarchy is to indicate the complex set of linkages that exists between functions of stream and riparian systems and to indicate which functions are most critical and interrelated to the restoration of stream and riparian functions.

Fischenich (2006) found that the most critical functions include those that address hydrodynamic processes (1, 3, 6), sediment transport processes (4, 7), stream stability (2) and riparian buffer restoration (5, 11). By addressing these fundamental functions and processes, a restored stream and riparian system are capable of supporting more dependent functions that typically require time to establish, such as diverse biological communities (9), chemical and nutrient processes (14), diverse habitats (15) and improved water and soil quality (11).

### 4.2 » THE STREAM FUNCTIONS PYRAMID

The Stream Functions Pyramid builds on the USACE work by placing stream functions in a hierarchy. However, the Pyramid uses parameters and measurement methods that are more often used in stream restoration approaches and assessment methodologies. It also provides a clear illustration of how physical functions support chemical and biological functions. This helps scientists, engineers and managers ensure that they are not only addressing the functions they are directly concerned about, but also the supporting functions that are required to achieve success.

The Stream Functions Pyramid Framework consists of four components that increase in detail. First, the broad-level view shows the five functional categories (Levels) with the underlying controlling variables of geology and climate. Second, function-based parameters are provided for each functional category. Third, measurement methods are provided for each function-based parameter. And fourth, where possible, performance standards are provided for the measurement methods. These terms can easily be confused with broader definitions of parameter, metric, tool and others. To help avoid confusion, definitions for these terms along with the criteria used to select function-based parameters, measurement methods and performance standards are provided below. See Appendix A for the entire Stream Functions Pyramid Framework. Also reference the Stream Functions Pyramid page at [www.stream-mechanics.com](http://www.stream-mechanics.com) for updates and examples of how the Pyramid is being used.

***The Stream Functions Pyramid Framework consists of four components that increase in detail.***

Typically, the Pyramid is applied at a reach scale even though some of the functions occur at a watershed scale, e.g., hydrology functions. Applications are discussed in detail in Chapter 11, including examples of how the Pyramid can be used in reach-scale function-based assessments and watershed management plans. However, even when used in watershed management plans, many of the measurement methods described below are conducted at a reach scale. The reach scale information can then be used in the broader context of watershed health, i.e., providing reaches that are functionally impaired or healthy, and as an aid in identifying potential restoration sites.

### 4.3 » STREAM FUNCTIONS PYRAMID: BROAD-LEVEL VIEW

The broad-level view is shown in Figure 4.1. The functional categories have been

modified from Fischenich (2006) to more closely match functions with parameters that are commonly used in the fields of hydrology, hydraulics, geomorphology, physicochemistry (called physicochemical on the Pyramid) and biology. The purpose of the broad-level Pyramid view is to show that the primary direction of cause-and-effect relationships flows from the bottom of the Pyramid to the top. In other words, functions higher on the Pyramid are more dependent on lower-level functions. This does not mean that cause-and-effect relationships can't or don't flow from higher levels to lower levels. The intention of the Pyramid is to show the dominant flow of cause-and-effect relationships. A dashed line is used to separate the functional categories to illustrate that the transition between categories is not a "hard" boundary. Cause-and-effect relationships can flow in both directions. For example, everything in the Pyramid is ultimately controlled by geology and the region's climate. If climate changes or there is a major geologic event, e.g., volcanic eruption, changes will occur throughout the Pyramid. Within the Pyramid, Hydrology and Hydraulic functions support Geomorphology functions like sediment transport, i.e., without water being contributed from the watershed and creating flow dynamics in the channel, sediment transport would not occur. Of course, channel form (geomorphology) does affect hydraulics through channel slope, sediment supply and boundary conditions. This is a downward example of cause and effect, but it is not as dominant as the requirement for water to be in the channel. Wohl (2004) alludes to these cause-and-effect relationships by stating, "We cannot save trout without saving their river and floodplain habitats. We cannot save river and floodplain habitats — and the plants and insects of the trout's food web — if we do not also maintain the processes controlling water and sediment entering the river corridor from the surrounding hillslopes and uplands." This concept exemplifies how the underlying physical functions support the biological functions.

This may seem obvious; however, many assessment methodologies address biological indicators without addressing the underlying controls provided by geomorphology, hydraulics and hydrology (Somerville, 2010). This concept also helps the practitioner match the project goal with the corresponding stream functions to avoid problems where practitioners design ineffective projects because they ignore the underlying hydrology, hydraulic and geomorphic functions (Fischenich, 2006).

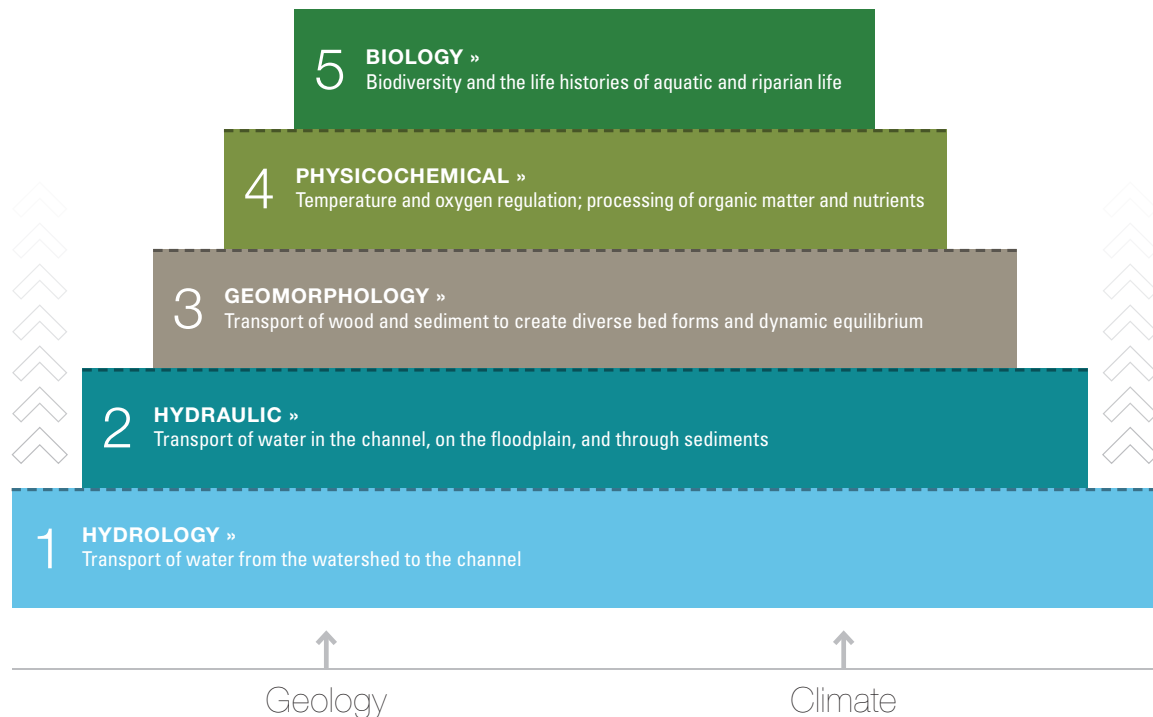
### Function Descriptions by Level

Function-based parameters and measurement methods are not shown on the broad-level Pyramid. Rather, a statement is provided to define the overall function of a given

***The intention of the Pyramid is to show the dominant flow of cause-and-effect relationships. A dashed line is used to separate the functional categories to illustrate that the transition between categories is not a "hard" boundary.***

## Chapter 4: The Stream Functions Pyramid

**FIGURE 4.1** STREAM FUNCTIONS PYRAMID — OVERVIEW  
(See Appendix A for a full-size version.)



category. This information is based on Fischenich (2006), Somerville (2010), industry standards and professional experience. A description is provided below for each functional category. These statements are used to help select function-based parameters in the next Pyramid view.

### Level 1: Hydrology

Hydrology functions transport water from the watershed to the channel. Hydrology is placed at the bottom of the Pyramid because water contributed from the watershed strongly affects the higher-level functions. Very simply put, without surface water flow, there would not be channel formation and the subsequent aquatic ecosystem. This definition of hydrology is most common in the engineering community and although it is related to hydraulics, the calculations are made separately, e.g., the USACE hydrologic model HEC-HMS (Scharffenberg and Fleming, 2010) and the USACE hydraulic model HEC-RAS (Brunner, 2010). Physical and life scientists tend to merge hydraulics into hydrology. However, from a stream assessment and restoration perspective, there are advantages to having both categories. The Pyramid keeps these functions separate for two reasons: 1) When conducting assessments or implementing a stream restoration project, it is important to distinguish between watershed scale functions of water transport (Hydrology) and reach scale relationships that describe how water interacts with the channel

(Hydraulics); and 2) The opportunity for functional lift is very different between the two.

### Level 2: Hydraulics

Hydraulic functions transport water in the channel, on the floodplain and through sediments. Again, this is a broad statement — it defines how water behaves once it reaches a channel and how it interacts with the bed, banks, floodplain, hyporheic zone, etc. (Dingman, 2008). It is important to note that this function works in channels of all sizes, from valley bottom swales (ephemeral channels) to large rivers. It is also present in all forms of geology and climate zones (Knighton, 1998). The energy associated with moving water has the ability to do work, such as transporting sediment, which is a geomorphology function (Leopold et al., 1992). The Hydraulic functions are closely related to Geomorphology functions and many interrelationships exist between these two categories. For example, sinuosity (Level 3) affects channel slope, which in turn affects channel velocity (Level 2). However, the dominant cause-and-effect relationships involve Hydraulics supporting Geomorphology. At a basic level, water must be present in the channel before sediment can be moved, regardless of sinuosity and other measures of channel form. Hydraulic functions also affect many functions in Levels 4 and 5 because they determine the amount of force and power that is exerted by the water on aquatic habitats.

### Level 3: Geomorphology

The function of geomorphology, as defined here, is the transport of wood and sediment to create diverse bed forms and dynamic equilibrium. The relative importance or even presence of certain Geomorphology functions varies greatly with changes in geology and climate. For example, wood transport and storage is extremely important to channel stability in headwater mountain streams but not important in low-gradient, grassland streams. In addition, some streams are naturally unstable and are not in a state of dynamic equilibrium, e.g., glacial outwash plains and some alluvial fans. However, the Hydrology and Hydraulic functions come together with the Geomorphology functions to create a channel form that is appropriate for the underlying geology and climate of the region. From a stream assessment and restoration perspective, we are most interested in these functions as they relate to the creation of diverse bed forms and channel stability (dynamic equilibrium) that has a dramatic effect on Level 4 and 5 functions, which are often the ultimate desire of a restoration project.

### Level 4: Physicochemical

Physicochemical functions include temperature and oxygen regulation, and processing of organic matter and nutrients. These functions are generally more affected by the underlying functions than vice versa, even though some of these functions occur as soon as water is present in the channel, e.g., water temperature. However, the Physicochemical category was placed above Geomorphology because a restoration practitioner would typically address functions here (Level 3) in order to see improvements in Physicochemical functions. For example, fast riffles and deep pools (bed form diversity), along with

shade and a wide buffer help regulate stream temperature. It is true that some projects may only need to address water-quality stressors, e.g., a point-source discharge and animal waste inputs, rather than restore the underlying functions. However, even in these cases, an assessment should be made to ensure that the underlying, supporting functions are present so that the stream will naturally recover once the stressor is removed.

### Level 5: Biology

Biology is located at the top of the Pyramid because these functions are dependent on all the underlying functions. These functions include the biodiversity and the life histories of aquatic and riparian organisms. Biology functions can affect lower-level functions, e.g., beaver activities; however, as with the other levels, the dominant cause-and-effect relationship is upward. A healthy aquatic ecosystem must have sufficient water contributed from the watershed, the right levels of hydraulic forces, proper bed form diversity and channel stability, suitable temperature and oxygen regimes, and so on. The value of the Pyramid at this level is that it helps regulators, scientists and engineers to identify the underlying functions that must be present in order to achieve functional improvements in biology. This is currently not happening. As Somerville (2010) points out, many assessment methods omit these underlying functions.

## 4.4 » STREAM FUNCTIONS PYRAMID: FUNCTION-BASED PARAMETERS

Figure 4.2 shows a more detailed view of the Pyramid with examples of function-based parameters that can be used to quantify or describe the *functional statement* provided in the broad-level view. The term “function-based” is used to acknowledge that the parameter may be a “structural” type of parameter or an actual function. Structural

***The Stream Functions Pyramid uses the term function-based parameter to take the emphasis off of structural measures versus actual functions. Rather, function-based parameters are used individually or in combination to quantify or describe a particular aspect of the functional statement provided in the broad-level view.***

parameters describe a stream condition at a point in time, e.g., percent riffle and pool. A function parameter is expressed as a rate and directly relates to a stream process that helps create and maintain the character of the stream corridor (Allan, 1995). The Stream Functions Pyramid uses the term function-based parameter to take the emphasis off of structural measures versus actual functions. Rather, function-based parameters are used individually or in combination to quantify or describe a particular aspect of the functional statement provided in the broad-level view. For example, within the Hydrology category (Level 1), flood frequency is a function-based parameter that can be used to quantify the occurrence of a given discharge. It is not a function, but it does

provide critical information about the transport of water from the watershed to the channel, which is a function. Another example is bed form diversity, a function-based parameter in Geomorphology (Level 3). Bed form diversity is not a function, it is a structural measure. However, complex bed form diversity, e.g., gravel riffles with low embeddedness and slow-moving deep pools are an indication that sediment transport processes are working appropriately. Sediment transport is a function; however, it is much more difficult to measure than bed form diversity and may not be necessary for stream assessments that are focused on functionality. This does not mean that sediment transport should not be assessed for vertical stability or for a restoration design. In the end, stream assessments and designs may include a mix of structural measures and functions based on the complexity of the project and financial constraints. However, the combination of structural measures and functions can be considered function-based if they help describe or quantify a particular functional category, as expressed by the functional statement in Figure 4.1 (The Stream Functions Pyramid — Overview).

The function-based parameters shown on the Pyramid are fairly comprehensive and can be used in a wide range of settings. However, they should be considered as examples. Some parameters may be more important than others for a given region. In addition, some regions or unique projects within a region may need to add parameters. The criteria used to include function-based parameters within the Pyramid are provided below.

***The function-based parameters shown on the Pyramid are fairly comprehensive and can be used in a wide range of settings. However, they should be considered as examples.***

### Criteria for Selecting Function-Based Parameters

For all Pyramid Levels

- Quantifies or describes (typically quantitative, but can be qualitative) a portion of the functional statement. The functional statements are provided above in Function Descriptions by Level.
- Has at least one measurement method that can be assigned. A function-based parameter can typically be measured in multiple ways, hence, it is broader than a measurement method.
- Can be a structural measure or a function.
- May or may not be applicable to all climate zones, geologic settings and eco-regions.

For Levels 1 through 3

- Must be a parameter that a practitioner can calculate or measure and use for restoration design and/or stream assessments.
- For restoration projects, typically include parameters that can be manipulated by the practitioner to create functional lift.

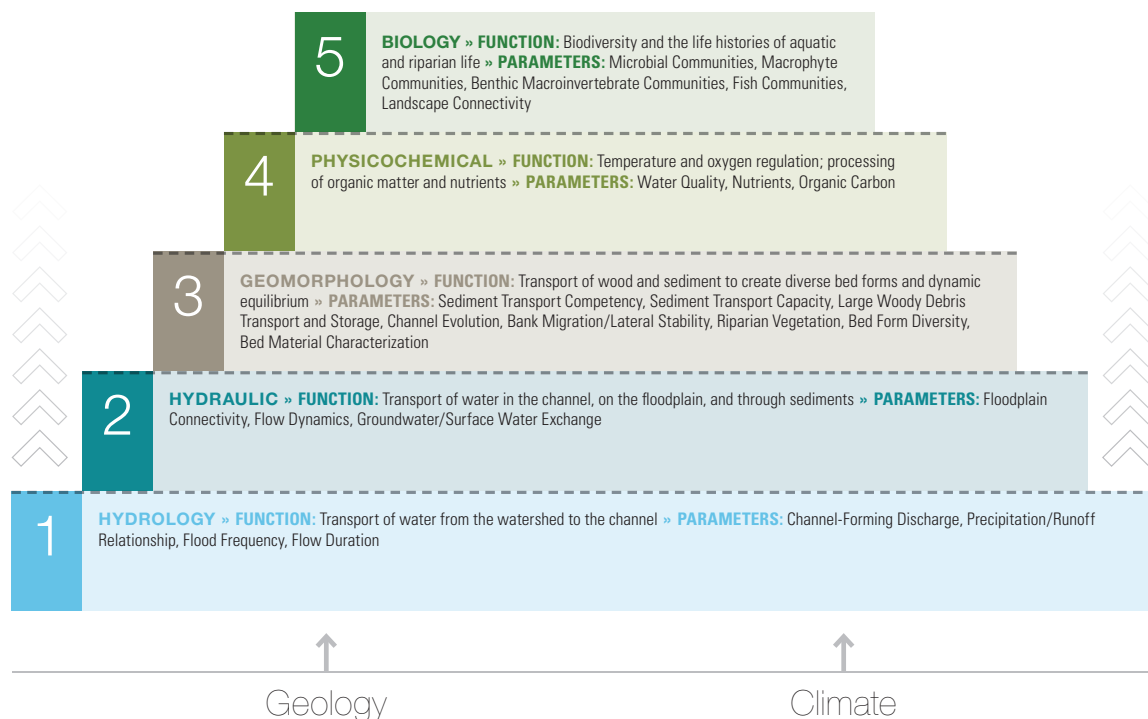
## Chapter 4: The Stream Functions Pyramid

For Levels 4 through 5

- If adding a parameter to these Levels, consider if there are supporting lower-level parameters.

Ultimately, the suite of parameters selected will be dependent on the project's goals and budget, since some parameters can be measured quickly and inexpensively and others require long-term monitoring and expensive equipment. These issues can be addressed by selecting the appropriate measurement method. Chapter 11 provides examples of how to select parameters and measurement methods for various applications.

**FIGURE 4.2** STREAM FUNCTIONS PYRAMID — FUNCTIONS & PARAMETERS  
(See Appendix A for full-size version.)



### 4.5 » STREAM FUNCTIONS PYRAMID: MEASUREMENT METHODS

Table 4.3 shows examples of measurement methods associated with each parameter. Measurement methods are more specific than function-based parameters by including specific calculations, simple spreadsheet models, sophisticated computer models, rapid field-based assessments, and in some cases, assessment methods that influence more than one function-based parameter. However, unlike the function-based parameter, there is typically a well-defined approach for conducting the measurement method.

Most parameters have at least two measurement methods and some, like the Geomor-

phology category, have several for each parameter. Some measurement methods are rapid-based approaches (requiring a small amount of time and effort to make the measurement) and others require intensive monitoring and analysis. This provides the user with a wide selection of methods to quantify, describe, and understand stream functions. General descriptions about the individual measurement methods are provided in Chapters 6-10. These chapters correspond to a functional category (Hydrology, Hydraulics, etc) with the measurement methods under the function-based parameter sections. This document does not provide a lot of detail about how the measurement methods relate to each other. As real-world applications are developed, these relationships should become clearer. In the meantime, users will find links and references to additional resources that can be used to develop a more comprehensive understanding of how multiple measurement methods can be used together to quantify a function-based parameter.

Ultimately, the suite of function-based parameters and measurement methods selected will depend on the purpose of the assessment and the funding level. Again, Chapter 11 provides examples of how to select parameters and measurement methods for various applications.

Table 4.3 provides a list of all the measurement methods associated with the function-based parameters that have been included in this document. These measurement methods should not be considered all-inclusive, but rather, represent examples that are frequently used in stream assessment and restoration. A more detailed table is provided in Appendix Ac that includes additional information about each measurement method, including: type, level of effort, level of complexity, and whether or not the measure is a direct versus indirect measurement of a function-based parameter. The criteria used to make these determinations are provided below and details for each parameter are provided in Chapters 6-10.

### Type of Measurement Method

As discussed above, the measurement methods include a wide range of tools, techniques, metrics and even assessment approaches. Appendix Ac identifies each type of measurement method, using the following criteria/definitions:

- Tool: Includes spreadsheet and computer models, typically with predictive ability. Tools are more automated than a technique.
- Technique: Techniques are empirical equations, statistical approaches and field survey techniques/methods. Techniques are not part of a larger computer model/tool, e.g., HEC-RAS, which is a tool.

***Measurement methods are more specific than function-based parameters by including specific calculations, simple spreadsheet models, sophisticated computer models, rapid field-based assessments, and in some cases, assessment methods that influence more than one function-based parameter.***

## Chapter 4: The Stream Functions Pyramid

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- **Metric:** A metric or parameter, which is more specific than a function-based parameter. It has a well-defined method for being measured. For example, flow dynamics is a function-based parameter and velocity is a measurement method of the metric type. This is a subtle, but important difference.
- **Assessment Approach:** Includes established assessment approaches, e.g., rapid bioassessment protocol. It often assesses more than the function-based parameter shown in the Pyramid, meaning that the Pyramid is only referring to a portion of the assessment methodology.

### Level of Effort

Appendix Ac assigns a level of effort to each measurement method, including rapid, moderate and intensive. The overriding criteria is to determine how much effort is required to arrive at a final answer, so level of effort can include field and office/lab work. In general, rapid measurement methods require less than half a day in the field to assess a one-mile stream reach. Some rapid measurement methods use simple spreadsheets, maps or other office-based measurement methods that do not require field work. Other measurement methods, like regional curves, are simple to use if the curve has been developed, moderate if developing a watershed specific curve, and intensive for developing regional curves for a hydro-physiographic region. A moderate level of effort generally requires one day to one week of fieldwork for a one-mile stream assessment and another day or more to process and analyze the data. Some methods may not require field data, but still require time to collect existing data, e.g., from websites and databases. The results can be compared to existing performance standards and do not require monitoring over time, e.g., annual surveys to determine functionality. Intensive measurement methods require long-term (multi-year) monitoring efforts in order to develop trends that are often compared to reference conditions. The actual monitoring effort may be rapid, i.e., it takes less than half a day to assess one mile of stream; however, achieving results will take multiple measurements over time to develop a trend and is therefore intensive. The level of effort should not be confused with level of expertise, since some of the more qualitative and rapid measurement methods rely on professional judgment and, therefore, a high level of expertise.

### Level of Complexity

Appendix Ac assigns a level of complexity to each measurement method, including simple, moderate and complex. Simple methods can be assessed after minimal training, e.g., on-the-job training and workshops. Simple can also mean that the sample is relatively easy to collect and analyze without the need of sophisticated equipment. Simple methods do not require elaborate or lengthy steps or processes to acquire the data. Moderately complex measurement methods require more effort and expertise than simple methods. These measurement methods often require someone with formal training and some experience. They may also require several steps to collect and analyze the data or to make calculations and estimates. Complex measurement methods should be completed by professionals with sufficient academic training and professional experience. These methods often require complex field and/or office procedures or complex modeling and analysis.

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### Direct Versus Indirect

Appendix Ac also shows if the measurement method is a direct or indirect measure of the function-based parameter. Direct measurement methods often do not require additional interpretation about the function-based parameter; they directly measure or assess the parameter. Indirect measures may require additional interpretation or only provide a partial, or incomplete, understanding of the function-based parameter. Assessment approaches typically include the additional interpretation needed for translating indirect measures to function-based parameters. Direct measures provide a more straightforward answer about a function-based parameter, whereas an indirect measure is more of an estimate.

**TABLE 4.3** PARAMETERS AND MEASUREMENT METHODS

HYDROLOGY	
PARAMETER	MEASUREMENT METHOD
Channel-Forming Discharge	1. Regional Curves
Precipitation/Runoff Relationship	1. Rational Method 2. HEC-HMS 3. USGS Regional Regression Equations
Flood Frequency	1. Bulletin 17b
Flow Duration	1. Flow Duration Curve 2. Crest Gage 3. Monitoring Devices 4. Rapid Indicators
HYDRAULICS	
PARAMETER	MEASUREMENT METHOD
Floodplain Connectivity	1. Bank Height Ratio 2. Entrenchment Ratio 3. Stage Versus Discharge
Flow Dynamics	1. Stream Velocity 2. Shear Stress 3. Stream Power
Groundwater/Surface Water Exchange	1. Piezometers 2. Tracers 3. Seepage Meters
GEOMORPHOLOGY	
PARAMETER	MEASUREMENT METHOD
Sediment Transport Competency	1. Shear Stress Curve 2. Required Depth and Slope 3. Spreadsheets and Computer Models

**TABLE 4.3** PARAMETERS AND MEASUREMENT METHODS (CONT.)

<b>GEOMORPHOLOGY</b>	
<b>PARAMETER</b>	<b>MEASUREMENT METHOD</b>
Sediment Transport Capacity	<ol style="list-style-type: none"> <li>1. Computer Models</li> <li>2. FLOWSED and POWERSED</li> <li>3. BAGS</li> </ol>
Large Woody Debris Transport and Storage	<ol style="list-style-type: none"> <li>1. Wohl LWD Assessment</li> <li>2. Large Woody Debris Index</li> </ol>
Channel Evolution	<ol style="list-style-type: none"> <li>1. Simon Channel Evolution Model</li> <li>2. Rosgen Stream Type Succession Scenarios</li> </ol>
Bank Migration/Lateral Stability	<ol style="list-style-type: none"> <li>1. Meander Width Ratio</li> <li>2. BEHI / NBS</li> <li>3. Bank Pins</li> <li>4. Bank Profiles</li> <li>5. Cross-Sectional Surveys</li> <li>6. Bank Stability and Toe Erosion Model</li> </ol>
Riparian Vegetation	<ol style="list-style-type: none"> <li>1. Buffer Width</li> <li>2. Buffer Density</li> <li>3. Buffer Composition</li> <li>4. Buffer Age</li> <li>5. Buffer Growth</li> <li>6. Canopy Density</li> <li>7. Proper Functioning Condition (PFC)</li> <li>8. NRCS Visual Assessment Protocol</li> <li>9. Rapid Bioassessment Protocol</li> <li>10. Watershed Assessment of River Stability and Sediment Supply (WARSSS)</li> <li>11. USFWS Stream Assessment Ranking Protocol (SAR)</li> </ol>
Bed Form Diversity	<ol style="list-style-type: none"> <li>1. Percent Riffle and Pool</li> <li>2. Facet Slope</li> <li>3. Pool-to-Pool Spacing</li> <li>4. Depth Variability</li> </ol>
Bed Material Characterization	<ol style="list-style-type: none"> <li>1. Size Class Pebble Count Analyzer</li> <li>2. Riffle Stability Index (RSI)</li> </ol>

**TABLE 4.3** PARAMETERS AND MEASUREMENT METHODS (CONT.)

<b>PHYSICOCHEMICAL</b>	
<b>PARAMETER</b>	<b>MEASUREMENT METHOD</b>
Water Quality	<ol style="list-style-type: none"> <li>1. Temperature</li> <li>2. Dissolved Oxygen</li> <li>3. Conductivity</li> <li>4. pH</li> <li>5. Turbidity</li> </ol>
Nutrients	<ol style="list-style-type: none"> <li>1. Field test kits using reagents reactions</li> <li>2. Laboratory analysis</li> </ol>
Organic Carbon	<ol style="list-style-type: none"> <li>1. Laboratory analysis</li> </ol>
<b>BIOLOGY</b>	
<b>PARAMETER</b>	<b>MEASUREMENT METHOD</b>
Microbial Communities	<ol style="list-style-type: none"> <li>1. Taxonomic Methods</li> <li>2. Non-Taxonomic Methods</li> <li>3. Biological Indices</li> </ol>
Macrophyte Communities	<ol style="list-style-type: none"> <li>1. Taxonomic Methods</li> <li>2. Non-Taxonomic Methods</li> <li>3. Biological Indices</li> </ol>
Benthic Macroinvertebrate Communities	<ol style="list-style-type: none"> <li>1. Taxonomic Methods</li> <li>2. Non-Taxonomic Methods</li> <li>3. Biological Indices</li> </ol>
Fish Communities	<ol style="list-style-type: none"> <li>1. Taxonomic Methods</li> <li>2. Non-Taxonomic Methods</li> <li>3. Biological Indices</li> </ol>
Landscape Connectivity	<ol style="list-style-type: none"> <li>1. Spatial Analysis</li> <li>2. Species Tracking</li> <li>3. Habitat Models</li> </ol>

#### **4.6 » FUNCTION-BASED PARAMETERS AND MEASUREMENT METHOD: DESCRIPTIONS BY CATEGORY**

A more detailed description of the function-based parameters and measurement methods shown in Table 4.3 is provided below. These descriptions are stratified by functional category and discuss how the function-based parameters and measurement methods work together. In addition, information is provided about how the parameters and measurement methods relate to stream restoration.

##### **Level 1: Hydrology**

The function-based parameters shown on the Pyramid are used by practitioners to

determine how much water will reach the channel and how much water the channel should carry to maintain dynamic equilibrium. The parameters used to assess these functions include precipitation/runoff relationships, channel forming discharge, flood frequency and flow duration. Each parameter and its associated measurement method are discussed in detail in Chapter 6.

Hydrology parameters are typically independent parameters in a stream restoration project, meaning, for example, that a designer does not have the ability to influence or change the precipitation/runoff relationship or channel forming discharge. These parameters are simply quantified and then used as inputs for a more detailed hydraulic analysis. While this is common, it is not always the case. There are scenarios where a project may be able to “improve” the runoff relationship, such as by implementing stormwater best management practices. This can be a critical component of stream restoration projects in urban environments.

### Level 2: Hydraulic

Results from Level 1 are used as input parameters in Level 2 to quantify two broad-level parameters: floodplain connectivity and flow dynamics. Floodplain connectivity is measured by the bank height ratio, entrenchment ratio and stage-versus-discharge relationships (rating curves). These measurement methods are used to determine if the channel can accommodate the targeted volume of water consistent with design goals and/or management objectives. The bank height ratio is a common method used to assess floodplain connectivity by comparing the bankfull depth to the total depth of the channel. Ideally, channels should not carry more than the bankfull discharge. For streams in alluvial valleys, flood flows should be spread across the floodplain. The entrenchment ratio, which describes the width of the floodprone area in relation to the bankfull width, is used to further describe floodplain connectivity (Rosgen 2009). In addition, estimates of the stage-versus-discharge relationship can be measured or estimated to directly assess floodplain connectivity. Flow dynamics is assessed through measures of velocity, shear stress and stream power, which change with increasing stage and discharge. Groundwater/surface water exchange is also included because this is an important process that supports physicochemical and biological processes that will be described later (Knighton, 1998). A detailed description of each Hydraulic parameter and its measurement method is described in Chapter 7.

Like Hydrology, Hydraulic parameters and measurement methods include structural measures and functions. Discharge and groundwater/surface water exchange are functions and can be quantified as rates-per-unit time, and they have a significant effect on the form of the channel and influence functions in Levels 3-5. Bank height and entrenchment ratios are structural measures, expressed as dimensionless ratios. However, they do relate to functions since the bank height ratio correlates to the stage that transports the bankfull discharge, and the entrenchment ratio describes the flow area inundated with the discharge at twice the stage of bankfull. In other words, they help to describe flow dynamics.

Stream restoration projects have the greatest effect on Level 2 and Level 3 functions

because projects occur at a reach scale and most of these functions can be modified as part of the design process. For example, the majority of stream restoration projects located in alluvial valleys and perennial streams include the goal of reconnecting the stream to a floodplain. Designers may accomplish this goal by raising the stream bed, lowering the floodplain or creating a bankfull bench. This approach often follows Rosgen's Priority Levels of restoring incised channels, as described in Chapter 3 (Rosgen 1997). To accomplish this goal, the designer calculates the bankfull discharge (Level 1) and then designs a cross section that will convey flows up to the bankfull discharge (Level 2). The degree of functional lift is determined by assessing the difference in pre- and post-restoration incision, which can easily be represented by the bank height ratio and entrenchment ratio. Re-establishing floodplain connectivity is one of the most important things that a restoration project can do at a reach scale because it affects so many of the upper-level functions.

### Level 3: Geomorphology

The parameters used to assess Geomorphology functions include sediment transport competency, sediment transport capacity, large woody debris transport and storage, channel evolution, lateral stability, riparian vegetation, bed form diversity and bed material characterization. There are many different measurement methods provided for these parameters — more than any other category. Of these parameters, sediment transport, lateral stability and components of the riparian vegetation are quantified as rates and are considered functional measures. Channel evolution is not measured as a rate, but does imply a change in form over time and relates to channel-forming processes. However, the amount of time is not quantified. Bed form diversity is a structural measure, usually assessed as the percent of riffle and pool length per unit of channel length, depth variability and/or substrate distributions. Nevertheless, bed form diversity is an important structural measure that quantifies the effects of sediment transport and is much easier to assess. The transport of wood is also an important function in this category, although its degree of importance varies by stream type. For some stream types (Rosgen A and B), wood transport and storage is important for maintaining channel stability. For other stream types (Rosgen C and E) wood and organic matter transport and storage can be important for stability, but is more important in its role for supporting Level 4 and 5 functions. A detailed description of each parameter and measurement method is provided in Chapter 8.

Stream restoration designs often focus on Level 3 parameters. Like Level 2, a restoration project can affect these parameters at a reach scale, although the longer the reach the better with regard to functional lift. Restoration activities associated with Level 3 often include improving bed form diversity and reducing streambank erosion. Bed form diversity is often improved by designing the appropriate dimension, pattern and profile for the given valley type. Meandering perennial streams in alluvial valleys, for instance, create riffle-pool sequences. Large woody debris and in-stream rock and wood structures are used to further improve depth variability and channel stability and complexity. In addition, most stream restoration projects include planting vegetation on the streambanks and the riparian zone to provide bank stability and to support Level 4 and 5 functions.

### Level 4: Physicochemical

Physicochemical functions include physical and chemical processes that create baseline water chemistry, breakdown organic matter and transform nutrients. It could be argued that once water reaches the channel (Hydrology and Hydraulic functions) chemical and biological processes begin to occur. However, from a stream restoration perspective, these functions are affected (and can be improved) by the presence of water and its interaction with bed forms, structures like woody debris, and the riparian vegetation. For example, dissolved oxygen can be increased by lowering the temperature through a robust riparian buffer and by the presence of steep, rocky riffles. These parameters are addressed in the lower levels.

Physicochemical water quality assessments include the following parameters: nutrients, organic carbon, dissolved oxygen, temperature, pH, specific conductivity and turbidity. Nutrients and organic carbon can be assessed rapidly in the field with test kits, but are more often measured in a laboratory. Organic matter and nutrient processing are always measured as rates and significantly contribute to the character of the stream system; therefore, these parameters are direct measures of function. Dissolved oxygen, temperature, pH and conductivity are typically measured at a point in time rather than a rate over time and are considered a structural measure. However, with continuous monitoring, parameters such as temperature can be considered a function. For example, the rate of change in water temperature as air temperature changes is a functional measure of thermal regulation. A detailed description of each parameter and measurement method is provided in Chapter 9.

It is difficult for stream restoration projects to directly affect Physicochemical parameters because they are affected by so many variables. They are supported by the lower-level functions, but they are also sensitive to weather and climate change, inputs from the upstream watershed and adjacent land uses, and even Level 5 functions. The relationship to Level 5 is discussed in more detail below. A reach scale stream restoration project often has very little control over these factors. Therefore, if a primary goal of a restoration project is to improve these functions, project site selection is as important (if not more important) than the reach scale activities associated with Levels 1-3, but especially Levels 2 and 3. The ideal situation for a restoration project that seeks to restore Level 4 functions is to have a healthy upstream watershed and reach scale impairments that can be improved by restoration activities. In this case, once the reach scale restoration activities have been completed, the project can benefit from a healthy watershed and not be limited by poor water quality. Common Level 2 and 3 restoration activities that support Level 4 functions include floodplain connectivity, bed form diversity, lateral stability, overhanging vegetation and a wide riparian buffer. This does not mean that Level 4 functions cannot be achieved in the future if the upstream health of the watershed improves. Watershed management plans are important tools that can combine reach scale restoration with preservation, stormwater BMP's, and other forms of water quality improvements to restore watersheds beyond individual stream reaches.

### Level 5: Biology

Biology functions describe the processes that support the life histories of aquatic and riparian plants and animals. These life histories are dependent on all the lower-level functions, which is why Biology is at the top of the Pyramid. For instance, healthy fish populations cannot exist without the proper flow duration, velocity distributions, bed forms, temperature, water chemistry, etc. that are created through the interactions of all five levels. Parameters that describe Biology functions include microbial communities, macrophytes, macroinvertebrate communities, fish communities and landscape pathways. A detailed description of each parameter and various measurement methods is provided in Chapter 10.

Like Level 4, most reach scale restoration activities that support Level 5 occur at Levels 2 and 3. If a project goal is to have a healthy native fish population, the stream reach must have the proper flow duration, flow dynamics, bed form diversity, lateral stability, vegetative cover, temperature regulation, dissolved oxygen, pH and conductivity. As discussed in Level 4, site selection is just as critical as the reach scale restoration efforts because the quality of water and sediments entering the project reach are critical to the health of the aquatic life.

### 4.7 » STREAM FUNCTIONS PYRAMID: PERFORMANCE STANDARDS

The final layer to the Framework includes performance standards associated with the measurement methods. The performance standards are divided into functional capacity types, including: Functioning, Functioning-at-Risk, and Not Functioning, which are similar to the categories used in the Proper Functioning Condition method (Prichard et al., 1998). These categories are defined below:

- **Functioning:** A Functioning score means that the measurement method is quantifying or describing one or more aspects of a function-based parameter in a way that **does support** a healthy aquatic ecosystem. A single functioning measurement method may not mean that the function-based parameter or overall category (e.g., Geomorphology) is functioning.
- **Functioning-at-Risk:** A Functioning-at-Risk score means that the measurement method is quantifying or describing one or more aspects of a function-based parameter in a way that **can support** a healthy aquatic ecosystem. In many cases, this indicates the function-based parameter is adjusting in response to changes in the reach or the watershed. The trend may be towards lower or higher function. A Functioning-at-Risk score implies that the aspect of the function-based parameter, described by the measurement method, is between Functioning and Not Functioning.
- **Not Functioning:** A Not Functioning score means that the measurement method is quantifying or describing one or more aspects of a function-based parameter in a way that **does not support** a healthy aquatic ecosystem. A single functioning measurement method may not mean that the function-based parameter or overall category (e.g., Geomorphology) is not functioning.

Most published performance standards are not described in terms of Functioning, Functioning-at-Risk or Not Functioning, so professional judgment was required to distribute the values. Performance standards that are available for each measurement method are provided in Chapters 6-10, and a summary of all the performance standards is provided in Appendix Ad. Many of the performance standard values, especially the dimensionless ratios, should be considered as examples that can be modified based on regional variations in reference condition.

***Many of the performance standard values, especially the dimensionless ratios, should be considered as examples that can be modified based on regional variations in reference condition.***

Some measurement methods do not include performance standards because they either do not exist or the measurement method is more associated with design than the actual performance of a function-based parameter. An example is the bankfull

discharge, a Level 1 measurement method for the channel-forming discharge parameter. The bankfull discharge is used in natural channel designs and geomorphic assessments and it drives many of the functions in Level 2 and 3, thereby supporting functions in Levels 4 and 5. It is a critically important measurement method; however, it is a result of the watershed characteristics and is unique to every stream. Therefore, it would be difficult to create a reliable performance standard for the bankfull discharge. There are other measurement methods, such as the bank height ratio used to measure floodplain connectivity, that are closely related to the bankfull discharge, can be much easier to measure, and have performance standards that can be used, irrespective of geology or climate.

The criteria used to select performance standards, in priority order, include:

The criteria used to select performance standards, in priority order, include:

- Provided in peer-reviewed journals;
- Provided in government documents;
- Provided in books or proceeding papers; and
- Professional judgment of the authors.

### **4.8 » STREAM FUNCTIONS PYRAMID AND RESTORATION ACTIVITIES**

The above discussion provided an overview of the Stream Functions Pyramid Framework, describing the functions by category and listing the function-based parameters and measurement methods that can be used to describe the functions. A description of performance standards was also provided. In the following section, an example is provided to illustrate how restoration activities can improve stream functions using the Pyramid as a guide. This will help explain how a stream restoration project can improve stream functions at a reach scale or as part of a larger watershed improvement effort. However, not all types of stream restoration or water quality improvement projects fit neatly into the Pyramid.

### Restoration of Channelized and Incised Channels

The restoration of channelized, incised streams is used as an example because it is a common approach in areas with well-established stream restoration and mitigation programs. Therefore, many stream mitigation programs appropriately discuss the importance of channel evolution and floodplain connectivity in their SOP (USACE Wilmington District et al., 2003; USACE Savannah District, 2004; USACE Norfolk District and VDEQ, 2007; and USACE Charleston District, 2010). Early stream mitigation programs were prevalent in the eastern United States, a region where channelized and incised streams are abundant. As mitigation programs continue to develop in the western regions, other types of impairments will increasingly be addressed by stream mitigation programs. However, incised channels are prevalent throughout the United States and will continue to be addressed by restoration and mitigation programs.

### Background

Channelization is an engineering practice with a long history in the United States, starting in the 19th century. From 1820 to 1970, more than 200,000 miles of streams and rivers were channelized to reduce flooding, provide drainage for agriculture, and improve navigation (Wohl, 2004). Locally, channelization increases drainage and reduces flooding by increasing stream gradient (typically by straightening the channel), thereby increasing stream power, which typically leads to further incision (Darby and Thornes, 1992; Hupp, 1992). The increased width, depth and cross-sectional area following channelization and incision reduce floodplain inundation, decreasing water and sediment storage on the floodplain (Kroes and Hupp, 2010; Pizzuto, 1987). Shields et al. (2010) compared physical, chemical and biological functions between an incised channel and non-incised channel with a similar mix of agriculture and forested land uses in northern Mississippi. The results of this study showed that the incised channel had turbidity and suspended solids levels that were two to three times higher than the non-incised channel. Total phosphorus, total Kjeldahl nitrogen, and chlorophyll a concentrations were significantly higher in the incised channel; however, nitrate was significantly higher in the non-incised channel. There were twice as many fish species with four times the amount of biomass in the non-incised stream. Correlation analysis showed that hydrologic perturbations were associated with the water quality degradation, leading the authors to recommend that ecological engineering should provide as much attention on mediating hydrologic perturbations and habitat quality as on pollutant loading. The research cited above did not use the Stream Functions Pyramid or the Fischenich (2006) framework; however, it did show that negative changes to lower-level (physical) functions, like Hydrology, Hydraulics and Geomorphology (Levels 1-3) had negative impacts on Physicochemical and Biology functions (Levels 4-5). The research also showed that restoration efforts should address these lower-level functions in order to show changes in the higher-level functions. Examples of how to use the Pyramid to link restoration activities to functional improvement is provided below.

**Linking Restoration Approach to Stream Functions Pyramid**

Typically, restoration credits are based on restoration and enhancement definitions that include changes to dimension, pattern and profile (e.g., USACE Wilmington District et al., 2003). The Stream Functions Pyramid is a tool that can help change the definitions of restoration and enhancement to focus on functional lift rather than changes to dimension, pattern and profile. Consider the example in Table 4.4 showing restoration activities that are used to restore incised, channelized streams. The restoration activities are shown in the first column. The second column links a function-based parameter from the Pyramid that is *directly* improved as part of the design and implementation phase of the restoration activity. The third column shows *indirect* improvements of other function-based

***The Stream Functions Pyramid is a tool that can help change the definitions of restoration and enhancement to focus on functional lift rather than changes to dimension, pattern and profile.***

parameters within the same function category (level) or higher. This implies that the restoration activity and direct manipulation of function-based parameters in Pyramid Levels 2 and 3 will *support* the improvement of certain function-based parameters in Levels 2 through 5. The word support is stressed, because these restoration activities are implemented at a reach scale and cannot change the condition of the upstream watershed. It is possible that poor upstream

conditions can prevent functional lift at the project reach, especially with Level 4 and 5 functions. Performance standards and subsequent monitoring are used to determine if the direct and indirect functional improvements are actually achieved.

**TABLE 4.4 LINK BETWEEN RESTORATION ACTIVITY AND FUNCTIONAL IMPROVEMENT**

RESTORATION ACTIVITY	FUNCTION-BASED PARAMETER that is <i>directly</i> changed during the design and implementation phases	OTHER FUNCTION-BASED PARAMETERS that are <i>indirectly</i> supported
Re-connect the stream to the floodplain by raising the channel or excavating the floodplain	Level 2 – Floodplain connectivity	Level 2 – Groundwater/surface water exchange, flow dynamics Level 3 – Sediment transport competency and capacity, bank migration/lateral stability Level 4 – Nutrients Level 5 – Microbial Communities, Macrophyte Communities, benthic macroinvertebrates, fish communities

**TABLE 4.4** LINK BETWEEN RESTORATION ACTIVITY AND FUNCTIONAL IMPROVEMENT (CONT.)

RESTORATION ACTIVITY	FUNCTION-BASED PARAMETER that is <i>directly</i> changed during the design and implementation phases	OTHER FUNCTION-BASED PARAMETERS that are <i>indirectly</i> supported
Re-meander the stream on the floodplain	Level 3 – Bed form diversity	Level 2 – flow dynamics, groundwater/surface water interaction Level 3 – Sediment transport competency and capacity, bank migration/lateral stability Level 4 – Water quality, Nutrients, Organic Carbon Level 5 – Microbial Communities, Macrophyte Communities, Benthic macroinvertebrates, fish communities
Add bed form structure and complexity, e.g. in-stream structures	Level 3 – Bed form diversity	Level 3 – Large woody debris transport and storage, bed material characterization Level 4 – Water quality, Nutrients, Organic Carbon Level 5 – Microbial Communities, Macrophyte Communities, Benthic macroinvertebrates, fish communities
Plant streambank and riparian vegetation	Level 3 – Riparian Vegetation	Level 3 – Bank migration/lateral stability Level 4 – Water quality, Nutrients, Organic Carbon Level 5 – Microbial Communities, Macrophyte Communities, Benthic macroinvertebrates, fish communities

**Example Projects that May Not Need the Pyramid**

The Stream Functions Pyramid Framework is more applicable to some types of projects and less to others. Stream restoration projects that involve physical manipulation to intermittent and perennial stream channels can benefit from the Stream Functions Pyramid. Stormwater Best Management Practices, regenerative design (Flores et al., 2011), Low Impact Development, and other practices that occur in ephemeral channels and uplands may benefit less from using the Pyramid. In addition, water quality solutions, like treat-

ing point source discharges and lime dosing, may not need the Pyramid to set project goals or develop assessment methods. However, even in these cases, it is always appropriate to ask, “What are the supporting functions that are required to meet the desired result?”

This is important because other problems may exist in addition to the obvious impairment.

For example, low pH is a commonly known problem in many West Virginia streams. The state agencies have created a dosing program to add lime to the stream and increase pH. Results have been positive; however, in a presentation at the 2011 Mid-Atlantic Stream Restoration Conference, Anderson (2011) showed variable improvements in trout populations. The reasons are not known; however, very little additional information (other than water chemistry) was collected. The goal of this effort was to restore the trout fishery. Therefore, an understanding of key functions in all five levels is needed in order to find a solution. Reducing pH may be the most important part of the solution, but other function-based parameters may also need to be addressed, e.g., improved bed form diversity, to recover trout populations.

Implementation of upland stormwater BMPs probably does not need the Pyramid. The goals of these projects are typically to reduce flow energy, reduce nutrients and remove other inorganic and organic compounds. These projects would rely more on conventional approaches to stormwater treatment.

### 4.9 » APPLICATION OF THE STREAM FUNCTIONS PYRAMID FRAMEWORK

The Stream Functions Pyramid is a conceptual model, a broad-level view showing the supporting relationships between functions. It also provides *examples* of function-based parameters, measurement methods and performance standards. Together they create the Stream Functions Pyramid Framework. It is not an all-inclusive framework and other parameters, measurement methods and performance standards can be added. The Pyramid framework is more of a thought process than a set of guidelines, and it is definitely not a cookbook. As such, it can be challenging to figure out how to start applying the Pyramid or how to “enter” the Pyramid. This section provides general explanations and examples about how to think about and apply the Pyramid as it relates to goal setting, function-based assessments and developing Standard Operating Procedures (SOPs). Refer to Chapter 11 for more detailed information about how the Pyramid can be applied.

#### Setting Project Goals and Objectives

Fischenich (2006) reports that a common goal of stream restoration is to restore stream habitat. However, he points out that habitat has the least effect on the other functions and is affected by the most functions. The Stream Functions Pyramid can be used by practitioners to establish goals that are more specific than restoring habitat. It can also be used to identify and think through the underlying, supporting functions that would need to be addressed to achieve a desired result.

Restoring habitat as a goal is too broad. One could ask, “Habitat for whom?” Most of the planet provides habitat for something, so a goal like this does not communicate why the project is needed or what it hopes to accomplish. A better goal would be to restore

habitat for a specific species of concern, e.g., native, southern brook trout. Of course, this goal should come after some form of functional assessment has been completed to determine that brook trout habitat is in need of restoration and that the watershed can support brook trout if the reach is restored. The Pyramid framework can assist with this process by helping the restoration team think through the underlying functions that are needed to support brook trout. First, it must be acknowledged that restoring brook trout is a Level 5 function; it relates to the life history of an aquatic organism (brook trout). So the team would “enter” the Pyramid at Level 5. If they enter at Level 5, there must be supporting functions in Levels 1-4. Now the team must identify those functions and function-based parameters. Again, this is not a cookbook, and the Pyramid does not automatically prescribe the supporting functions. This is a thought process that requires qualified professionals to be able to identify the appropriate parameters. For example, the first question might be, “What are the Level 4 function-based parameters that are needed to support native brook trout?” The answer would include appropriate temperature and oxygen regulation, as trout need cool, highly oxygenated water. Water quality must also be sufficient to support native brook trout populations, which could be affected by lower-level functions at a reach scale, as well as the health of the upstream watershed. Using the temperature and oxygen regulation as an example to further explore how the Pyramid can be used, the team might ask, “How do we achieve the proper temperature and oxygen regulation? What are the supporting function-based parameters?” The answer is found in Level 3.

Geomorphology function-based parameters like bank migration/lateral stability, bed form diversity and riparian vegetation affect temperature and oxygen regulation. This is a critical understanding because these parameters can be manipulated as part of the design to change oxygen and temperature regulation. For example, the channel form can be changed to create riffles and deep pools, banks can be stabilized and the riparian corridor can be planted. The level 4 parameter of oxygen and temperature regulation cannot be directly manipulated; rather, changes at level 3 are made to affect changes at level 4.

The thought process continues. The team can now ask, “What Hydraulic (Level 2) function-based parameters are needed to support bank migration/lateral stability, bed form diversity and riparian vegetation?” In this case, all of the Level 2 function-based parameters (floodplain connectivity, flow dynamics and groundwater/surface water exchange) are important to support the identified Level 3 functions, as well as Level 4 functions. Floodplain connectivity minimizes the amount of energy and force within the channel banks by dissipating flood energy on a floodplain or floodprone area. However, the appropriate amount of energy is maintained in the channel to support the creation of appropriate bed forms, e.g., riffles and pools. Floodplain connectivity also affects flow dynamics and groundwater/surface water interaction, which helps create healthy hyporheic zones that can regulate water temperature and support macroinvertebrate populations, among other benefits. Floodplain connectivity is also a function-based parameter that can be directly modified by a restoration team and is often considered the most important restoration activity because it supports Levels 2-5 functions.

Finally, the team can ask, “What Level 1 function-based parameters are needed to support the higher-level function-based parameters listed above?” These function-based parameters support functions from Level 1 through Level 5. Level 1 function-based parameters, including channel-forming discharge, precipitation/runoff and flow duration, are important to restoring native brook trout. The channel-forming discharge is used to determine how large the channel should be and is directly used to determine floodplain connectivity. Runoff is a watershed calculation and may or may not be modified based on the size of the watershed, property control and condition. Flow duration is typically determined by watershed conditions, but can be moderately improved by some restoration activities. It is important to evaluate these Level 1 parameters to make sure that the Hydrology can support the project goals. And of course, if the underlying geology or climate regime does not support brook trout, the project should not be attempted.

This is a simple example of how the Pyramid can be used as a process for developing and thinking through reach scale project goals. Other function-based parameters could be identified, but questions about the supporting functions would be the same. And there are certainly many other goals that could be considered. For example, improving water quality is another common goal. Like habitat, this goal could be improved by being more specific. What water quality issues are being addressed (temperature and oxygen, nutrients, conductivity, pH, etc.)? The answer to this question will help the restoration team identify the supporting functions required to make this improvement and to determine if restoration activities that change function-based parameters are needed; or the team can determine if things outside of the Pyramid should be addressed, e.g., a treatment plant or lime dosing.

The last example discussed here relates to stream mitigation. Many stream mitigation SOPs (USACE Wilmington District et al., 2003; USACE Savannah District, 2004; USACE Norfolk District, 2007; USACE Charleston District, 2010) link restoration credits to changes in dimension, pattern and profile, based on the Rosgen (1996) definition of a stable channel. While this is an appropriate definition of channel stability, it does not explicitly relate to a stream function. This has resulted in numerous projects where the stated goal is to improve dimension, pattern and profile with no thought given to why these changes are being made, i.e., what functional improvements are desired. At worst, this has resulted in projects that have completely reconstructed channels that did not need reconstruction. At best, it resulted in projects where the improvements were misunderstood, e.g., the achievable goal was to reduce sediment supply from eroding stream-banks, but assumptions were made that it should improve macroinvertebrates. If stream mitigation programs changed the definition to the restoration of function-based parameters identified on the Pyramid, then it could better clarify why the project was being completed. In addition, the mitigation program could then require the restoration team to identify the supporting function-based parameters and what restoration activities will be used to achieve the goal.

### Developing Function-Based Stream Assessment Methods

The Stream Functions Pyramid Framework can be used as an aid to develop function-based assessments and to select or evaluate existing assessments. It can also be used as a way to organize watershed assessment plans. The term function-based is used instead of functional because the Pyramid includes a combination of functions and structural measures. However, this combination is considered function-based because the parameters and measurement methods are used to quantify or qualitatively describe the overall functional statement for a given Level. A detailed description of how the Pyramid Framework can be applied to function-based assessments, including developing, reviewing and organizing watershed management plans, is provided in Chapter 11. A general overview and example is provided below.

Stream assessments can be completed for a wide range of reasons, including but not limited to: fisheries management; threatened or endangered species recovery plans; drinking water source assessment; watershed/land use planning; compliance monitoring for State or Federal permits; documenting water quality trends (Somerville and Pruitt, 2004); before and after comparisons of stream restoration projects; and to determine the restoration potential for a degraded stream reach. Restoration potential is the highest level of restoration that can be achieved given the results of the function-based assessment, health of the upstream watershed and the project constraints.

Somerville (2010) found that the eight most commonly assessed parameters for regulatory and non-regulatory programs were: discharge, channel habitat units (bed forms), sinuosity, substrate particle size, bank stability and dominant bank material, riparian canopy cover, water temperature, and benthic macroinvertebrates. These parameters were often included in categories like physical, chemical and biological to meet the Clean Water Act categorization of functions or some form of modification, like habitat. In his study, hydrologic parameters were the least represented; even though studies like Fischenich (2006) and Shields et al. (2010) show that hydrologic parameters are critically important to supporting other functions.

Hughes et al. (2010) completed an evaluation of four qualitative indexes of physical habitat to see if they yielded similar results when applied to streams with varying disturbance and ecoregion. They also compared the results with independent assessments of vertebrate and invertebrate assemblage condition. The results showed that there were varying meanings of the term “habitat”; however, the different methods did yield similar results. The results were not as favorable when the physical habitat index scores were compared to biological index scores. This led the authors to conclude that there is more to

***The Pyramid Framework may help remedy this problem or at least improve predicative power by including those parameters that are known to support biological conditions. As Somerville (2010) illustrated, many of the current assessment methodologies do not include hydrologic parameters.***

learn about the factors that control biotic-assemblage structure across broad regional scales.

The Pyramid Framework may help remedy this problem or at least improve predicative power by including those parameters that are known to support biological conditions. As Somerville (2010) illustrated, many of the current assessment methodologies do not include hydrologic parameters. The Pyramid Framework takes this a step further by providing a structure for assessment developers to select biological parameters and then supporting parameters that are appropriate for their region. If the Pyramid Level 1-5 categories are used to organize the parameters, it will be easier to identify other supporting parameters that should be included.

In addition, since the Pyramid is a hierarchy, a framework is provided that can be used as a logical structure for creating functional assessment scores or indexes. For example, parameters lower in the Pyramid may be weighted differently than those higher in the Pyramid. For these applications, the assessments would likely have a method for summing values within a category to create an overall value, e.g., a Geomorphology score. Since measurement methods quantify a portion of a function-based parameter, and the function-based parameter describes the functional statement within a category, it is recommended that overall scores take place at the category level. There may be cases where the score could be made at the function-based parameter level; however, they should not be made at the measurement method level because a single measurement method rarely, if ever, fully describes the function-based parameter. Scoring based solely on an individual measurement method can lead to unintended consequences where the function-based parameter is not properly assessed, scored, or evaluated. For example, pool-to-pool spacing and pool depth variability are two measurement methods that quantify bed form diversity. Used together, they are appropriate indicators of the number of pools that are present in a study reach and the quality (depth) of those pools. However, if only one measurement method is used, the result is an inaccurate portrayal of bed form diversity. If pool depth alone is used, the result could be one deep pool out of a long stream length, e.g., one pool over a length of 2,000 feet. The score would show that bed form diversity is functioning when clearly it is not. Just using pool-to-pool spacing could yield a similar result. A reach could have the appropriate number of pools, but they may all be too shallow, perhaps from excessive sedimentation or an overly wide channel. Great care should be given to selecting measurement methods that fully describe the function-based parameter. And to avoid over emphasizing the measurement method, scoring should role up to the function-based parameter or category level.

Weighting will also apply to stream mitigation programs that ultimately need to link a score to debits and credits that relate to functional loss and lift, respectively. A step-wise approach for developing function-based assessments is provided in Chapter 11. However, weighting examples are not provided in this document. These examples will come from actual applications of the Framework and will be made available on the Stream Mechanics website ([www.stream-mechanics.com](http://www.stream-mechanics.com)).

### Creating SOPs for Stream Mitigation Programs

The Pyramid can be used by Interagency Review Teams (IRTs) to develop debit and credit determination methods and performance standards for stream mitigation projects. This was discussed in the text above regarding stream restoration; and Chapter 11 provides templates that show how the Pyramid Framework can be used to develop debits and credits. Appendix B also provides some case studies for a variety of debit and credit scenarios.

### Developing SOPs Beyond Stream Mitigation

The Stream Functions Pyramid can serve as an aid in creating SOPs for federal, state and local programs not associated with stream mitigation. These may include grant programs, impaired waters programs working on the development of Total Maximum Daily Loads (TMDLs), non-point source and stormwater management programs and others. Any program that deals with improving or preserving natural waterways can benefit from working through the thought process, questions and criteria that are outlined above.

## 4.10 » SUMMARY

The Stream Functions Pyramid is a simple, conceptual framework. It illustrates that stream functions should be addressed in a certain order while maintaining the concept that stream functions are interrelated. Many of the parameters support functions in their own level, upper levels and sometimes a lower level. It must be restated that the Pyramid was not developed to capture all the interrelationships between the parameters that are used to describe the functions. Fischenich (2006) is a better reference for showing specific interrelationships between functions.

The Pyramid can serve as a communication tool among the various disciplines that work in the fields of stream assessment, restoration and mitigation. There are very few individuals who are well versed in all five levels, so having a framework like the Pyramid makes it easier to communicate across disciplines and helps to ensure that future assessments do not make the same mistake illustrated by Fischenich (2006) and Somerville (2010), i.e., that most function-based assessments include habitat measures and rarely include hydrologic functions (split on the Pyramid into Hydrology and Hydraulic). This is critical because, as Fischenich (2006) and the Pyramid illustrate, these hydrologic functions must be working (at least to some level) in order to support Physicochemical and Biological functions. Existing assessments may be skewed towards Biological parameters because they are often prepared by biologists or ecologists who do not have a strong background in the hydrological sciences or geomorphology. Comparatively, there have been numerous “channel improvement” projects performed by hydraulic engineers that just deal with the Hydrology and Hydraulic functions and do not address Geomorphology, Physicochemical or Biology functions described by the Pyramid. This trend is changing and the Pyramid can be used as a guide to develop more comprehensive designs (and assessments) that address a wider range of stream corridor functions.

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# Chapter 11

## Application of the Stream Functions Pyramid

This chapter provides three different examples of how the Stream Functions Pyramid can be applied. These applications include creating function-based goals and objectives, developing stream assessment methods, and establishing stream mitigation debit and credit determination methods.

Goal setting is critical to the success of a project because it communicates why the project is being done and sets expectations on how success will be measured. The goal-setting section provides several examples of goals that will improve stream functions when achieved. The assessment and mitigation sections provide a broad overview of how the Pyramid can be applied. It does not provide a “cookbook” approach to developing a functional assessment methodology or stream mitigation Standard Operating Procedures (SOPs). Rather, the examples and templates provided below are intended to provide a broad-level framework. Scientists and managers may choose to create more specific or quantitative functional assessments and debit/credit determination methods based on the examples provided in this chapter.

### **11.1 » ADDING PARAMETERS, MEASUREMENTS AND PERFORMANCE STANDARDS**

The existing Stream Functions Pyramid Framework includes a wide range of function-based parameters that are applicable for a wide range of environmental settings. However, users may need to add a function-based parameter based on a unique project or assessment goal. This is most likely to occur at the Biology Level because not all forms of aquatic and riparian life are included, e.g., mussels and amphibians. To add a function-based parameter, users should follow the selection criteria outlined in Chapter 4.

### **11.2 » DEVELOPING GOALS AND OBJECTIVES**

Developing goals and objectives is important for projects of all sizes. Well-articulated goals and objectives establish a foundation for project success. Vague, too broad, or poorly articulated goals and objectives often lead to project failure (worst case) and misunderstandings at best. The terms goals and objectives are often used interchangeably; however, there is a difference. Goals are statements about why the project or effort is needed. They are general intentions and often cannot be validated. Objectives are more specific. They help explain how the project will be completed. They are tangible and can be validated, typically by the performance standard.

Even with this differentiation, it can be challenging to develop well-formulated goals and objectives. Part of this difficulty relates to the scale and type of effort that is being undertaken. For example, watershed management plans require goals and objectives at a broad scale, i.e., to cover a large watershed. Stream restoration projects require goals and

**Goals are statements about why the project or effort is needed. They are general intentions and often cannot be validated. Objectives are more specific. They help explain how the project will be completed. They are tangible and can be validated, typically by the performance standard.**

objectives that are typically formulated at a reach scale and after some type of assessment has been completed to determine the problem, i.e., what function(s) needs to be restored. This can be an iterative process as the project team tests the restoration needs against project and watershed constraints.

Regulatory and non-regulatory programs also have goals and objectives, but they may not be tied to a specific watershed or reach. For example, Trout Unlimited, a non-regulatory organization, has broad goals to improve the quality of trout streams, wherever trout streams exist. The Clean Water Act (FWPCA, 1972) has an overall goal for all waterways to be fishable and swimmable.

Section 303 of the CWA includes provisions to have all streams, and rivers support the designated uses identified in their water quality standards (FWPCA, 1972). No net loss of wetland resources is a goal of the Section 404 of the CWA program and the fundamental objective of compensatory mitigation in the regulatory program is to offset environmental losses resulting from unavoidable impacts [33.C.F.R. § 332.3(a)(1)/40 C.F.R. § 230.93(a)(1)].

Many existing stream SOPs associated with the CWA Section 404 program include references to restoring stream dimension, pattern and profile as a way to acquire restoration credits. This has resulted in many stream mitigation plans being created that state the goal of a project is to restore dimension, pattern, and profile, rather than stating goals that provide some type of functional lift to offset permitted losses and better align with the fundamental objective of the CWA Section 404 regulatory program.

The Stream Functions Pyramid can be used to help prepare better goals and objectives for watershed management plans, regulatory and non-regulatory programs, and stream restoration projects. Simply stated, the Pyramid can help link goals and objectives to stream functions. For example, the Pyramid can be used to help articulate goals that relate to the improvement or assessment of stream functions or even function-based parameters. The goal should relate to the primary function(s) of interest, e.g., life history of some type of aquatic life. This information is provided on the Pyramid Overview and the Pyramid Functions and Parameters. Objectives should help explain how the functional improvement will occur. Objectives can also be used to identify the supporting functions needed to meet the goal. The Pyramid Functions and Parameters, Measurement

Methods and Performance Standards are all helpful in formulating objectives. These figures and tables are provided in Appendix A. Other sources for developing stream restoration-related goals and objectives include the NRCS Stream Restoration Design Manual, Part 654, Chapter 2 (USDA NRCS 2007) and the USACE Technical Note, Ecosystem Restoration Objectives and Metrics (McKay et al., 2012).

Developing goals and objectives requires an understanding of how to “enter” the Pyramid, i.e. how to start using the Pyramid Framework. Examples for watershed management plans, regulatory/non-regulatory programs and project designs are provided below.

### Watershed Management Plans

Watershed management plans typically include two major components, an inventory of water resource problems, followed by options/recommendations for improvement. These improvement options may include preservation, restoration, stormwater best management practices (BMPs), Low Impact Development (LID), etc. A key to success is to link the appropriate improvement option to the appropriate impairment. This is an area where the Stream Functions Pyramid Framework can help articulate specific goals and objectives by answering the following questions:

1. Look at Pyramid figures in Appendix A. What types of functional losses have occurred in the watershed? Try to relate the losses to function-based parameters, e.g., channelization and loss of floodplain connectivity, and/or population declines to native fish species.
2. Can these functions be restored? This requires an understanding of the stream functions and the cause of the impairment, along with the potential for their improvement.
3. Look at Pyramid figures again. What supporting function-based parameters are needed to assess improvement to the impaired functions listed in number 1?
4. What types of restoration activities are needed to improve those function-based parameters? This could include stream preservation of healthy headwater streams and restoration of degraded stream channels. It could also include stormwater BMPs and LID. An experienced multi-disciplinary team will be required to link the improvement activity to the functional lift.

Answering these questions will allow the team to develop goals and objectives that relate to functional impairments and their potential improvements in the watershed. For example, depending on how the questions were answered, an example goal and associated objectives may include the following.

#### Goal:

Improve the health of a smallmouth bass fishery. (Note that this relates to Level 5 on the broad-level overview Pyramid.)

#### Objectives:

1. Reduce stream temperature and improve dissolved oxygen to concentrations required

- by smallmouth bass (Level 4).
2. Improve bed form diversity to meet smallmouth bass habitat requirements (Level 3).
  3. Provide floodplain connectivity to provide the flow dynamics needed for smallmouth bass (Level 2).
  4. Evaluate watershed runoff and flow duration to determine the suitability for supporting smallmouth bass (Level 1).

These objectives are specific function-based parameters that support the higher-level goal of restoring a smallmouth bass fishery. They are quantifiable, tangible and can be measured. In some cases, these parameters have measurement methods that include performance standards. The objectives provided above are just examples and could be changed or expanded for an actual watershed plan. In addition, a wide range of improvement options may be required to meet the watershed scale goals and objectives described above. These activities are discussed in item 4 of the Watershed Management Plans section above.

### Regulatory and Non-Regulatory Programs

The same approach provided above for watershed management plans can be used in regulatory and non-regulatory stream improvement programs. For example, non-regulatory programs, such as watershed coalitions and non-profit organizations, set programmatic goals and objectives. As with watershed management plans, these goals are typically established at Level 5 since they relate to some type of aquatic life impairment. An example would be Trout Unlimited with the goal to restore a fishery. The advantage of the Pyramid is that once the aquatic life of interest is identified, the supporting functions can be established through quantifiable objectives. This will help the organization focus its resources by addressing activities that specifically affect the critical functions.

The same holds true for regulatory programs like Sections 303 and 404 of the Clean Water Act (FWPCA, 1972). Under Section 303, states are required to have water quality standards that support designated uses for waterways. Streams that do not meet these requirements are placed on the 303(d) list. For pollutant-impaired waters, Total Maximum Daily Loads (TMDLs) must then be established to address the pollutant(s) causing the impairment. Nationwide, sediment is the second-ranked pollutant causing streams and rivers to be placed on the 303(d)(USEPA, 2012). The causes of impairment are often inferred from results of biological monitoring, i.e., sediment is often identified as a reason that macroinvertebrate populations are negatively impacted.

The Pyramid could be used in impaired waters programs to establish more specific targeted load reduction alternatives based on cause-and-effect relationships shown on the Pyramid. For example, an initial assessment may show that the macroinvertebrate populations have lower abundance and more tolerant taxa than the reference conditions for a given area. Next, the Stream Functions Pyramid can be used to identify all the supporting functions that are required to support a healthy macroinvertebrate community. Third, further assessments can be conducted to determine if those functions (using function-

based parameters and a measurement method appropriate for the study) are Functioning, Functioning-at-Risk or Not-Functioning. Finally, objectives could be established that focus on the improvements needed to change the Not-Functioning and Functioning-at-Risk parameters to Functioning. This would likely include more parameters than just sediment, but would yield a plan with much more detail and potential for success.

The Pyramid can also be used to improve goals and objectives related to Section 404 of the Clean Water Act and compensatory mitigation. As was discussed above, many mitigation providers relate restoration goals to changes in channel dimension, pattern and profile. Mitigation credits are often provided based on these, among other, changes (USACE Wilmington District et al., 2003; USACE Norfolk District and VDEQ, 2007; and USACE Charleston District, 2010). The Pyramid can help practitioners develop goals and objectives that relate directly to stream functions. Over the last few years, attention to stream mitigation requirements associated with stream impacts from coalmining activities in Appalachia has increased. Practitioners and the regulatory community have grappled with how to assess functional lift through compensatory mitigation, especially for projects that include onsite mitigation. The process starts with setting appropriate goals and objectives. An example of how the Pyramid can be used to provide goals and objectives for on-site stream mitigation associated with large scale landscape modifications, such as mining, is provided below.

### **Example Goals:**

1. Achieve replacement of aquatic functions (functions are defined in a function-based assessment) through onsite mitigation.
2. Use natural channel design techniques to re-establish a small headwater stream network after mining activities have ceased.

### **Example Objectives:**

1. Water quality (pH and conductivity) will have similar or more suitable ranges compared to the pre-disturbance condition.
2. Bed form diversity, defined by pool-to-pool spacing and depth variability, will be improved compared to the pre-disturbance condition and will be characterized as Functioning using the Stream Functions Pyramid.
3. A 50-foot-wide riparian buffer composed of native grasses and trees will be established.
4. The restored channel will include large woody debris that meets a Functioning level.
5. The restored channel will have streambank erosion rates that are less than or equal to the existing condition and meet a Functioning level.
6. Floodplain connectivity in the restored channel will meet a Functioning level. Note: floodplain connectivity in v-shaped and colluvial valleys is characterized by a flood-prone area that can be very small.
7. Post-restoration flow duration will match pre-disturbance flow duration.
8. Post-restoration aquatic IBI scores will match or exceed pre-disturbance values.

These goals and objectives are just examples and would be modified based on the function-based assessment and local knowledge of the site. The value of using specific objectives, like the ones above, is that developing performance standards becomes much easier. The performance standards simply quantify the objectives.

### Restoration Project Design Goals and Objectives

***Restoration projects generally occur at a reach scale and can have significant functional lift of Level 2 and 3 parameters. However, to achieve goals in Levels 4 and 5, a combination of reach scale restoration and adequate upstream watershed health are required. In other words, site selection becomes critically important to achieving Level 4 and 5 goals.***

The Stream Functions Pyramid Framework may be the most useful in developing design goals and objectives, which are developed once a restoration site has been selected and some form of functional or existing condition assessment has been completed. Using the Pyramid to assist with functional assessments is discussed in the next section. More information about developing goals and objectives associated with natural channel designs is provided below.

Developing design goals and objectives can be an iterative process. Typically, a broad goal is established early in the process, perhaps prior to the functional assessment. This goal could relate to a broad watershed goal, like restoring a smallmouth bass fishery as described above under Watershed Management Plans. After the assessment, other functional impairments may be identified that prohibit the restoration of a smallmouth bass fishery. These impairments may occur in the upstream watershed and cannot be addressed by the restoration project. In this case, the team would need to pick a different approach or establish new goals based on what can be achieved at the site (reach scale). Often the goal can be revised to improve function-based parameters in Levels 2 and 3, e.g., floodplain connectivity, bed form diversity, lateral stability and riparian vegetation. This will not directly restore a smallmouth bass fishery, but it can indirectly help smallmouth bass recovery by providing the channel form and habitats that they require.

This example illustrates the importance of setting project goals and objectives that are compatible with the health of the watershed. Restoration projects generally occur at a reach scale and can have significant functional lift of Level 2 and 3 parameters. However, to achieve goals in Levels 4 and 5, a combination of reach scale restoration and adequate upstream watershed health are required. In other words, site selection becomes critically important to achieving Level 4 and 5 goals.

### Common Mistakes and Ideas for Improvement

A common stream restoration goal is simply to improve aquatic habitat (Fischenich, 2006). This is a poorly stated goal because it does not tell the reader what organism the habitat is for. Habitat requirements for mussels are different than habitat for a trout. If a habitat goal is going to be used, the goal, at a minimum, should state what species the habitat is for, e.g., “The goal of this project is to restore a southeastern native brook trout fishery.” Now the reader knows why the project is proposed. Of course, the term “habitat” is still broad and could include many things. So an even better goal would be “To improve the abundance of native brook trout populations within the project reach.” This is a goal that can be evaluated, and the measure of success is very specific. Objectives associated with this goal would identify the lower-level function-based parameters that must be Functioning in order to increase the abundance of native brook trout. And since this is a Level 5 goal, a thorough assessment of the watershed must be completed to determine if the upstream conditions will support brook trout, even after reach scale restoration. If not, another project reach, perhaps farther upstream, will need to be selected.

Another common and poorly stated goal is to improve water quality. Like habitat, water quality is a very broad concept and means different things to different people. For example, practitioners in West Virginia will typically equate water quality to pH and conductivity because of their work with the coalmining industry. Practitioners working in the eastern US Coastal Plain region will typically think of water quality as a nutrient (e.g., nitrogen and phosphorus) issue. Practitioners in the eastern US Piedmont and Mountain regions may think of water quality as a sediment or turbidity problem. Practitioners in the Pacific Northwest often think of water quality as a temperature problem. There are many other examples across the country, depending on the primary causes of water quality impairment. The key is to be specific. Use the goal to clearly establish why water quality is being addressed: to improve pH, conductivity, nutrients, sediment or other physicochemical properties. And, as with all of the goals, the next step is to develop objectives that identify the supporting, lower-level function-based parameters that must be Functioning in order to meet the goal. This also provides an opportunity to determine if stream restoration is the appropriate solution, or if other techniques are required. For example, stream restoration may have a minimal influence on conductivity and pH.

### 11.3 » FUNCTION-BASED STREAM ASSESSMENTS

The Pyramid is a framework that can be used as an aid in developing and reviewing function-based stream assessments. Somerville (2010) showed that stream assessments are often completed for a variety of regulatory and non-regulatory reasons, and range from broad assessments of stream condition to specific regulatory requirements. Three uses of function-based stream assessments will be discussed below and include:

- Determining restoration potential and functional lift;
- Determining stream functions lost and gained as part of a compensatory mitigation project; and
- Locating potential stream restoration projects as part of a watershed management plan.

A function-based assessment may include parameters from the Pyramid that are functions themselves; parameters that are not functions but help to describe the function from that category, e.g., bank height ratio from the Geomorphology category to help explain flow dynamics and floodplain connectivity. Parameter selection will be determined by the purpose of the assessment, the funding level and the geographic region. For example, flow duration is more limiting in some regions (and for some restoration types) than it is in others. Simple parameters may be selected for rapid-based assessments, and more complex parameters (that are also functions) may be selected for more intensive studies.

Regardless of the reason for completing function-based stream assessments, the following steps should be completed when using the Pyramid as a guide.

1. Determine the purpose of the assessment.
2. Select parameters from the Pyramid and/or other sources of information about parameters that describe stream functions relevant to the study. Include supporting functions.
3. Determine the appropriate methods for measuring the parameters, e.g., rapid versus intensive, and simple versus complex. This selection will also be dependent on the budget and purpose of the assessment.
4. Determine if the measurement methods need to be adapted based on unique regional characteristics, e.g., karst topography or endangered species.
5. Review the performance standards that are associated with the measurement methods, and determine if they are appropriate based on local environmental conditions and the purpose of the assessment. If possible, update performance standards with information from local reference streams.
6. If deemed necessary by the purpose, develop a scoring method to determine the overall functionality score of the stream reach, i.e., Overall Functioning, Functioning-at-Risk or Not Functioning. Consider having an overall score per functional category as well, e.g., Geomorphology, to help show where functional problems may exist.
7. Establish the length of the assessment (monitoring) period.
8. Implement function-based stream assessment, evaluate its effectiveness in assessing stream functions, and adapt method as necessary.

A description for each of the three general uses for stream assessment methods is provided below, along with examples of parameters from the Pyramid that could be included for that assessment.

### **Determining Restoration Potential and Functional Lift**

The Stream Functions Pyramid Framework can be used to determine the restoration potential at a proposed project site. Restoration potential is the highest level of restoration or functional lift that can be achieved given the site constraints and health of the watershed. Once the restoration potential is known, specific design goals and objectives can be established, or original goals and objectives may need to be refined.

These assessments may include parameters from all five levels of the Pyramid that

quantify and describe the pre-restoration condition of the channel. Common Level 1 parameters include the precipitation/rainfall relationship, channel forming discharge and flood frequency. These parameters are used to quantify and describe the transport of water from the watershed to the channel, and they are needed in order to complete the Hydraulic and Geomorphology portions of the assessment. Common Level 2 parameters include both flow dynamics and floodplain connectivity, since these are critical for determining channel stability. Flow dynamics are typically assessed by measuring stream velocity, shear stress and stream power. Floodplain connectivity is most commonly assessed using the bank height ratio and entrenchment ratio. If the bankfull stage is unknown, stage-versus-discharge estimates using a hydraulic computer model can also be used to assess floodplain connectivity. However, to complete a proper hydraulic assessment to determine channel stability, field surveyed cross sections are required. A longitudinal profile is helpful for measuring bank height ratios along the reach. The profile can also be used for Level 3 assessment.

Level 3 parameters include sediment transport competency and capacity, channel evolution, streambank erosion rates, bed form diversity, large woody debris assessments, and riparian vegetation assessments. These parameters may be measured using rapid or more intensive approaches, based on the complexity of the project and funding level. However, the main purpose of the Level 3 assessment is to determine if the channel is vertically and laterally stable. Channel evolution assessments are used in combination with the above measures to estimate the future trend, i.e., whether the stream is evolving towards stability or instability. Of course, some stream types are naturally unstable; however, these streams should not be candidates for restoration. Common Level 4 parameters include basic water quality measures like pH, conductivity, temperature and dissolved oxygen. Assessments in the eastern US Coastal Plain region may also include nutrient assessments. Level 5 function-based parameters sometimes include macroinvertebrate and fish community assessments. Landscape connectivity is rarely used, but should be considered for providing watershed scale improvements.

The assessment results can then be used to determine the restoration potential. For example, the assessment may indicate that a stream reach is severely incised with extreme bank erosion, low bed form diversity, and no riparian vegetation. If this site is in a rural setting (low lateral constraints) with a healthy watershed, then the restoration potential is high because functional lift can likely be achieved through Level 5. However, if this same site is in an urban area or a setting with lateral constraints — like a road or

***Restoration potential is the highest level of restoration or functional lift that can be achieved given the site constraints and health of the watershed. Once the restoration potential is known, specific design goals and objectives can be established, or original goals and objectives may need to be refined.***

even cropland — that cannot be removed from production, then the restoration potential is lower because the functional lift may only occur in Levels 2 and 3.

Table 11.1 can be used to illustrate the baseline functions at the project site along with the proposed functional lift; the examples provided above are shown in the table. The values are arbitrary and not associated with a project. The purpose is simply to show how the function-based parameters, measurement methods and performance standards may be used as part of an assessment. The function-based parameters and measurement methods are selected based on the restoration potential, and the performance standards are used to quantify the functional lift.

### **Determining Stream Functions Lost and Gained as Part of a Compensatory Mitigation Project**

The 2008 Mitigation Rule recommends that some type of functional assessment be completed at the permitted impact site and the mitigation site. The purpose of the functional assessment is to determine the functional loss at the permitted impact site and the functional lift at the mitigation site. Functional lift is defined as the difference between the pre-restoration and post-restoration condition. This process is intended to result in replacement of aquatic resources, in this case, the stream ecosystem.

Developing a function-based assessment for this purpose would be very similar to the one used to determine restoration potential and functional lift (described above). One difference is that the assessment would need to be applied at the permitted impact site and the mitigation site. The level of assessment will vary at the impact site, as the level of impact varies from minor (e.g., a culvert replacement or utility crossing) to major (e.g. surface mining or new road construction). For example, if only a few parameters are being affected, then only a few parameters need to be included in the assessment. If all five levels are being affected, the assessment should include parameters from all five levels. For the mitigation sites, the assessment can be more consistent with, and will be similar to, what is described in the restoration potential and functional lift section above. These parameters would then be assessed as part of the monitoring phase, and the data used to determine if performance standards are being achieved.

### **Locating Potential Stream Restoration Projects Using a Watershed Management Plan**

Watershed management plans are becoming common among non-regulatory and regulatory programs. These plans are typically used to (1) identify the sources of stream and water quality impairments; (2) identify stream reaches and sub-watersheds that are relatively un-impacted, and (3) develop management plans to improve stream health and water quality. Federal programs that support watershed management plans include grants provided by Section 319 of the Clean Water Act ( FWPCA, 1972), Total Maximum Daily Loads (TMDL), 2008 Mitigation Rule, and others.

Function-based stream assessments fit well with watershed management plans. They are often used as the method for differentiating between impaired and unimpaired

TABLE 11.1 FUNCTIONAL LIFT DETERMINATION

LEVEL AND CATEGORY	PARAMETER	MEASUREMENT METHOD	PRE-RESTORATION CONDITION		POST-RESTORATION CONDITION	
			VALUE	RATING	VALUE	RATING
1 – Hydrology	Channel-Forming Discharge	Regional Curves	200 cfs	N/A	200 cfs	N/A
						Used as an input parameter for Level 2 and 3
2 – Hydraulics	Floodplain Connectivity	Bank Height Ratio	3.0	Not Functioning	1.0	Functioning
3 – Geomorphology	Bed Form diversity	Entrenchment Ratio	1.1	Not Functioning	3.0	Functioning
	Channel Evolution	Pool-to-pool spacing	> 7	Not Functioning	4 to 5	Functioning
Riparian Vegetation	Simon	Stage 2 to 3	Not Functioning	Stage 6	Functioning	
				Width is 12 meters with some human activity	Functioning-At-Risk	Width is > 18 meters and no human activity
4 – Physicochemical	Lateral Stability	BEHI/NBS	High/High	Not Functioning	Low/Low	Functioning
	Water quality	Temperature	Higher than upstream reference reach; does not meet species requirements	Not Functioning	Same as upstream reach and meets species requirements	Functioning
5 – Biology	Macroinvertebrate Communities	Virginia Stream Condition Index	7	Not Functioning	4	Functioning

stream reaches. To complete this task, these assessment methods are often implemented differently at the watershed scale and the reach scale. At the watershed scale, GIS, remote sensing and aerial photography are used to broadly assess parameters that would indicate stable, healthy streams versus unstable streams. These parameters from the Pyramid might include riparian vegetation, lateral stability and landscape pathways, all of which can be assessed with GIS and aerial photography. Some watersheds may be included in FEMA-regulated floodplains and contain Hydrology and Hydraulic characterizations that can be used to estimate floodplain connectivity and flow dynamics.

From this initial screening, on-the-ground, rapid-based assessments can be used to further determine channel stability, channel evolution, restoration potential, basic water chemistry and biological health. Rapid methods are needed so that long reaches of channel can be assessed in a relatively short period of time. The result is a map showing the location of impaired stream reaches, their proximity to other land uses, and a priority ranking for restoration. For example, an impaired stream downstream of a high quality sub-watershed, or an impaired reach between two stable reaches, would be high priorities because the functional lift would transcend the project reach length. Conversely, an impaired reach downstream of multiple point source discharges, or areas of rapid development, may receive a lower priority; therefore, other techniques like stormwater BMPs and Low Impact Development may be recommended instead. Once reaches are selected for a project, a more intensive assessment method to determine channel stability and restoration potential can be implemented.

Additional information about conducting watershed assessments can be found at <http://water.epa.gov/type/watersheds>. There is a wealth of information on this website, but one tool that may be particularly helpful for evaluating potential stream restoration sites is the Recovery Potential Project, a landscape screening tool for assessing the restorability of impaired waters.

### 11.4 » KEY PARAMETERS

The Stream Functions Pyramid includes over 30 parameters, but it is unlikely that a project would ever need to assess them all. However, there are core or key parameters that can be listed for a variety of common projects, such as restoring channelized streams in alluvial valleys back into meandering streams, restoring small headwater

***The Stream Functions Pyramid includes over 30 parameters, but it is unlikely that a project would ever need to assess them all.***

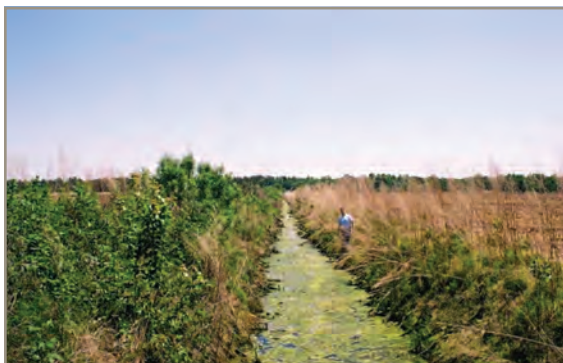
streams associated with mining, and improving salmonid fish habitat. Examples of key function-based parameters that should be evaluated before and after restoration are provided below. A variety of rapid and more intensive measurement methods are also provided.

#### **Restoring Channelized Streams in Alluvial Valleys to Meandering Streams**

Many projects in the eastern US attempt to restore streams that were enlarged and

deepened through channelization and incision. These projects occur in alluvial valleys, in both urban and rural settings, and with a variety of substrate compositions. The Rosgen Priority Levels are often used as an approach for restoring these streams. Figures 11.1a and 11.1b show before and after photos of a stream restoration project in the Coastal Plain of North Carolina. Figure 11.1a shows a channelized, incised stream that lacks bed form diversity due to low sinuosity and dredging. There is minimal riparian vegetation and nutrient runoff that can easily enter the stream from the adjacent cropland causing eutrophication. Figure 11.1b shows the same project site approximately one growing season after restoration construction was completed. The stream is shallower than the pre-restoration condition, creating enhanced floodplain connectivity and an elevated water table that supports the development of riparian wetlands. The meandering pattern carries both baseflow and bankfull flows effectively, providing longer retention times and opportunities for denitrification. The biggest driver of denitrification is the increased floodplain access by stormflows, water storage on the floodplain, shallow depth to the water table, and establishment of a woody riparian buffer over time.

**FIGURE 11.1A** PRE-RESTORATION



**FIGURE 11.1B** POST-RESTORATION



*Source: Reproduced with permission from Michael Baker Corporation*

This project, like most other restoration projects where channelized streams are converted back into meandering systems, highlights four key parameters that must be addressed to achieve project success. The key parameters include: floodplain connectivity, bed form diversity, lateral stability and riparian vegetation. These function-based parameters are shown below in Table 11.2. The second column provides measurement methods that can rapidly be assessed with minimal field measurements. The third column provides measurement methods that provide a more detailed assessment of the stream reach; however, they also require more effort. These more intensive measurement methods require more time in the field to collect data and, in some cases, require repeated monitor-

***The key parameters include: floodplain connectivity, bed form diversity, lateral stability and riparian vegetation.***

ing over several years, e.g., developing rating curves, establishing erosion rates and measuring vegetation growth.

If these four function-based parameters are addressed properly along with proper site selection, then there is a high probability of achieving success by improving the physical, chemical and biological integrity of the stream. This table should not be used to assume that parameters in other levels of the Pyramid are not important (these all come from Levels 2 and 3). Rather, the intent is to show that these parameters are generally the critical foundation to a healthy stream in most alluvial valleys.

**TABLE 11.2 KEY PARAMETERS FOR ASSESSING STREAM FUNCTIONS ASSOCIATED WITH RESTORING MEANDERING STREAMS**

PARAMETER	SIMPLE MEASUREMENT METHOD	MORE INTENSIVE MEASUREMENT METHOD
Floodplain Connectivity	Bank Height Ratio, Entrenchment Ratio,	Rating curves (discharge vs. stage)
Bed Form Diversity	Percent Riffle and Pool	Depth Variability
Lateral Stability	Streambank Erosion Rates using BANCS model	Measuring Streambank Erosion Rates with permanent cross sections
Riparian Vegetation	Riparian Buffer Width	Riparian Vegetation Density and Composition-Vegetation Plots

**Restoring Small Headwater Streams**

The key parameters listed in Table 11.2 would need to be modified slightly for assessing stream functions associated with the restoration of small headwater streams, such as those commonly found in the Appalachian Mountains. The restoration of high-gradient, very small intermittent and ephemeral channels as part of stream mitigation projects is common in coalmining regions. In other areas of the Appalachian Mountains, Trout Unlimited and resource agencies work to restore native brook trout populations in headwater perennial mountain streams that are typically located in colluvial and v-shaped valleys. Unlike the lateral meandering streams discussed above, these streams dissipate energy through vertical meandering of the stream bed, i.e., through a step-pool bed form sequence (Wohl, 2000). These streams do not have floodplains that are built by river meandering processes, but rather have floodprone areas that often extend the width of the bowl- or v-shaped valley. Figures 11.2a and 11.2b show an example of a small headwater mountain stream restoration project. Figure 11.2a shows the stream before restoration. The bed form is devoid of pools due to past cattle trampling and channel widening. Figure 11.2b shows the project after restoration construction. Boulder and wood structures were used to create a step-pool bed form, re-establishing the vertical meandering processes. A bowl-shaped floodprone area provides energy dissipation during flood

events, and a riparian buffer was established to provide lateral stability.

**FIGURE 11.2A PRE-RESTORATION**

*Cows are periodically allowed to graze.*



**FIGURE 11.2B POST-RESTORATION**



*Source: Reproduced with permission from Michael Baker Corporation*

The same key function-based parameters associated with a natural channel design and listed in Table 11.2 are included here in Table 11.3, with one minor exception. Since these channels do not have floodplains, the function-based parameter is changed to floodprone area connectivity, as it is still important for the channel to only carry the amount of water necessary for sediment transport requirements. Flood flows should be transported in the floodprone area. The simple measurement method for bed form diversity also changes, from percent riffle-pool to pool-to-pool spacing, which is a better measure of vertical meandering and has better performance standards (Leopold, 1994; Gregory et al., 1994; Whittaker, 1987; Chin, 1989, and Grant et al., 1990).

**TABLE 11.3 CRITICAL CATEGORIES FOR ASSESSING FUNCTIONS BEFORE AND AFTER STREAM RESTORATION PROJECTS**

PARAMETER	SIMPLE MEASUREMENT METHOD	MORE INTENSIVE MEASUREMENT METHOD
Floodplain Connectivity (Floodprone Area Connectivity)	Bank Height Ratio, Entrenchment Ratio,	Rating Curves (discharge vs. stage)
Bed Form Diversity	Pool-to-Pool Spacing	Depth Variability
Lateral Stability	Streambank Erosion Rates using BANCS Model	Measuring Streambank Erosion Rates with Permanent Cross Sections
Riparian Vegetation	Riparian Buffer Width	Riparian Vegetation Density and Composition-Vegetation Plots

## Chapter 11: Application of the Stream Functions Pyramid

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Table 11.3 is primarily for natural channel design, i.e., these parameters are key design parameters that can have a major effect on creating higher-order functional improvements. Additional function-based parameters may be selected when evaluating headwater mountain stream restoration projects for functional lift that is associated with mining activities. Table 11.4 provides an example of the minimum function-based parameters per functional category that are recommended. Measurement method examples are provided that would be appropriate for a mitigation project; some are rapid and others are more intensive.

**TABLE 11.4 POSSIBLE FUNCTION-BASED PARAMETERS AND MEASUREMENT METHODS FOR EVALUATING FUNCTIONAL LIFT IN SMALL, HIGH GRADIENT STREAMS**

FUNCTIONAL CATEGORY	FUNCTION-BASED PARAMETER	MEASUREMENT METHOD
Hydrology	Rainfall / Runoff	Rationale Method
Hydrology	Flow Duration	Rapid Indicators
Hydraulics	Floodplain (Floodprone area) Connectivity	Bank Height Ratio Entrenchment Ratio
Geomorphology	Large Woody Debris	Large Woody Debris Index
Geomorphology	Bed Form Diversity	Pool-to-Pool Spacing Depth Variability
Geomorphology	Lateral Stability	BEHI/NBS
Geomorphology	Riparian Vegetation	Buffer Width Buffer Composition Buffer Density
Physicochemical	Water Quality	pH Conductivity
Biological	Macroinvertebrate Communities	State Protocol, if available

There are exceptions to the key parameters listed above. It is likely that many small, headwater ephemeral stream channels in the mountain regions are the product of erosion and channel formation due to land clearing practices during post-European settlement. In some of these systems, forest regeneration has occurred over the decades, and the channel that formed is stable. However, from a functional standpoint, it would be better to have valley bottoms rather than channels that provide greater storage capacity for water, wood, and other forms of organic matter. Restoration would typically not be recommended in stable environments; however, small-channel and no-channel approaches for restoring disturbed systems are being investigated by various researchers and practitioners. Examples of natural channel design in small headwater channels can be reviewed at <https://louisville.edu/speed/civil/si>.

### Key Parameters for other Types of Restoration

The key parameters listed above are applicable to many full-scale restoration projects. However, some forms of restoration do not require aggressive changes to channel form, and different key parameters may be required for restoration success. Water removal impacts in the arid West are an example where the key parameters listed above would not apply. In these environments, the channel form may include floodplain connectivity, bed form diversity, laterally stability, and have riparian vegetation common for arid regions; however, historically perennial streams can become ephemeral due to excessive water withdrawals. In these cases, flow duration is the key parameter and the restoration activities may include policy/management changes rather than natural channel designs.

Other examples of restorations that may require minimal or no adjustments to channel form include removal of fish passage impediments and eliminating water quality impairments associated with point-source discharges and stormwater runoff. However, these key parameters listed above should still be assessed, or at least considered, before moving forward with other forms of restoration, especially for perennial streams in alluvial valleys. More likely, additional function-based parameters would be added to the list, rather than removing them.

## 11.5 » REVIEWING EXISTING STREAM ASSESSMENTS

Government agencies often want to evaluate existing stream assessment protocols before making the decision to develop a new one. Somerville and Pruitt (2004) and Somerville (2010) provide a good starting point for evaluating existing stream assessment protocols. New protocols continue to be developed, especially related to stream mitigation. The draft Regional Guidebook for High-gradient Ephemeral and Intermittent Headwater Streams, USACE (2010), is an example of a functional assessment methodology that has been developed in response to mitigation requirements in coalmining regions of West Virginia and Kentucky. Given the volume of existing assessment methodologies, it is important to have criteria for selecting an existing methodology or for making the decision to develop a new methodology. The following checklist may help with this decision.

### Checklist for Selecting Existing Stream Assessment Methodologies

1. Determine why a stream assessment is needed. What is the purpose?
2. Is the assessment needed to meet regulatory requirements?
3. Is the existing stream assessment protocol appropriate for your region? In other words, some protocols are developed for very specific environmental settings and conditions, e.g., high gradient or arid.
4. Has the existing stream assessment protocol been peer reviewed, validated, or otherwise assessed for accuracy and precision in relation to direct functional measures?
5. How much is already known about the functional impairments of the watershed? Some understanding of existing impairments is helpful when selecting an existing protocol because the impairments can be related to the function-based parameters from the Pyramid. Then these parameters can be compared to the parameters as-

sessed in the protocol. If there is a good match, then the existing protocol may be selected. Otherwise, other protocols should be reviewed and potentially new protocols may needed to be developed.

6. Are lower-level functional categories included, e.g., Hydrology, Hydraulics, and Geomorphology? Generally, existing protocols are weak in these categories. Review the protocol to ensure that the supporting/"driver" parameters are included.
7. Are the key parameters described in the above sections included? If not, is there a good reason?

### 11.6 » DEVELOPING DEBITS AND CREDITS

The development of stream debit and credit determination methods continues to evolve as USACE Districts implement the 2008 Mitigation Rule. The Rule does not provide a formula for developing debit or credits. It simply states that a description of the debits or credits will be provided, including the rationale used. In some regions, IRTs have incorporated credit determination methods into SOPs; however, in other areas, the credit determination method is left up to the mitigation provider. The Rule defines debits as a unit of measure that accounts for the functional loss at a permitted impact site. Some mitigation SOPs, like the Unified Stream Methodology (USACE Norfolk District and

***The Stream Functions Pyramid can also be used to separate restoration efforts that improve Level 2 and 3 functions, and those that restore through Level 5. As such, IRTs may choose to consider creating two levels of restoration: Restoration 1 and Restoration 2.***

VDEQ, 2007) and the Charleston, SC SOP (USACE Charleston District, 2010) provide debit calculations based on a stream condition assessment, similar to a function-based assessment. However, some of the techniques described in the Function-based Assessment section above could be used to better link the functions lost at a permitted impact site to the functions gained at a mitigation site.

Stream mitigation credits are units of measure that represent the accrual or attainment of stream functions at a compensatory mitigation site (33.C.F.R. § 332/40 C.F.R. § 230). The accrual or attainment of stream

function occurs through a variety of approaches, including restoration, enhancement, re-establishment and preservation. The Pyramid Framework can be used to help show the functional lift, especially with stream restoration approaches. Stream restoration is defined in the 2008 Mitigation Rule as the "manipulation of the physical, chemical and biological characteristics of a site with the goal of returning natural/historic functions to a former or degraded aquatic resource." Most stream mitigation SOPs cite this definition; however, functional lift is often tied to the Priority Levels of Restoration (Rosgen, 1997) and/or changes to stream dimension, pattern and profile (Somerville, 2010).

This has led to several problems, including: (1) incentivizing maximum channel manipulation to show changes in dimension, pattern and profile to receive the maximum amount of credits; (2) focusing the objectives and performance standards on dimension, pattern and profile changes instead of stream functions or function-based parameters, making the communication of functional lift difficult; and (3) removing evidence of functional lift from the evaluation of project success. This credit determination method has resulted in many projects being evaluated simply on visual observations of channel stability, in-stream structure integrity, and condition of the riparian buffer. The Stream Functions Pyramid, and the forms shown in the assessment section, can help articulate function-based goals, develop function-based assessments, and then develop credit determination methods based on the potential functional lift. Examples of how to do this are provided in the next section.

The Stream Functions Pyramid can also be used to separate restoration efforts that improve Level 2 and 3 functions, and those that restore through Level 5. As such, IRTs may choose to consider creating two levels of restoration: Restoration 1 and Restoration 2. Restoration 1 would restore functions through Level 5 and represent the highest level of restoration achievable. This would require reach-scale restoration and an upstream watershed that supports aquatic life identified in Level 5. It could also include watershed-scale restoration for small headwater systems. More details are provided below about credits; however, 1 credit per foot is proposed as the maximum number attainable, essentially representing 100% restoration. Restoration 2 is also defined as the restoration of reach-scale functions; however, the upstream watershed may not be suitable for supporting species of interest in Level 5. The restoration project may still be worthwhile (based on the function-based assessment); however, functions are only restored through Level 3.

Therefore, the maximum achievable credits for Restoration 2 would be less than for Restoration 1; perhaps the maximum is 0.8 credits per foot for the example. However, if a mitigation provider continued to work in the watershed and showed appropriate levels of functional improvement in Level 5, the IRT may want to allow the provider to request the additional 0.2 credits per foot to achieve the full 1.0 credit per foot. This would offer incentive for the mitigation providers to perform watershed-scale restoration.

One value in this restoration level approach is that it clearly identifies function-based parameters that a mitigation provider can control (Restoration 2) versus function-based parameters that are more dependent on upstream watershed condition (Restoration 1). For a Restoration 2 example, projects that restore meandering pattern to channelized

***One value in this restoration level approach is that it clearly identifies function-based parameters that a mitigation provider can control (Restoration 2) versus function-based parameters that are more dependent on upstream watershed condition (Restoration 1).***

streams would show functional improvement in the key parameters shown in Table 11.2 (floodplain connectivity, bed form diversity, lateral stability, riparian vegetation). The mitigation provider has a lot of control over the design and functionality of these parameters. This should improve communication between the provider and the IRT, making the development of performance standards much more specific and quantitative than many current approaches that simply deal with channel form (dimension, pattern and profile). However, further improvements in Levels 4 and 5 are dependent on upstream watershed conditions. To achieve Restoration 1 and receive full restoration credit, the upstream watershed condition combined with reach-scale restoration creates a Functioning ecosystem through Level 5. The mitigation provider does not have control of the upstream watershed condition; however, they do have control over how the project site is selected.

### Debit and Credit Templates Overview

The purpose of this section is to show how the Stream Functions Pyramid Framework can be used as an aid in developing stream debit and credit determination methods. Example debit and credit determination templates will be provided, along with examples and case scenarios to illustrate how the Pyramid Framework can be used — at least at a broad level. The main goal of this section is simply to illustrate how the Pyramid might be used to develop debits and credits. It is not intended to be a policy recommendation, but rather “food for thought”. It is a tool, not a rule; however, the approach does try to address requirements in the 2008 Mitigation Rule.

Example templates are provided below to aid IRTs in developing debits and credits. The templates are meant to provide IRTs with ideas on how they can create an SOP that utilizes the Stream Functions Pyramid to help show functional lift. They should be modified to fit local needs and conditions. The SOP template does not address credit release schedules, land protection measures, monitoring designs, service area delineation or other elements of a stream mitigation plan. Rather, the SOP templates focus on how to show appropriate compensation by matching the functions lost at the impact site to the functions gained at the mitigation site by comparing the difference between pre- and post-conditions. These conditions are assessed using the function-based parameters, measurement methods and performance standards from the Pyramid Framework.

Example applications of the template for several impact scenarios (debits) and mitigation scenarios (credits), representing a wide range of conditions from across the country, are provided in Appendix B. The debit scenarios include:

1. Culvert installations,
2. Channelization and bank hardening, and
3. Surface mining of high gradient streams.

The credit scenarios include:

1. Restoration of incised streams;
2. Restoration of stream flow for channels that have excessive water withdrawal;

3. Salmonid fish passage and habitat restoration; and
4. Restoration of high gradient, headwater streams.

### Debit and Credit Templates Structure

There are three sample debit and three sample credit templates provided below, along with a description of each. Template 1 for debits and credits shows the functional loss and lift, respectively. Template 2 provides a place where the user can write notes about the rationale used to complete Template 1. There is a Debit Template 2 and a Credit Template 2. Template 3 provides a method for calculating debits (Debit Template 3) and credits (Credit Template 3). A detailed description of each is provided below.

The *Debit Template 1: Functional Loss Determination* (Table 11.5) shows the Pyramid level number and category name. For each category (Hydrology, Hydraulics, etc.) the table shows the parameter selected from the Pyramid, the measurement method, the pre-disturbance condition and the post-disturbance condition. The key parameters are selected based on the type of impact and whether or not the impact is expected to affect the parameter. For example, if a culvert is going to be installed in a stream with a mature bottomland hardwood forest, the riparian vegetation parameter would be selected. This would show that the buffer is Functioning before the permitted impact and is Not Functioning after the impact. All the information needed to complete this table is provided in Chapters 5-9. A summary is provided in Appendix A.

The *Credit Template 1: Functional Lift Determination* (Table 11.6) is identical to the Debit Template 1 (Table 11.5) with two exceptions. The pre-disturbance condition and post-disturbance condition have been changed to pre-restoration condition and post-restoration condition. Parameters and measurement methods are selected to best represent the potential improvement in stream functions.

***The main goal of this section is simply to illustrate how the Pyramid might be used to develop debits and credits. It is not intended to be a policy recommendation, but rather “food for thought”. It is a tool, not a rule; however, the approach does try to address requirements in the 2008 Mitigation Rule.***

TABLE 11.5 DEBIT TEMPLATE 1: FUNCTIONAL LOSS DETERMINATION

LEVEL AND CATEGORY	PARAMETER	MEASUREMENT METHOD	PRE-DISTURBANCE CONDITION		PREDICTED POST-DISTURBANCE CONDITION	
			VALUE	RATING	VALUE	RATING
1 – Hydrology	Insert key parameter from the Pyramid. Refer to Chapters 5-9.	Choose the appropriate measurement method for the selected parameter.	Enter the actual value determined using the measurement method.	Enter Functioning, at-Risk or Not Functioning based on the performance standard value.	Enter the predicted or measured value determined using the measurement method.	Enter Functioning, at-Risk or Not Functioning based on the performance standard value.
			Example	Example	Example	Example
2 – Hydraulics	Example Floodplain Connectivity	Example Bank Height Ratio	1.0	Functioning	2.5	Not Functioning
		Entrenchment Ratio	3.0	Functioning	1.1	Not Functioning
3 – Geomorphology						
4 – Physicochemical						
5 – Biology						

TABLE 11.6 CREDIT TEMPLATE 1: FUNCTIONAL LIFT DETERMINATION

LEVEL AND CATEGORY	PARAMETER	MEASUREMENT METHOD	PRE-RESTORATION CONDITION		POST-RESTORATION CONDITION	
			VALUE	RATING	VALUE	RATING
1 – Hydrology	Insert key parameter from the Pyramid. Refer to Chapters 5-9.	Choose the appropriate measurement method for the selected parameter.	Enter the actual value determined using the measurement method.	Enter Functioning, Functioning-at-Risk or Not Functioning based on the performance standard value.	Enter the measured value determined using the measurement method.	Enter Functioning, Functioning-at-Risk or Not Functioning based on the performance standard value.
			Example	Example	Example	Example
2 – Hydraulics	Example Floodplain Connectivity	Example Bank Height Ratio Entrenchment Ratio	3.0	Not Functioning	1.0	Functioning
			1.1	Not Functioning	3.0	Functioning
3 – Geomorphology						
4 – Physicochemical						
5 – Biology						

The next tables (Table 11.7 and 11.8) are templates that can be used to provide supporting text about the above pre- and post-condition tables. On the debit side, the table is used to describe the pre-disturbance condition and the rationale for selecting the parameters and measurement methods. The rationale used to predict the post-impact condition should also be provided. The approach is similar on the credit side. For this template, a description of the pre- and post-restoration condition is provided, along with the rationale for selecting key parameters and measurement methods.

**TABLE 11.7 DEBIT TEMPLATE 2: PRE- AND POST-DISTURBANCE CONDITIONS AND RATIONALE**

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**Describe Pre-and Post-Disturbance Condition and Rationale for Selecting Parameters**

*Enter a short description of the pre- and post-disturbance condition for each functional category. Explain why the selected parameters and their measurement method were used. Also include the rationale for the expected outcome. An abbreviated example is provided below for a **permitted culvert installation**. The remainder of this example is provided in Appendix B.*

Hydrology: The watershed hydrology is stable and is not expected to change. Therefore, Hydrology parameters were not selected.

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Hydraulic: The existing channel is not incised and has access to a wide alluvial floodplain, i.e., there is floodplain connectivity. In this example, the culvert will likely cause channel incision downstream of the culvert, and bank height ratios are likely to increase, causing a Not Functioning score. The culvert will provide grade control for the upstream channel and the bank height ratio may decrease because of aggradation.

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Geomorphology: see Appendix B, Table B2a

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Physicochemical: see Appendix B, Table B2a

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Biological: see Appendix B, Table B2a

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**TABLE 11.8 CREDIT TEMPLATE 2: PRE- AND POST-RESTORATION CONDITIONS AND RATIONALE**

**Describe Pre-and Post-Restoration Condition and Rationale for Selecting Parameters**

*Enter a short description of the pre-and post-restoration condition for each functional category. Explain why the selected parameters and their measurement method were used, along with the rationale for the expected improvement. An abbreviated example is provided below for the **restoration of an incised channel**. The remainder of this example is provided in Appendix B.*

Hydrology: The watershed hydrology is stable and is not expected to change. Therefore, Hydrology parameters were not selected.

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Hydraulic: The existing channel is severely incised (Bank Height Ratio of 3) and does not have access to a wide alluvial floodplain. The channel will be reconnected to the floodplain through a Rosgen Priority 1 Restoration. The Bank Height Ratio will be reduced to 1.0, and all flows greater than bankfull will spread onto a floodplain that is 50 times wider than the channel, making the entrenchment ratio well over 2.2.

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Geomorphology: see Appendix B, Table B11a

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Physicochemical: see Appendix B, Table B11a

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Biological: see Appendix B, Table B11a

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The third set of templates (Tables 11.9 and 11.10) provides debit and credit ratios based on the results from Template 1. The ratios used to create debits and credits can be modified. The ones used in this template are for demonstration purposes and were chosen to encourage mitigation providers to select projects that have the potential for the greatest functional lift. Credits range from 0 to 1 credit-per-foot of restored channel. Debits range from 1 to 2 debits-per-foot. Therefore, an impact that creates maximum functional loss would be assigned 2 debits-per-foot. Since the maximum credit ratio is 1 credit-per-foot, they will have to perform mitigation on twice the stream length that was impacted. Since a portion of credits is released before a site reaches maturity, a greater amount of mitigation is necessary to address this temporal loss as well as the risk of project failure.

Table 11.9 provides example debit ratios. The first column shows the functionality of the stream reach before an impact occurs. Functionality ranges from Low to High and is based on the pre-disturbance condition from Debit Template 1. The remaining columns show the predicted functional loss from the permitted impact, ranging from no functional loss to high functional loss, based on the predicted functional loss from Debit Template 1. Debit ratios are then assigned to the different levels of functional loss. Therefore, high-quality streams that are more severely impacted would yield more debits than degraded streams that were minimally impacted. A debit adjustment factor is provided for scenarios that may need to be modified based on unique site conditions or because the result fits between two categories.

**TABLE 11.9** DEBIT TEMPLATE 3: DEBIT CALCULATIONS

PRE-DISTURBANCE CONDITION	POST-DISTURBANCE CONDITION			
	No Functional Loss	Low to Moderate Functional Loss	Moderate to High Functional Loss	Debit Adjustment (+/-)
<b>Low</b> (Mix of Functioning-at-Risk and Not Functioning)	<b>(Post-disturbance condition matches pre-disturbance condition)</b>  <b>No mitigation required</b>	Greater number of Functioning-at-Risk and Not Functioning Scores 1.1 to 1.2	Mostly Not-Functioning Scores 1.2 to 1.3	0.1
<b>Moderate</b> (Mix of Functioning, Functioning-at-Risk, and Not Functioning)		Loss of Functioning scores and/or greater number of Functioning-at-Risk and Not Functioning Scores 1.3 to 1.5	Mix of Functioning-at-Risk and Not Functioning Scores 1.5 to 1.7	0.1
<b>High</b> (Functioning)		Mix of Functioning, Functioning-at-Risk, and Not Functioning Scores 1.7 to 1.9	Mix of Functioning-at-Risk and Not Functioning Scores 2.0	0.2

Tables 11.10 and 11.11, provide examples of credit determination method templates for Restoration 1 and Restoration 2 projects. Specific examples are provided in Appendix B. The table below includes four columns: Credit Category, Pre-Restoration Condition, Post-Restoration Condition and Credit Ratio. The credit ratio is expressed as credit-per-foot with the highest ratio set at 1.0 credit-per-foot for a Restoration 1 project with a Maximum Lift score. Maximum Lift is the first row under the Credit Category. So if a project was 5,000 feet long, the maximum number of credits that could be attained is 5,000. The other categories are Moderate and Low lift. So a project that has several Functioning scores in the baseline condition would have a Low lift and would be given less credit. Note that the post-restoration condition is the same for Maximum, Moderate and Low lift. The difference is in the baseline condition. This reflects a goal of achieving the highest restoration or enhancement possible, but acknowledges that some sites start in a more degraded condition; thus, more lift is created and more credit is given. Again, these ratios are provided only as a guide. Appendix B provides other examples of credit determination methods for other scenarios.

## Chapter 11: Application of the Stream Functions Pyramid

**TABLE 11.10** CREDIT TEMPLATE 3: CREDIT CALCULATIONS FOR RESTORATION 1

RESTORATION 1 CREDIT CATEGORIES	PRE-RESTORATION CONDITION	POST-RESTORATION CONDITION	CREDITS PER FOOT
Maximum Lift	All parameters in Pyramid Levels 2 and 3 have Not Functioning scores. Parameters in Levels 4 and 5 are Not Functioning or Functioning-at-Risk.	Functioning scores for Levels 1-5	0.8 to 1.0
Moderate Lift	Mix of Not-Functioning and Functioning-at-Risk scores for parameter Levels 2 through 5.	Functioning scores for Levels 1-5	0.6 to 0.8
Low Lift	Mix of Not-Functioning, Functioning-at-Risk and Functioning scores for parameter Levels 2 through 5.	Functioning scores for Levels 1-5	0.4 to 0.6

*Credits = Credit Ratio (in Credits/Ft) times the restored stream length (ft).*

**TABLE 11.11** CREDIT TEMPLATE 3: CREDIT CALCULATIONS FOR RESTORATION 2

RESTORATION 2 CREDIT CATEGORIES	PRE-RESTORATION CONDITION	POST-RESTORATION CONDITION	CREDITS PER FOOT
Maximum Lift	All parameters in Pyramid Levels 2 and 3 have Not Functioning scores.	Functioning scores for Levels 1-3	0.6 to 0.8
Moderate Lift	Mix of Not-Functioning and Functioning-at-Risk scores for parameter Levels 2 through 3.	Functioning scores for Levels 1-3	0.4 to 0.6
Low Lift	Mostly Functioning-at-Risk and Functioning scores for parameter Levels 2 through 3. May include some Not-Functioning scores.	Functioning scores for Levels 1-3	0.2 to 0.4

*Credits = Credit Ratio (in Credits/Ft) times the restored stream length (ft).*

### Enhancement Credits

The Pyramid Framework can be used to help develop enhancement credits, although less emphasis is placed on these projects within this document. The 2008 Mitigation Rule defines enhancement as the manipulation of the physical, chemical and biological characteristics of an aquatic resource to heighten, intensify or improve a specific aquatic resource function(s). Enhancement may lead to a gain in certain functions, but could also lead to a decline in other functions. Enhancement does not increase the aquatic resource area, e.g., stream length. An appropriate way to develop stream enhancement credits using the Stream Functions Pyramid Framework as a guide is to complete a function-based assessment before making the determination of whether restoration or enhancement is the better solution. The assessment may be rapid or intensive depending on the project; however, information about which function-based parameters are Functioning and Not Functioning must be determined before the practitioner can know what needs to be enhanced.

Enhancement can lead to projects that achieve the same level of functionality as a Restoration 1 approach above; however, they can also lead to projects that still have several function-based parameters with a Functioning-at-Risk or Not Functioning score. Therefore, the key difference between restoration and enhancement, as described here, is the level of functional lift. Restoration 1 includes changes to many function-based parameters, along with proper site selection, to achieve a fully functioning score. Enhancement may include a change to only one parameter to achieve a fully functioning score, if all other key parameters are functioning, e.g., the riparian buffer. In this example, the product is the same but the amount of functional lift is much less with an enhancement approach. Enhancement can also improve one function-based parameter like lateral stability, but not improve other key parameters like floodplain connectivity or bed form diversity. This would lead to a stream that has some improvement in stream function, but the change is not necessarily significant. And because the stream is not connected to the floodplain, the channel could lose other functions in the future.

A table is not provided for calculating enhancement credits. Rather, some examples of enhancement scenarios are provided below. These examples show how to focus on enhancements to function-based parameters rather than practices like benching or in-stream structures. These practices will likely be used; however, the credits should be based on changes to function-based parameters and not the number of structures. Of course, enhancement credits should also be less than restoration credits on a per, foot basis.

#### Example Enhancement Scenarios:

1. Projects in non-incised, rural streams within alluvial valleys. The stream is well connected to a floodplain and there are diverse bed forms created from the appropriate plan form geometry and bed form complexity. Streambanks are not eroding at levels above reference conditions, i.e., banks are stable. However, the riparian buffer is thin with only a single row of trees along the streambank.

Enhancement credits could be provided for expanding the buffer. In this case, higher order functions like de-nitrification and even improvements to benthics and fish may occur — if supported by the upstream watershed.

2. Same setting as number 1 and same conditions, except in addition to having a narrow riparian buffer, the bed form diversity is also low, e.g., mostly riffle bed forms due to straightening and vegetation/debris removal.

Enhancement would include improving the bed form diversity, e.g., percent riffle and pool, depth variability, and improving the buffer width and composition. This would be a higher level of enhancement because more than one function-based parameter is being improved.

3. Urban setting, flood control channel. A channelized, trapezoidal channel with streambanks stabilized by rip rap and some vegetation.

High level of enhancement would include providing limited floodplain connectivity by excavating bankfull benches, providing bed form diversity through the installation of in-stream structures, and planting a narrow buffer. Lower-level enhancement would be bank stabilization using vegetation, e.g., bioengineering and perhaps bed form diversity with in-stream structures; however, significant benching and vegetation beyond the top of the streambank would be limited.

### Example of Calculating Debits and Credits

The following is an example of how the templates can be used to calculate debits and credits from a hypothetical permitted impact site and a mitigation site.

#### Impact Site

- 500 feet of culvert with 200 feet of downstream impact and 100 feet of upstream impact. Total impact length is 800 feet.
- The functional condition before disturbance shows a mix of Not-Functioning, Functioning-at-Risk and Functioning scores for Level 2 through 5 parameters. This equals a Functionality Before Impact score of Moderate (Table 11.9).
- A standard installation approach is used instead of an arch culvert or bridge, so post-construction functions will include a greater number of Not-Functioning and Functioning-at-Risk scores for Level 2 through 5 parameters. This equals a Moderate Functional Loss from Table 11.9.
- A Moderate/Moderate score yields a ratio range of 1.3 to 1.5 debits per foot. For this example, a ratio of 1.5 is used.
- The total debits equal  $1.5 \times 800 = 1,200$  debits. In other words, 1,200 credits are needed to compensate for the impacts.
- This example could have been broken into three reaches, including upstream of the culvert, through the culvert, and downstream of the culvert, since the impacts will likely vary. An example of calculating debits by reach for a culvert installation is shown in Appendix B.

### Off-Site Mitigation

- A 10,000-foot stream restoration site is located that meets the Restoration 1 criteria. A Restoration 1 site includes full restoration of Level 2 and 3 functions and the watershed supports Level 4 and 5 functions.
- The pre-restoration condition shows that all parameters in Pyramid Levels 2 and 3 have Not Functioning scores. Parameters in Levels 4 and 5 are Not Functioning or Functioning-at-Risk.
- The post-restoration condition is predicted to show Functioning scores for Levels 1-5. The stream is well connected to the floodplain with diverse and complex bed forms that are representative of the stream type. Riparian buffer is diverse and has sufficient width to support Level 4 and 5 functions. Since the upstream watershed supports Level 4 and 5 functions, it is predicted that the project reach will achieve Functioning scores for Levels 4 and 5 as well.
- This results in a Maximum Lift score, with a credit ratio range of 0.8 to 1.0 credits per foot.
- For this example, a credit ratio of 1.0 is selected.
- The total credits available at this site are  $10,000 \text{ ft} \times 1.0 \text{ credits/ft} = 10,000 \text{ credits}$ .

As was mentioned previously, the debits and credits can be modified to meet local conditions and requirements. The debit and credit range selected for these examples was based on two important factors. First, more credits were provided for scenarios that improved more functions, i.e., the more functions that are restored, the more credits. Second, a multiplier is applied to the debits to ensure that debits are never less than the length of impact. The maximum is 2.2:1, meaning that 2.2 times the amount of impacted length may be required for mitigation. The multiplier acknowledges the fact that impacts occur immediately during construction and that mitigation sites take years to reach functional maturity. Since a portion of credits is released before the site reaches maturity, a greater amount of mitigation is warranted for temporal losses to stream functions.

### 11.7 » STEPS TO DEVELOPING DEBITS AND CREDITS

The following provides general steps for using the Pyramid to develop unique debit and credit determination methods. These steps also provide guidance on how to collect the information necessary to complete the templates described above. Actual steps and tasks will vary based on local needs and conditions, and additional steps will be needed to meet other 2008 Mitigation Rule requirements. For example, the steps below do not address how to develop the Prospectus or the Mitigation Banking Instrument.

#### Steps to Develop Debits Using the Pyramid

1. List types of impacts for the service area, i.e., culvert crossings, channelization, etc.
2. Select key function-based parameters from the Pyramid that are typically associated with each type of impact. The selected parameters should be based on some form of function-based assessment.

3. Select the appropriate measurement method for each parameter, e.g., simple and rapid-based or more complex and time intensive. This selection should be based on the severity of the impact and difficulty in predicting functional loss.
4. Perform function-based assessment on stream reach proposed to be impacted.
5. Record values for each measurement method and use the performance standards to determine if the function-based parameter is Functioning, Functioning-at-Risk and Not Functioning. Record values on Debit Template 1 (Table 11.5).
6. Provide justification for the selection of function-based parameters and measurement methods in Debit Template 2 (Table 11.6).
7. Develop overall scoring method (optional). Note: This document does not provide a scoring method that combines parameters, their measurement method and performance standard into an overall index of stream function. The document does show a method for calculating debits without this overall score; however, a function index might be a helpful tool for future use.
8. Determine overall baseline condition using scoring method developed in step 6, or refer to the debit calculation method shown in Debit Template 3 (Table 11.9).
9. Calculate overall debits for site. The formula used in this document is the debit ratio multiplied by the impacted stream length.

### Steps to Develop Credits Using the Pyramid

1. Develop or use existing watershed management plans for each service area. Locate areas of water quality impairment and stream degradation. Determine the causes of impairment. Also locate areas of high water quality and healthy stream channels. Use the plan to identify stream reaches that can produce high-quality mitigation and, if possible, support the overall improvement of the watershed.
2. Based on the watershed management plan, determine the different types of techniques required to improve watershed health, e.g., stormwater BMPs, stream restoration, stream enhancement, riparian corridor preservation.
3. Perform a function-based assessment of the potential project reach.
4. Determine the restoration potential based on the assessment, watershed condition and constraints.
5. Establish function-based design goals and objectives.
6. Select key parameters from the Pyramid based on the assessment and restoration potential. Select parameters that are expected to change as a result of the restoration or enhancement activity.
7. Select the appropriate measurement method for each parameter, e.g., simple and rapid-based or more complex and time intensive. This selection should be based on the level of effort required to show functional lift.
8. Record the function-based parameter, measurement method and scores using the performance standards on Credit Template 1 (Table 11.6).
9. Provide justification for selecting the parameters and measurement methods on Credit Template 2 (Table 11.8).

10. Develop overall scoring method (optional). Note: This document does not provide a scoring method that combines parameters, their measurement method and performance standard into an overall index of stream function. The document does show a method for calculating credits without this overall score; however, a function index would be a helpful tool for future use.
11. Determine overall baseline condition using scoring method developed in step 10, or refer to the credit calculation method shown in Tables 11.10 and 11.11.
12. Calculate overall credits predicted for the site. The formula used in this document is the credit ratio multiplied by the restored or enhanced stream length.
13. Develop a monitoring plan to verify that the functional lift meets or exceeds the performance standards.

# Appendices

## **A. STREAM FUNCTIONS PYRAMID**

- A. Overview Graphic
- B. Functions & Parameters Graphic
- C. Parameter & Measurement Method Table
- D. Performance Standard Table

## **B. APPLICATION SCENARIOS**

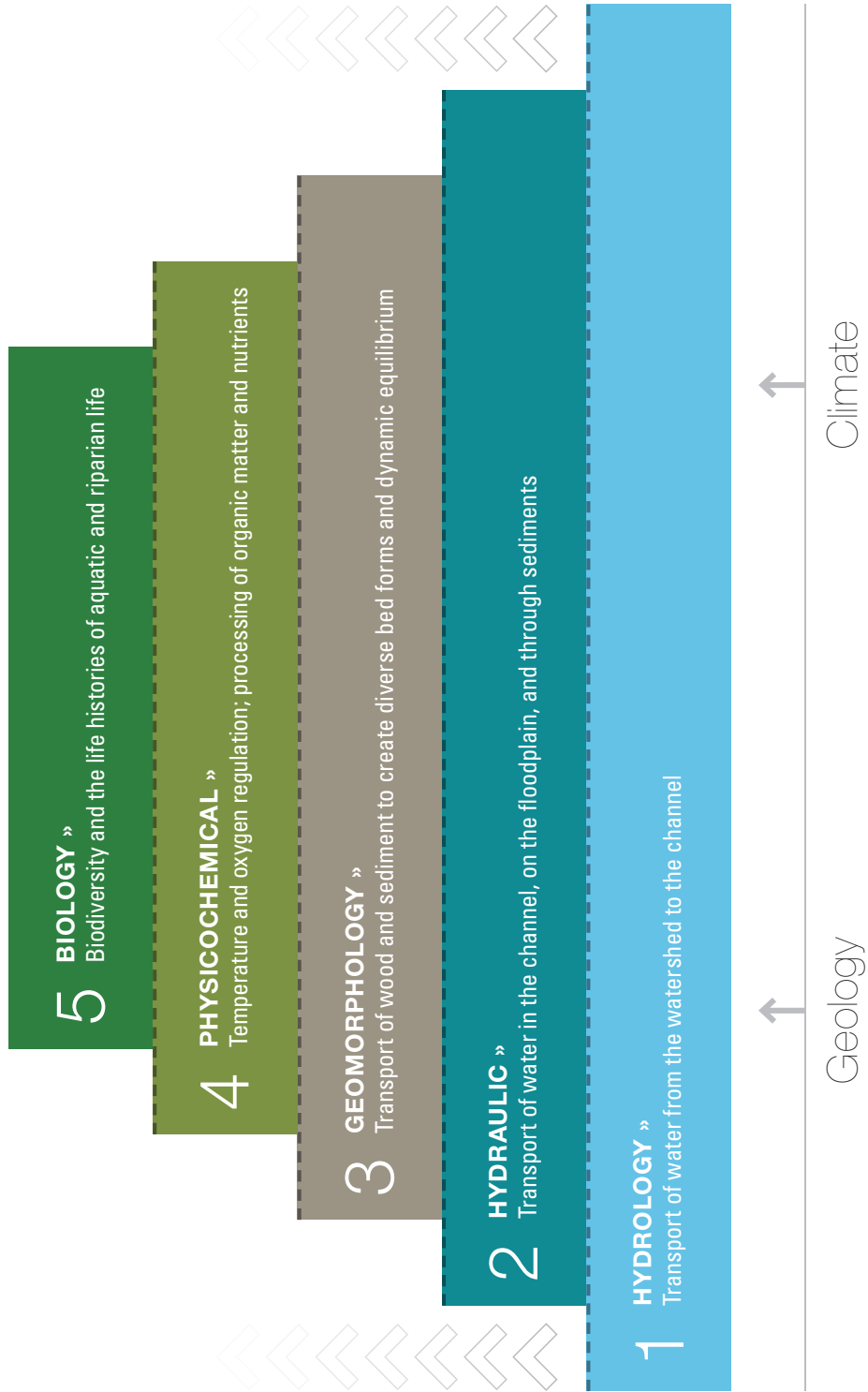
### **PERMITTED IMPACT SCENARIOS (DEBITS)**

- 1. Culvert installations
- 2. Channelization and Bank Hardening
- 3. Surface Mining of High-Gradient Streams

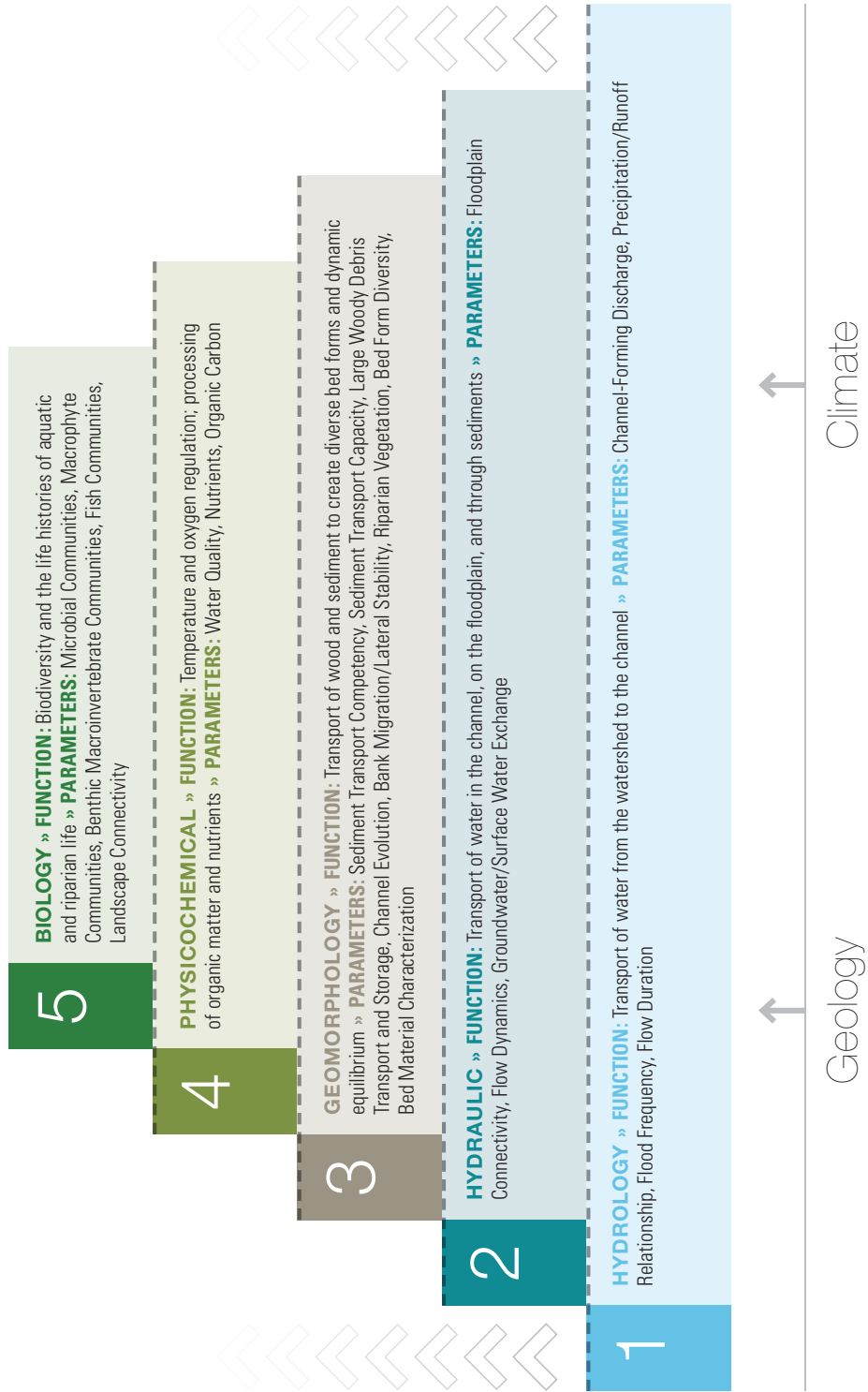
### **STREAM MITIGATION SCENARIOS (CREDITS)**

- 1. Restoration of Incised Channels in Alluvial Valleys
- 2. Restoration of Stream Flow for Channels That Have Excessive Water Withdrawal
- 3. Salmonid Fish Passage and Habitat Restoration
- 4. Restoration of High-Gradient, Headwater Streams

**APPENDIX A: STREAM FUNCTIONS PYRAMID**  
a. OVERVIEW GRAPHIC



**APPENDIX A: STREAM FUNCTIONS PYRAMID**  
**b. STREAM FUNCTIONS PYRAMID: FUNCTIONS & PARAMETERS**



**APPENDIX A: STREAM FUNCTIONS PYRAMID**

**c. PARAMETER & MEASUREMENT METHOD TABLE**

(Details about the categories for the measurement methods, including type, level of effort, level of complexity, and direct/indirect assessment, are provided in Chapter 4. The parameters and measurement methods shown here are examples. Additional parameters and measurement methods can be added based on user needs. Refer to Chapter 4 for instructions on how to add parameters and measurement methods.)

HYDROLOGY					
PARAMETER	MEASUREMENT METHOD	TYPE	LEVEL OF EFFORT	LEVEL OF COMPLEXITY	ASSESSMENT OF PARAMETER
Channel-Forming Discharge	1. Regional Curves	1. Technique	1. Rapid to Intensive, dependent on curve	1. Simple to Complex, dependent on curve	1. Indirect
Precipitation/Runoff Relationship	1. Rational Method 2. HEC-HMS 3. USGS Regional Regression Equations	1. Tool 2. Tool 3. Technique	1. Rapid 2. Moderate 3. Rapid	1. Moderate 2. Complex 3. Moderate	1. Indirect 2. Indirect 3. Indirect
Flood Frequency	1. Bulletin 17b	1. Technique	1. Moderate	3. Complex	1. Direct
Flow Duration	1. Flow Duration Curve  2. Crest Gauge 3. Monitoring Devices 4. Rapid Indicators	1. Technique  2. Tool 3. Tool 4. Assessment approach	1. Moderate to Intensive, dependent on data source 2. Rapid 3. Intensive 4. Rapid	1. Moderate/Complex  2. Simple 3. Moderate 4. Simple	1. Direct/Indirect  2. Indirect 3. Direct 4. Indirect

**APPENDIX A: STREAM FUNCTIONS PYRAMID (CONT.)**  
 c. PARAMETER & MEASUREMENT METHOD TABLE

<b>HYDRAULICS</b>					
PARAMETER	MEASUREMENT METHOD	TYPE	LEVEL OF EFFORT	LEVEL OF COMPLEXITY	ASSESSMENT OF PARAMETER
Floodplain Connectivity	1. Bank Height Ratio	1. Technique	1. Rapid/Moderate	1. Simple/Moderate	1. Direct
	2. Entrenchment Ratio	2. Technique	2. Rapid/Moderate	2. Simple/Moderate	2. Direct
	3. Stage Versus Discharge	3. Technique	3. Intensive	3. Complex	3. Indirect
Flow Dynamics	1. Stream Velocity	1. Metric	1. Moderate/Intensive	1. Moderate/Complex	1. Direct
	2. Shear Stress	2. Metric	2. Moderate/Intensive	2. Moderate/Complex	2. Direct
	3. Stream Power	3. Metric	3. Moderate/Intensive	3. Moderate/Complex	3. Direct
Groundwater/Surface Water Exchange	1. Piezometers	1. Tool	1. Intensive	1. Complex	1. Direct
	2. Tracers	2. Tool	2. Intensive	2. Complex	2. Direct
	3. Seepage Meters	3. Tool	3. Intensive	3. Complex	3. Direct

**APPENDIX A: STREAM FUNCTIONS PYRAMID (CONT.)**  
**c. PARAMETER & MEASUREMENT METHOD TABLE**

<b>GEOMORPHOLOGY</b>					
<b>PARAMETER</b>	<b>MEASUREMENT METHOD</b>	<b>TYPE</b>	<b>LEVEL OF EFFORT</b>	<b>LEVEL OF COMPLEXITY</b>	<b>ASSESSMENT OF PARAMETER</b>
Sediment Transport Competency	1. Shear Stress Curve	1. Technique	1. Rapid to Intensive, dependent on curve availability	1. Simple to Complex, dependent on curve availability	1. Indirect
	2. Required Depth and Slope	2. Technique/ Tool	2. Moderate	2. Moderate	2. Indirect
	3. Spreadsheets and Computer Models	3. Tool	3. Moderate/ Intensive	3. Moderate/ Complex	3. Indirect
Sediment Transport Capacity	1. Computer Models	1. Tool	1. Moderate/ Intensive	1. Moderate/ Complex	1. Indirect
	2. FLOWSED and POWERSED	2. Tool	2. Intensive	2. Complex	2. Indirect
	3. BAGS	3. Tool	3. Rapid/Moderate	3. Simple/Moderate	3. Indirect
Large Woody Debris Transport and Storage	1. Wohl LWD Assessment	1. Assessment approach	1. Rapid/Moderate	1. Simple/Moderate	1. Direct for storage and Indirect for transport
	2. Large Woody Debris Index	2. Assessment approach	2. Moderate	2. Moderate	2. Direct for storage and Indirect for transport

**APPENDIX A: STREAM FUNCTIONS PYRAMID (CONT.)**  
**c. PARAMETER & MEASUREMENT METHOD TABLE**

<b>GEOMORPHOLOGY</b>					
<b>PARAMETER</b>	<b>MEASUREMENT METHOD</b>	<b>TYPE</b>	<b>LEVEL OF EFFORT</b>	<b>LEVEL OF COMPLEXITY</b>	<b>ASSESSMENT OF PARAMETER</b>
Channel Evolution	<ol style="list-style-type: none"> <li>1. Simon Channel Evolution Model</li> <li>2. Rosgen Stream Type Succession Scenarios</li> </ol>	<ol style="list-style-type: none"> <li>1. Technique</li> <li>2. Technique</li> </ol>	<ol style="list-style-type: none"> <li>1. Rapid/Moderate</li> <li>2. Moderate</li> </ol>	<ol style="list-style-type: none"> <li>1. Simple/Moderate</li> <li>2. Moderate</li> </ol>	<ol style="list-style-type: none"> <li>1. Indirect</li> <li>2. Indirect</li> </ol>
Bank Migration/ Lateral Stability	<ol style="list-style-type: none"> <li>1. Meander Width Ratio</li> <li>2. BEHI / NBS</li> <li>3. Bank Pins</li> <li>4. Bank Profiles</li> <li>5. Cross-Sectional Surveys</li> <li>6. Bank Stability and Toe Erosion Model</li> </ol>	<ol style="list-style-type: none"> <li>1. Technique</li> <li>2. Technique/ Tool</li> <li>3. Technique</li> <li>4. Technique</li> <li>5. Technique</li> <li>6. Tool</li> </ol>	<ol style="list-style-type: none"> <li>1. Rapid/Moderate</li> <li>2. Moderate/ Intensive</li> <li>3. Intensive</li> <li>4. Intensive</li> <li>5. Intensive</li> <li>6. Intensive</li> </ol>	<ol style="list-style-type: none"> <li>1. Simple</li> <li>2. Moderate</li> <li>3. Moderate</li> <li>4. Moderate</li> <li>5. Moderate</li> <li>6. Complex</li> </ol>	<ol style="list-style-type: none"> <li>1. Indirect</li> <li>2. Indirect</li> <li>3. Direct</li> <li>4. Direct</li> <li>5. Direct</li> <li>6. Indirect</li> </ol>

**APPENDIX A: STREAM FUNCTIONS PYRAMID (CONT.)**  
**c. PARAMETER & MEASUREMENT METHOD TABLE**

<b>GEOMORPHOLOGY</b>					
PARAMETER	MEASUREMENT METHOD	TYPE	LEVEL OF EFFORT	LEVEL OF COMPLEXITY	ASSESSMENT OF PARAMETER
Riparian Vegetation	<ol style="list-style-type: none"> <li>1. Buffer Width</li> <li>2. Buffer Density</li> <li>3. Buffer Composition</li> <li>4. Buffer Age</li> <li>5. Buffer Growth</li> <li>6. Canopy Density</li> <li>7. Proper Functioning Condition (PFC)</li> <li>8. NRCS Visual Assessment Protocol</li> <li>9. Rapid Bioassessment Protocol</li> <li>10. Watershed Assessment of River Stability and Sediment Supply (WARSSS)</li> <li>11. USFWS Stream Assessment Ranking Protocol (SAR)</li> </ol>	<ol style="list-style-type: none"> <li>1. Technique</li> <li>2. Technique</li> <li>3. Technique</li> <li>4. Technique</li> <li>5. Technique</li> <li>6. Technique</li> <li>7. Assessment approach</li> <li>8. Assessment approach</li> <li>9. Assessment approach</li> <li>10. Assessment approach</li> <li>11. Assessment approach</li> </ol>	<ol style="list-style-type: none"> <li>1. Rapid</li> <li>2. Moderate/Intensive</li> <li>3. Moderate/Intensive</li> <li>4. Intensive</li> <li>5. Intensive</li> <li>6. Moderate/Intensive</li> <li>7. Rapid</li> <li>8. Rapid</li> <li>9. Rapid</li> <li>10. Intensive</li> <li>11. Rapid</li> </ol>	<ol style="list-style-type: none"> <li>1. Simple</li> <li>2. Moderate</li> <li>3. Moderate</li> <li>4. Moderate</li> <li>5. Moderate</li> <li>6. Moderate</li> <li>7. Simple</li> <li>8. Simple</li> <li>9. Simple</li> <li>10. Complex</li> <li>11. Simple</li> </ol>	<ol style="list-style-type: none"> <li>1. Indirect</li> <li>2. Direct</li> <li>3. Direct</li> <li>4. Direct</li> <li>5. Direct</li> <li>6. Direct</li> <li>7. Indirect</li> <li>8. Indirect</li> <li>9. Indirect</li> <li>10. Indirect</li> <li>11. Indirect</li> </ol>

**APPENDIX A: STREAM FUNCTIONS PYRAMID (CONT.)**  
**c. PARAMETER & MEASUREMENT METHOD TABLE**

<b>GEOMORPHOLOGY</b>					
PARAMETER	MEASUREMENT METHOD	TYPE	LEVEL OF EFFORT	LEVEL OF COMPLEXITY	ASSESSMENT OF PARAMETER
Bed Form Diversity	1. Percent Riffle and Pool	1. Technique	1. Rapid/Moderate	1. Moderate	1. Direct
	2. Facet Slope	2. Technique	2. Moderate	2. Moderate	2. Indirect
	3. Pool-to-Pool Spacing	3. Technique	3. Rapid/Moderate	3. Moderate	3. Indirect
	4. Depth Variability	4. Technique	4. Moderate	4. Moderate	4. Direct
Bed Material Characterization	1. Size Class Pebble Count Analyzer	1. Tool	1. Moderate/Intensive	1. Moderate	1. Direct
	2. Riffle Stability Index (RSI)	2. Technique	2. Moderate/Intensive	2. Moderate	2. Indirect
<b>PHYSICOCHEMICAL</b>					
PARAMETER	MEASUREMENT METHOD	TYPE	LEVEL OF EFFORT	LEVEL OF COMPLEXITY	ASSESSMENT OF PARAMETER
Water Quality	1. Temperature	1. Metric	1. Rapid/Intensive	1. Simple/Moderate	1. Direct
	2. Dissolved Oxygen	2. Metric	2. Rapid/Intensive	2. Simple/Moderate	2. Direct
	3. Conductivity	3. Metric	3. Rapid/Intensive	3. Simple/Moderate	3. Direct
	4. pH	4. Metric	4. Rapid/Intensive	4. Simple/Moderate	4. Direct
	5. Turbidity	5. Metric	5. Rapid/Intensive	5. Simple/Moderate	5. Direct
Nutrients	1. Field test kits using reagents reactions	1. Technique	1. Rapid for screening	1. Simple	1. Direct
	2. Laboratory analysis	2. Technique	2. Intensive	2. Complex	2. Direct

**APPENDIX A: STREAM FUNCTIONS PYRAMID (CONT.)**  
 c. PARAMETER & MEASUREMENT METHOD TABLE

<b>BIOLOGY</b>					
PARAMETER	MEASUREMENT METHOD	TYPE	LEVEL OF EFFORT	LEVEL OF COMPLEXITY	ASSESSMENT OF PARAMETER
Organic Carbon	1. Laboratory analysis	1. Technique	1. Intensive	1. Complex	1. Direct
Microbial Communities	1. Taxonomic Methods	1. Technique	1. Intensive	1. Complex	1. Direct
	2. Non-Taxonomic Methods	2. Technique	2. Intensive	2. Complex	2. Direct
	3. Biological Indices	3. Assessment approach	3. Moderate/Intensive	3. Moderate/Complex	3. Indirect
Macrophyte Communities	1. Taxonomic Methods	1. Technique	1. Intensive	1. Complex	1. Direct
	2. Non-Taxonomic Methods	2. Technique	2. Intensive	2. Complex	2. Direct
	3. Biological Indices	3. Assessment approach	3. Moderate/Intensive	3. Moderate/Complex	3. Indirect
Benthic Macroinvertebrate Communities	1. Taxonomic Methods	1. Technique	1. Intensive	1. Complex	1. Direct
	2. Non-Taxonomic Methods	2. Technique	2. Intensive	2. Complex	2. Direct
	3. Biological Indices	3. Assessment approach	3. Moderate/Intensive	3. Moderate/Complex	3. Indirect
Fish Communities	1. Taxonomic Methods	1. Technique	1. Intensive	1. Complex	1. Direct
	2. Non-Taxonomic Methods	2. Technique	2. Intensive	2. Complex	2. Direct
	3. Biological Indices	3. Assessment approach	3. Moderate/Intensive	3. Moderate/Complex	3. Indirect
Landscape Connectivity	1. Spatial Analysis	1. Technique	1. Intensive	1. Complex	1. Direct
	2. Species Tracking	2. Technique	2. Intensive	2. Complex	2. Direct
	3. Habitat Models	3. Technique	3. Intensive	3. Complex	3. Direct

**APPENDIX A: STREAM FUNCTIONS PYRAMID**

**d. PERFORMANCE STANDARDS TABLE**

**Notes:**

1. Since there are no Hydrology Performance Standards, there is not a Hydrology Summary Table
2. Many of the performance standard values, especially the dimensionless ratios, should be considered as examples that can be modified based on regional differences in reference conditions.
3. Great care should be taken when selecting measurement methods and performance standards. Refer to Chapters 6-10 and the associated references before selecting measurement methods and performance standards.

PARAMETER	MEASUREMENT METHOD	PERFORMANCE STANDARD			SOURCE
		FUNCTIONING	FUNCTIONING-AT-RISK	NOT FUNCTIONING	
Floodplain Connectivity	Bank Height Ratio (BHR)	1.0 to 1.2	1.3 to 1.5	> 1.5	Rosgen, 2001 (proceedings) and 1994 (book)
	Entrenchment Ratio (ER) for C and E Stream Types	> 2.2	2.0 to 2.2	< 2.0	
	Entrenchment Ratio (ER) for B and Bc Stream Types	> 1.4	1.2 to 1.4	< 1.2	
	Dimensionless rating curve	Project site $Q/Q_{b\text{kf}}$ plots on the curve	Project site $Q/Q_{b\text{kf}}$ plots above the curve	Project site $Q/Q_{b\text{kf}}$ of 2.0 plots above 1.6 for $d_{db\text{kf}}$	Dunne and Leopold 1978 (book)
Flow Dynamics	Bankfull Velocity for C and E stream types (ft/s)	3 to 6	6 to 7	> 7	Dunne and Leopold 1978 (book)
	Bankfull Velocity for Cc (ft/s)	< 3	3 to 4	> 5	
	Bankfull Velocity for B stream types (ft/s)	4 to 6	6 to 7	> 7	

**APPENDIX A: STREAM FUNCTIONS PYRAMID (CONT.)**  
**d. PERFORMANCE STANDARDS TABLE**

GEOMORPHOLOGY				PERFORMANCE STANDARD		SOURCE
PARAMETER	MEASUREMENT METHOD	FUNCTIONING	FUNCTIONING-AT-RISK	NOT FUNCTIONING		
Large Woody Debris	Large Woody Debris Index (LWDI)	LWDI of project reach equals LWDI of reference reach.	LWDI of project reach does not equal LWDI of reference reach, but is trending in that direction.	LWDI of project reach does not equal LWDI of reference reach and is not trending in that direction.		Davis et al., 2001 (USFS Technical Report)
<b>Rosgen's Stream Type Succession Scenarios</b>						
Channel Evolution	1. E→C→Gc→F→C→E	E, C	C→Gc and F→C	Gc, F		Rosgen 2010 (conference workshop)
	2. C→D→C	C	C→D and D→C	D		
	3. C→D→Gc→F→C	C	C→D and F→C	D, Gc, F		
	4. C→G→F→Bc	C, Bc	C→G and F→Bc	G, F		
	5. E→Gc→F→C→E	E, C	E→Gc and F→C	Gc, F		
	6. B→G→Fb→B	B	B→G and Fb→B	G, Fb		
	7. Eb→G→B	Eb, B	Eb→G and G→B	G		
	8. C→G→F→D→C	C	C→G and D→C	G, F, D		
	9. C→G→F→C	C	C→G and F→C	G, F		
	10. E→A→G→F→C→E	E	E→A and F→C	A, G, F		
	11. C→F→C→F→C	First and last C	C→F	F		
	12. C→G→F→C→C→C	First and last C	C→G and C→C	G, F, Fourth C		
<b>Simon Channel Evolution Model Stages</b>						
	1. Sinuous, pre-modified	✓				Simon 1989 (journal)
	2. Channelized			✓		
	3. Degradation			✓		

**APPENDIX A: STREAM FUNCTIONS PYRAMID (CONT.)**  
**d. PERFORMANCE STANDARDS TABLE**

GEOMORPHOLOGY		PERFORMANCE STANDARD			SOURCE
PARAMETER	MEASUREMENT METHOD	FUNCTIONING	FUNCTIONING-AT-RISK	NOT FUNCTIONING	
Channel Evolution	4. Degradation and widening			✓	Simon 1989 (journal)
	5. Aggradation and widening		✓ *	✓	
	6. Quasi-equilibrium	✓			
* Only late Stage 5 of the Simon model, where the stream has begun to construct a new floodplain at a lower elevation, is considered to be Functioning-at-Risk.					
Bank Migration/ Lateral Stability	Meander Width Ratio for C and E stream types	≥ 3.5 (based on reference reach surveys)	3.0 to 3.5 as long as sinuosity is ≥ 1.2	< than 3.0	
	Lateral Erosion rate – Low BEHI Curve	Very low to Moderate NBS	Moderate to Very High NBS	Extreme NBS	
	Lateral Erosion rate – Moderate BEHI Curve	Very low to Low NBS	Low to High NBS	High to Extreme NBS	
	Lateral Erosion rate – High and Very High BEHI Curve	N/A	Low to Moderate NBS	Moderate to Extreme NBS	Rosgen, 2001 (proceedings) and 2006 (book)
	Lateral Erosion rate – Extreme BEHI Curve	N/A	Low NBS	Low to Extreme NBS	
	Lateral Erosion Rate (Bank Pins and Bank Profiles)	Erosion rate is similar to reference reach values, generally < 0.1 ft/yr	0.1 to 0.5 ft/yr	> 0.5 ft/yr	

**APPENDIX A: STREAM FUNCTIONS PYRAMID (CONT.)**  
**d. PERFORMANCE STANDARDS TABLE**

GEOMORPHOLOGY		PERFORMANCE STANDARD			SOURCE
PARAMETER	MEASUREMENT METHOD	FUNCTIONING	FUNCTIONING-AT-RISK	NOT FUNCTIONING	
Bank Migration/ Lateral Stability	Lateral Erosion Rate for C4 streams (Cross Sections)	$\frac{w/Dproj}{w/Dref} = 1.0$ to 1.2	$\frac{w/Dproj}{w/Dref} = 1.2$ to 1.4	$\frac{w/Dproj}{w/Dref} = > 1.4$	Simon and Langendoen 2006 (proceedings)
	Bank Stability and Toe Erosion Model	$F_s > 1.3$	$1.0 < F_s < 1.3$	$F_s < 1.0$	
	Average Buffer Width (Ft) C and E Stream Types	$> 150$	30 to 150	$< 30$	Meyer et al., 2005 (journal)
	Buffer Width (Ft) from Meander Belt Width for C and E Stream Types	Meander belt width at least 3.5 times the bankfull width plus $\geq 15$ feet from outside of meander bend	Meander belt width at least 3.5 times the bankfull width plus 10 to 15 feet from outside of meander bend	Meander belt width $\leq 3.5$ times the bankfull width and/or $\leq 10$ feet from outside of meander bend	Proposed as an option in this document
Riparian Vegetation	Buffer Density (Stems/ac)	Parameter is similar to reference reach condition, with no additional maintenance required.	Parameter deviates from reference reach condition, limiting function, but the potential exists for full functionality over time or with moderate additional maintenance.	Significantly less functional than reference condition; little or no potential to improve without significant restoration effort.	
	Buffer Age				
	Buffer Composition				
	Buffer Growth				
	Canopy Density				
	Proper Functioning Condition (PFC)	Proper Functioning Condition	Functional At-Risk	Nonfunctional	Prichard et al., 1998 (USFS Technical Report)

**APPENDIX A: STREAM FUNCTIONS PYRAMID (CONT.)**  
**d. PERFORMANCE STANDARDS TABLE**

GEOMORPHOLOGY		PERFORMANCE STANDARD			SOURCE
		MEASUREMENT METHOD	FUNCTIONING	FUNCTIONING-AT-RISK	
Riparian Vegetation	NRCS Rapid Visual Assessment Protocol	Natural vegetation extends at least one to two active channel widths on each side, or if less than one width, covers entire floodplain. (8-10)	Natural vegetation extends at least one-half to one-third active channel widths on each side, or filtering function moderately compromised. (3-5)	Natural vegetation less than one-third active channel widths on each side, or lack of regeneration, or filtering function severely compromised. (1)	NRCS Technical Report
	The EPA Rapid Bioassessment Protocol (RBP)	Width of riparian zone > 18 meters; humans have not impacted zone. (Optimal, 9-10)	Width of riparian zone 12-18 meters; human activities have minimally impacted zone. (Sub-Optimal, 6-8)	Width of riparian zone < 6 meters; little or no riparian vegetation due to human activity. (Poor, 0-2)	Barbour et al., 1999 (EPA Technical Report)

**APPENDIX A: STREAM FUNCTIONS PYRAMID (CONT.)**  
**d. PERFORMANCE STANDARDS TABLE**

GEOMORPHOLOGY		PERFORMANCE STANDARD			SOURCE
PARAMETER	MEASUREMENT METHOD	FUNCTIONING	FUNCTIONING-AT-RISK	NOT FUNCTIONING	
Riparian Vegetation	USFWS Stream Assessment Ranking (SAR)	All three zones of vegetation exist; runoff is primarily sheet flow; hillslopes < 10%; hillslopes > 200 ft from stream; ponding or wetland areas and litter or debris jams are well represented.	Only Zone 2 of vegetation is well represented; runoff is equally sheet and concentrated flow (moderate gully and rill erosion); hillslopes 20-40%; hillslopes 50-100 ft from stream; ponding or wetland areas and litter or debris jams are minimally represented.	No zones of vegetation well represented; runoff is primarily concentrated flow (extensive gully and rill erosion); hillslopes > 40%; hillslopes < 50 ft from stream; ponding or wetland areas and litter or debris jams are not well represented or completely absent.	Allen et al., 1999

**APPENDIX A: STREAM FUNCTIONS PYRAMID (CONT.)**  
**d. PERFORMANCE STANDARDS TABLE**

GEOMORPHOLOGY				SOURCE	
PARAMETER	MEASUREMENT METHOD	PERFORMANCE STANDARD		NOT FUNCTIONING	SOURCE
		FUNCTIONING	FUNCTIONING-AT-RISK		
<b>Perennial Streams in Alluvial Valleys (C, E)</b>					
Bed Form Diversity	Percent Riffle	60 to 70	70 to 80 40 to 60	> 80 < 40	Professional Judgement
	Pool-to-Pool Spacing Ratio (Watersheds < 10 mi <sup>2</sup> )	4 to 5	3 to 4 and 5 to 7	< 3.0 and > 7	Leopold 1994, Gregory et al., 1994 journal), Whittake 1987 (book), Chin 1989 (journal), and Grant 1990 (journal)
	Pool-to-Pool Spacing Ratio (Watersheds > 10 mi <sup>2</sup> )	5 to 7	3.5 to 5 and 7 to 8	< 3.5 and > 8	Leopold 1994, Gregory et al., 1994 journal), Whittake 1987 (book), Chin 1989 (journal), and Grant 1990 (journal)
Bed Form Diversity	Depth Variability – Gravel Bed Streams (Pool Max Depth Ratio)	> 1.5	1.2 to 1.5	< 1.2	Rosgen 2006 (book)
	Depth Variability – Sand Bed Streams (Pool Max Depth Ratio)	> 1.2	1.1 to 1.2	< 1.1	Rosgen 2006 (book)

**APPENDIX A: STREAM FUNCTIONS PYRAMID (CONT.)**  
**d. PERFORMANCE STANDARDS TABLE**

GEOMORPHOLOGY					SOURCE
PARAMETER	MEASUREMENT METHOD	PERFORMANCE STANDARD			SOURCE
		FUNCTIONING	FUNCTIONING-AT-RISK	NOT FUNCTIONING	
Bed Material Characterization	Bed material composition	Project Reach is not statistically different than reference reach.	N/A	Project Reach is statistically different (finer) than reference reach.	Bevenger and King, 2005 (USFS Technical Report)
<b>Moderate Gradient Perennial Streams in Colluvial Valleys</b>					
Bed Form Diversity	Pool-to-Pool Spacing Ratio (Slope between 3 and 5%)	2 to 4	4 to 6	>6	Leopold 1994, Gregory et al., 1994 journal), Whittake 1987 (book), Chin 1989 (journal), and Grant 1990 (journal)
	Depth Variability (Pool Max Depth Ratio)	> 1.5	1.2 to 1.5	< 1.2	Leopold 1994, Gregory et al., 1994 journal), Whittake 1987 (book), Chin 1989 (journal), and Grant 1990 (journal)

**APPENDIX A: STREAM FUNCTIONS PYRAMID (CONT.)**  
**d. PERFORMANCE STANDARDS TABLE**

PHYSICOCHEMICAL					SOURCE
PARAMETER	MEASUREMENT METHOD	PERFORMANCE STANDARD			NOT FUNCTIONING
		FUNCTIONING	FUNCTIONING-AT-RISK	NOT FUNCTIONING	
Water Quality	DO Temperature Turbidity	Meets water quality standards for designated use	Meets water quality standards for designated use	Does not meet water quality standards	Performance standards have not been developed for these parameters and are therefore based on reference reach comparisons and state water quality databases.
		Representative of reference reach and meets species requirements	Is not representative of reference reach and does not support species requirements	Is not representative of the reference reach  Does not support species requirements	
Water Quality	pH Conductivity Turbidity	Representative of values measured in reference reach	Does not have representative reference reach values or  Does not support designated use or species requirements	Statistically different than reference reach and does not support aquatic life	

**APPENDIX A: STREAM FUNCTIONS PYRAMID (CONT.)**  
**d. PERFORMANCE STANDARDS TABLE**

PHYSICOCHEMICAL					SOURCE
PARAMETER	MEASUREMENT METHOD	PERFORMANCE STANDARD			NOT FUNCTIONING
		FUNCTIONING	FUNCTIONING-AT-RISK	NOT FUNCTIONING	
Nutrients	Field test kits using reagents reactions	Meets water quality standards for designated use	Meets water quality standards for designated use, but is not representative of reference reach	Does not meet water quality standards	Performance standards have not been developed for these parameters and are therefore based on reference reach comparisons and state water quality databases.
		Representative of reference reach	Does not cause eutrophication	Is not representative of the reference reach	
	Laboratory analysis	Does not cause eutrophication		Causes eutrophication	
Organic Carbon	Laboratory analysis	Meet reference reach OC concentrations	Do not meet reference reach OC concentrations	Do not meet reference reach OC concentrations and are below a predetermined threshold determined for adequate organic processing	Performance standards have not been developed for these parameters and are therefore based on reference reach comparisons and state water quality databases.

**APPENDIX A: STREAM FUNCTIONS PYRAMID (CONT.)**  
**d. PERFORMANCE STANDARDS TABLE**

BIOLOGY					
PARAMETER	MEASUREMENT METHOD	PERFORMANCE STANDARD		SOURCE	
		FUNCTIONING	FUNCTIONING-AT-RISK / NOT FUNCTIONING		
Microbial Communities	Periphyton Index of Biological Integrity (PIBI)	≥ 72	61-71	Hill et al., 2000 (Journal)	
	<b>Biological Indices</b>				
Macrophytes	Mean Trophic Rank (MTR)	> 65	25-65	Holmes et al., 1999 (Technical Report)	
	Reference Index (RI)	-50 to 100	-70 to -50	Meilenger, 2005 (Journal)	
	<b>Biological Indices</b>				
Macroinvertebrate Communities	Family-Level Biotic Index (FBI) Ranges	0.00-4.25	4.26-5.75	Hilsenhoff, 1988 (Journal)	
	WVSCI Ranges	Excellent to Very Good	Good to Fair	Fairly Poor to Very Poor	
		68-100	45-61	0-45	Gerritsen et al., 2000; WVDEP
		Very Good to Good	Gray Area to Fair	Poor to Very Poor	
		61-100	40-60	0-40	Burton J. and J. Gerritsen, 2003
		Exceptional to Similar to Ref.	Impaired Tier 1	Impaired Tier1 & 2	
	SOS Multimetric Index	7-12	N/A	Engel and Voshell, 2002	
		Acceptable	Unacceptable		

**APPENDIX A: STREAM FUNCTIONS PYRAMID (CONT.)**  
**d. PERFORMANCE STANDARDS TABLE**

<b>BIOLOGY</b>					
PARAMETER	MEASUREMENT METHOD	PERFORMANCE STANDARD			SOURCE
		FUNCTIONING	FUNCTIONING-AT-RISK	NOT FUNCTIONING	
Fish Communities	<b>Biological Indices</b>				
	Mid-Atlantic Highlands IBI	IBI > 72	IBI = 56 to 71	IBI < 56	McCormick et al., 2001
	Mid-Western Fish Community IBI	Good to Excellent 48-60	Fair 40-44	Poor 0-34	Karr et al., 1986
		Good to Excellent	Fair	Poor to No Fish	

