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Operational Draft Regional Guidebook for the Functional Assessment of High-gradient Ephemeral and Intermittent Headwater Streams in Western West Virginia and Eastern Kentucky

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Environmental Laboratory

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Operational Draft Regional Guidebook for the Functional Assessment of High-gradient Ephemeral and Intermittent Headwater Streams in Western West Virginia and Eastern Kentucky

U.S. Army Corps of Engineers

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Final report

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Abstract: The Hydrogeomorphic (HGM) Approach is a method for developing functional indices and the protocols used to apply these indices to the assessment of ecosystem functions at a site-specific scale. The HGM Approach was initially designed to be used in the context of the Clean Water Act Section 404 Regulatory Program permit review to analyze project alternatives, minimize impacts, assess unavoidable impacts, determine mitigation requirements, and monitor the success of compensatory mitigation. However, a variety of other potential uses have been identified, including the determination of minimal effects under the Food Security Act, design of restoration projects, and management of wetlands.

This report uses a modified HGM Approach to develop a Regional Guidebook to (a) characterize High-gradient Ephemeral and Intermittent Headwater Streams, known collectively as High-gradient Headwater Streams in eastern Kentucky and western West Virginia, (b) provide the rationale used to select functions for the headwater subclasses, (c) provide the rationale used to select model variables and metrics, (d) provide the rationale used to develop assessment models, (e) provide data from reference streams and document their use in calibrating model variables and assessment models, and (f) outline the necessary protocols for applying the functional indices to the assessment of stream functions.

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Preface

This work was performed by the U.S. Army Engineer Research and Development Center (ERDC) in cooperation with U.S. Army Corps of Engineers (USACE) District offices in Huntington, West Virginia, and Louisville, Kentucky. Funding was provided through the Wetlands Regulatory Assistance Program (WRAP).

This report was prepared by Chris V. Noble and Jacob F. Berkowitz, Environmental Laboratory, ERDC; and James Spence, Huntington District, USACE. This guidebook was developed in cooperation with an Assessment Team (A-Team) of experts familiar with high-gradient headwater streams in the Appalachian region of eastern Kentucky and western West Virginia. Much of the discussion in Chapter 4 is taken or modified from "A Regional Guidebook for applying the Hydrogeomorphic Approach to Assessing the Functions of Headwater Slope Wetlands in Mississippi and Alabama Coastal Plains." The following A-Team members made major contributions to the development of this guidebook: James Spence, Mike Hatten, and Noah Kennedy; Huntington District, USACE.

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1 Introduction

Background

The Hydrogeomorphic (HGM) Approach is a collection of concepts and methods for developing functional indices and subsequently using them to assess the capacity of a wetland to perform functions relative to similar wetlands in a region. For the purposes of this guidebook the HGM Approach was modified to assess the capacity of a stream reach to perform functions relative to similar streams in a region. The HGM Approach does not directly measure functions, but assesses ecosystem functions using measures of commonly identified structural components important to stream function and simple logic models. Data were collected on sites with common impacts and these data were compared to data from sites identified by a group of local experts (A-Team) as functioning at the highest level naturally sustainable on the landscape. The HGM Approach typically focuses on structural components that can be measured rapidly, during any time of the year, using basic ecological sampling procedures. HGM is not an intensive inventory, or meant to replace Environmental Impact Statements, Indices of Biological Integrity, or other methods that might be identified by regulatory agencies as necessary for the proposed project. The approach was initially designed to be used in the context of the Clean Water Act Section 404 Regulatory Program permit review process to consider alternatives, minimize impacts, assess unavoidable project impacts, determine mitigation requirements, and monitor the success of mitigation projects. However, a variety of other potential applications for the approach have been identified, including determining minimal effects under the Food Security Act, designing restoration projects, and managing streams.

On 16 August 1996, a National Action Plan (NAP) to Implement the Hydrogeomorphic Approach was adopted (Federal Register 1997). The NAP was developed cooperatively by a National Interagency Implementation Team consisting of the U.S. Army Corps of Engineers (USACE), U.S. Environmental Protection Agency (USEPA), Natural Resources Conservation Service (NRCS), Federal Highways Administration (FHWA), and U.S. Fish and Wildlife Service (USFWS). The NAP outlines a strategy to promote the development of Regional Guidebooks for assessing the functions of regional wetland subclasses using the HGM Approach;

provides guidelines and a set of tasks required to develop Regional Guidebooks; and solicits the cooperation and participation of federal, state, and local agencies, academia, and the private sector in this effort.

The sequence of tasks necessary to develop a Regional Guidebook outlined in the NAP was used to develop this Regional Guidebook (Table 1). An initial workshop was held in Logan, West Virginia, on 11-13 December 2007. This workshop was attended by hydrologists, soil scientists, wildlife biologists, and plant ecologists from state and federal agencies with knowledge of high-gradient (>4 percent slope) streams in the Appalachian Region of eastern Kentucky and western West Virginia. Based on the results of this workshop, three regional subclasses were defined and characterized: High-gradient Ephemeral and Intermittent, and High-gradient Perennial Streams. Only the first two subclasses are addressed in this guidebook. Other tasks completed at the workshop included: definition of the reference domain, selection of stream functions, identification of model variables, and development of conceptual assessment models.

Table 1: HGM guidebook development sequence.

Task	Description
1	Organize Regional Assessment Team (A-Team)
A.	Identify Assessment Team members
B.	Train A-Team in the HGM Approach
2	Identify and Prioritize Regional Subclasses
A.	Identify Regional Subclasses
B.	Prioritize Regional Subclasses
C.	Define Reference Domains
D.	Initiate Literature Review
E.	Develop Preliminary Characterization of the Selected Regional Subclasses
3	Construct the Conceptual Assessment Models
A.	Review Existing Assessment Models
B.	Identify and Define Functions
C.	Identify Assessment Model Variables
D.	Identify Field Measures and Scales of Measurement
E.	Define Relationship Between Model Variables and Functional Capacity
F.	Define Relationship Between Variables by Developing the Aggregation Equation for the Functional Capacity Index (FCI)

Task	Description
G.	Complete Precalibrated Draft of the Regional Guidebook (PDRG)
At this point the document should include a preliminary characterization of the streams, potential functions with definitions, list of model variables for each function, and a conceptual assessment model for each function with preliminary rational	
4	Peer Review Precalibrated Draft of the Regional Guidebook
A.	Distribute PDRG to Peer Reviewers
B.	Conduct Interdisciplinary, Interagency Workshop of PDRG
C.	Revise PDRG to Reflect Peer Review Recommendations
D.	Distribute Revised PDRG to Peer Reviewers for Comment
E.	Incorporate Final Comments from Peer Reviewers on Revisions Into PDRG
5	Calibrate and Field Test Assessment Models
A.	Identify Reference Field Sites
B.	Collect Data from Reference Field Sites
C.	Analyze Reference Wetland Data[1]
D.	Calibrate Model Variables Using Reference Data
E.	Verify / Validate Assessment Models
F.	Field Test Assessment Models for Repeatability and Accuracy
G.	Revise PDRG Based on Calibration, Verification, and Validation into a Calibrated Draft Regional Guidebook (CDRG)
At this point the document should include a final characterization of the streams, functions with definitions, model variables with definitions, calibrated assessment models, a summary matrix of reference data with explanation of how reference data were analyzed and used to calibrate assessment models, and reference stream location map.	
6	Peer Review Calibrated Draft of the Regional Guidebook
A.	Distribute CDRG to Peer Reviewers
B.	Revise CDRG to Reflect Peer Review Recommendations
C.	Distribute CDRG to Peer Reviewers for Final Comment on Revisions
D.	Incorporate Final Comments From Peer Reviewers on Revisions into the Operational Draft of the Regional Guidebook (ODRG)
7	Field Test Operational Draft of the Regional Guidebook
8	Transfer Technology in Operational Draft Regional Guidebook to End Users
A.	Train End Users in the Use of the ODRG
B.	Provide Continuing Technical Assistance to End Users of the ODRG
9	Revise Operational Draft of the Regional Guidebook and Publish
1 Federal Register (1997)	

Subsequently, fieldwork was conducted to collect data from reference stream reaches. These data were used to revise and calibrate the conceptual assessment models. In October 2009, field testing of a draft of the Assessment Protocol (Chapter 5) was conducted by some members of the A-Team and representatives from EPA and Corps Regulatory Headquarters staff. Also in October 2009, independent field testing of the draft Assessment Protocol was conducted by a team from URS Corporation. Based on comments from the field testing, changes were made to clarify and improve the Assessment Protocol.

Objectives

The objectives of this Regional Guidebook are to (a) characterize the high-gradient headwater streams in the Appalachian region of eastern Kentucky and western West Virginia, (b) describe and provide the rationale used to select functions for high-gradient ephemeral and high-gradient intermittent streams, (c) describe model variables and metrics, (d) describe the development of assessment models, (e) provide data from reference stream reaches and document their use in calibrating model variables and assessment models, and (f) outline the necessary protocols for applying the functional indices to the assessment of stream functions.

Scope

This guidebook is organized as follows: Chapter 1 provides the background, objectives, and organization of the guidebook. Chapter 2 summarizes the major components of the HGM Approach and the development and application phases required to implement the approach. Chapter 3 characterizes the high-gradient ephemeral and high-gradient intermittent stream subclasses in the Appalachian region of eastern Kentucky and western West Virginia in terms of geographical extent, climate, geomorphic setting, hydrology, vegetation, soils, and other factors that influence stream function. Chapter 4 discusses each of the functions, model variables, and functional indices. This discussion includes a definition of each function; a quantitative, independent measure of the function for the purposes of model validation; a description of the stream ecosystem and landscape characteristics that influence the function; a definition and description of model variables used to represent these characteristics in the assessment model; a discussion of the assessment model used to derive the functional index; and an explanation of the rationale used to calibrate the index with reference data. Chapter 5 outlines the steps in the assessment protocol for conducting a functional assessment of high-gradient ephemeral and intermittent streams in the Appalachian region of eastern Kentucky and western West Virginia. Appendix A presents a Glossary. Appendix B contains supplementary information on selected model variables.

It is possible to assess the functions of high-gradient ephemeral and intermittent streams in the Appalachian region of eastern Kentucky and western West Virginia using only the information contained in Chapter 5. Users should familiarize themselves with the information in Chapters 2-4 prior to conducting an assessment.

Regulatory agencies are responsible for determining permit requirements. For example, in recently disturbed locations or atypical circumstances, a regulatory body may require data from an adjacent undisturbed area to be evaluated and applied to the assessment report. In other cases, regulatory agencies may consider that recently or intentionally disturbed areas did not meet reference standard conditions prior to disturbance.

2 Overview of the Hydrogeomorphic Approach

As discussed in Chapter 1, the HGM Approach is a collection of concepts and methods for developing functional indices and using them to assess the capacity of a wetland to perform functions relative to similar wetlands in a region. While the HGM Approach was initially developed for the assessment of wetlands, the method can be applied to any ecosystem (Brinson et al. 1998) including streams (Rowe et al. 2009). For this guidebook, the HGM process has been adapted for the assessment of streams. The HGM Approach includes four integral components: (a) classification, (b) reference sites or reaches, (c) assessment models/functional indices, and (d) assessment protocols. During the development phase of the HGM Approach, these four components are integrated into a Regional Guidebook for assessing the functions of a regional subclass. Subsequently, during the application phase, end users, following the assessment protocols outlined in the Regional Guidebook, assess the functional capacity of selected stream reaches. Each of the components of the HGM Approach and the development and application phases are discussed in this chapter. More extensive discussions can be found in Brinson (1993; 1995a, 1995b); Brinson et al. (1995, 1996, 1998); Smith et al. (1995); Hauer and Smith (1998); Smith (2001); Smith and Wakeley (2001); and Wakeley and Smith (2001).

Although this Regional Guidebook is used to assess stream functions, the basic HGM approach was maintained. Definitions of the various stream types that this guidebook is intended to assess can be found in Chapter 3. The following discussion of HGM principles and approaches refers to reference wetlands, assessment models/functional indices, and the assessment protocol. These concepts are applied to streams and stream assessment in the Regional Guidebook.

Reference sites

Reference wetlands are wetlands selected to represent the range of variability that occurs in a regional subclass as a result of natural processes and disturbance (e.g., succession, channel migration, fire, erosion, and sedimentation) as well as cultural alteration. The Reference Domain is the geographic area occupied by the reference wetlands (Smith et al. 1995). Ideally, the geographic extent of the Reference Domain will mirror the geographic area encompassed by the regional subclass; however, this is not always possible due to time and resource constraints.

Reference sites serve several purposes. First, they establish a basis for defining what constitutes a characteristic and sustainable level of function across the suite of functions selected for a regional subclass. Second, they establish the range and variability of conditions exhibited by model variables and provide the data necessary for calibrating model variables and assessment models. Finally, they provide a concrete physical representation of ecosystems that can be observed and measured.

Reference standard wetlands are the subset of reference wetlands that perform the suite of functions selected for the regional subclass at a level that is characteristic in the least altered sites in the least altered landscapes. Table 2 outlines the terms used by the HGM Approach in the context of reference wetlands, but which in this guidebook are applied to streams.

Table 2: Reference wetland terms and definitions.

Term	Definition
Reference domain	The geographic area from which reference wetlands (streams) representing the regional subclass are selected (Smith et al. 1995).
Reference wetlands	A group of wetlands (streams) that encompass the known range of variability in the regional subclass resulting from natural processes and disturbance and from human alterations.
Reference standard wetlands	The subset of reference wetlands (streams) that perform a representative suite of functions at a level that is both sustainable and characteristic of the least human-altered wetland (stream reaches) in the least human-altered landscapes. By definition, functional capacity indices for all functions in reference standard streams are assigned a value of 1.0.
Reference standard wetland variable condition	The range of conditions exhibited by model variables in reference standard wetlands (streams). By definition, reference standard conditions receive a variable subindex score of 1.0.
Site potential (mitigation context)	The highest level of function possible, given local constraints of disturbance history, land use, or other factors. Site potential may be less than or equal to the levels of function in reference standard streams of the regional subclass.
Project target (mitigation context)	The level of function identified or negotiated for a restoration or creation project.
Project standards (mitigation context)	Performance criteria and/or specifications used to guide the restoration or creation activities toward the project target. Project standards should specify reasonable contingency measures if the project target is not being achieved.

Assessment models and functional indices

In the HGM Approach, an assessment model is a simple representation of a function performed by an ecosystem. It defines the relationship between one or more characteristics or processes of the ecosystem. Functional capacity is simply the ability of an ecosystem to perform a function compared to the level of performance in reference standard ecosystems within the same subclass.

Model variables represent the characteristics of the ecosystem and surrounding landscape that influence the capacity of an ecosystem to perform a function. Model variables are ecological quantities that consist of five components (Schneider 1994): (a) a name, (b) a symbol, (c) a measure of the variable and procedural statements for quantifying or qualifying the measure directly or calculating it from other measures, (d) a set of variables (i.e., numbers, categories, or numerical estimates (Leibowitz and Hyman 1997)) that are generated by applying the procedural statement, and (e) units on the appropriate measurement scale. Table 3 provides several examples.

Table 3: Components of a model variable.

Name (Symbol)	Measure / Procedural Statement	Resulting Values	Units (Scale)
Channel substrate size ($V_{SUBSTRATE}$)	Median size of the bed material	0.0 to >100.0	inches
Large woody debris (V_{LWD})	Number of pieces of LWD	0.0 to >100.0	count
Soil detritus ($V_{DETRITUS}$)	Percent cover of soil detritus	0 to 100	percent

Model variables occur in a variety of states or conditions in reference sites or reaches. The state or condition of the variable is denoted by the value of the measure of the variable. For example, percent soil detritus, the measure of the percent cover of soil detritus, could be large or small. Based on its condition (i.e., value of the metric), model variables are assigned a variable subindex. When the condition of a variable is within the range of conditions exhibited by reference standard sites or reaches, a variable subindex of 1.0 is assigned. As the condition deviates from the reference standard condition (i.e., the range of conditions within which the variable occurs in reference standard sites or reaches), the variable subindex is assigned based on the defined relationship between model variable condition and functional capacity. As the condition of a variable deviates from the conditions exhibited in reference standard sites or reaches, it receives a progressively lower subindex reflecting its decreasing contribution to functional capacity. In some cases, the variable subindex drops to zero. For example, when the percent cover of soil detritus is 82 percent or greater, the subindex score for soil detritus is 1.0. As the percent cover falls below 82 percent, the variable subindex score decreases on a linear scale to zero (Figure 1).

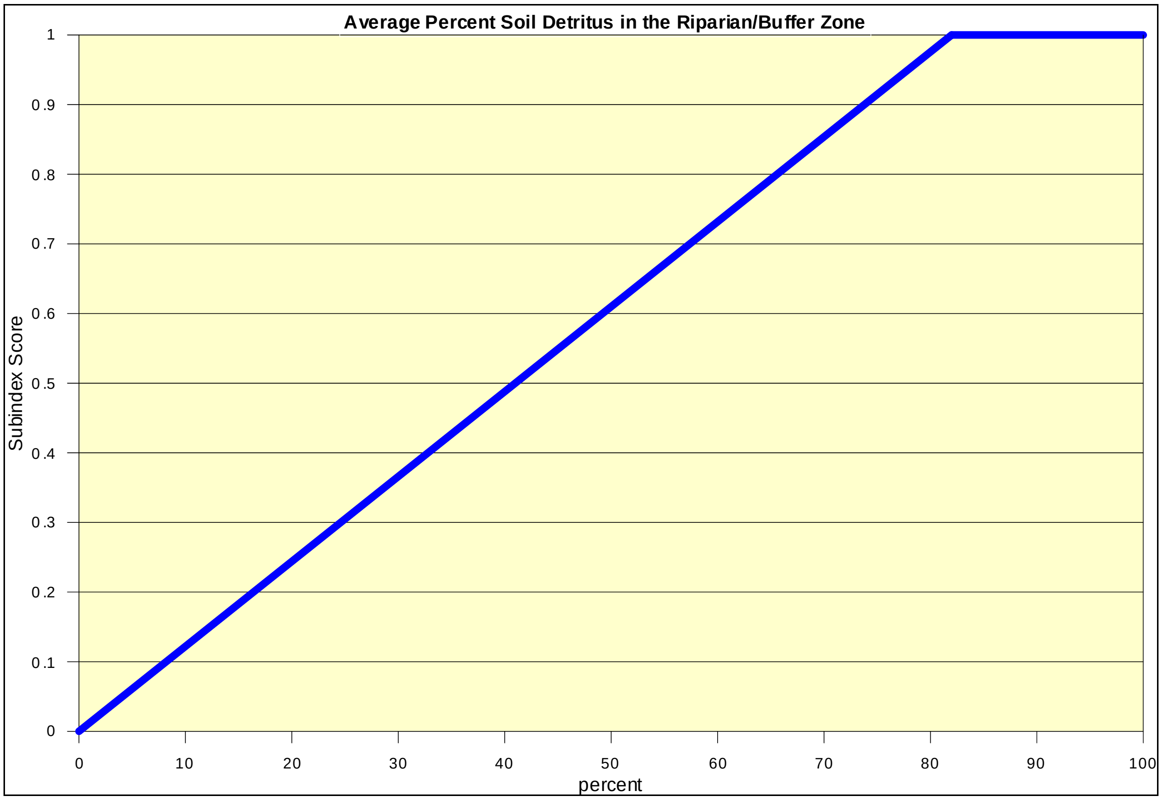


Figure 1. Example of linear scale used for determining variable subindex for the average percent soil detritus in the riparian/buffer zone.

Model variables are combined in an assessment model to produce a functional capacity index (FCI) that ranges from 0.0 to 1.0. The FCI is a measure of the functional capacity of an ecosystem relative to reference standard sites or reaches in the reference domain. Ecosystems with an FCI of 1.0 perform the function at a level characteristic of reference standard ecosystems within the same subclass. As the FCI decreases, it indicates that the capacity of the ecosystem to perform the function is less than that characteristic of reference standard sites or reaches.

Assessment protocol

The final component of the HGM Approach is the assessment protocol. The assessment protocol is a series of tasks and specific instructions that allow the user to assess particular ecosystem functions of an area using the functional indices in the Regional Guidebook. The first task is characterization of the site, which involves describing the ecosystem and the surrounding landscape, describing the proposed project and its potential impacts, and identifying the areas to be assessed. The second task is collecting the field data for model variables. The final task is data analysis, which involves calculation of functional indices.

Development phase

The development phase of the HGM Approach is carried out by an interdisciplinary team of experts known as the “Assessment Team” or “A-Team.” The product of the development phase is a Regional Guidebook for assessing the functions of a specific regional subclass (Figure 2). In developing a Regional Guidebook, the A-Team will complete the following major tasks. After organization and training, the first task of the A-Team is to classify the ecosystems within the region of interest into regional subclasses using the principles and criteria of the HGM Classification (Brinson 1993; Smith et al. 1995). Next, focusing on the specific regional

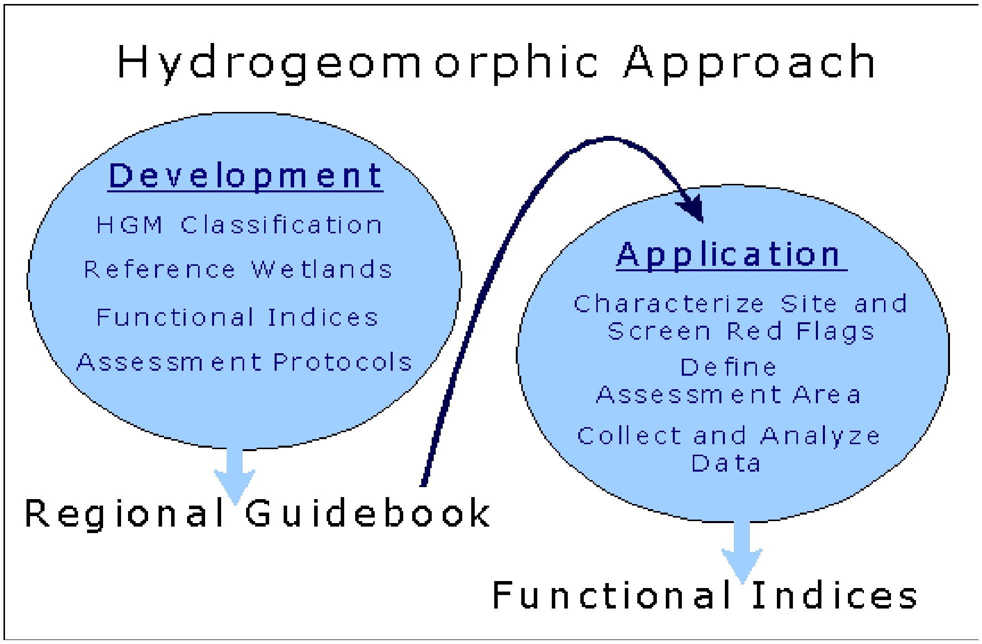


Figure 2. Development and application phases of the HGM Approach

subclasses selected, the A-Team develops an ecological characterization or functional profile of the subclass. The A-Team then identifies the important functions, conceptualizes assessment models, identifies model variables to represent the characteristics and processes that influence each function, and defines metrics for quantifying model variables. Next, reference sites or reaches are identified to represent the range of variability exhibited by the regional subclass. Field data are then collected from the reference sites or reaches and used to calibrate model variables and verify the conceptual assessment models. Finally, the A-Team develops the assessment protocols necessary for regulators, managers, consultants, and other users to apply the indices to the assessment of functions. Table 1 provides the steps usually involved in this general sequence.

Application phase

The Application Phase involves two steps. The first is using the assessment protocols outlined in the Regional Guidebook to carry out the following tasks (Figure 2).

a. Define assessment objectives.
b. Characterize the project site.
c. Screen for red flags.
d. Define the Assessment Area.
e. Collect field data.
f. Analyze field data.

The second step is to apply the results of the FCI assessment to the appropriate decision-making process of the permit review sequence, such as alternatives analysis, minimization, assessment of unavoidable impacts, determination of compensatory mitigation, design and monitoring of mitigation, comparison of management alternatives or results, determination of restoration potential, or identification of acquisition or mitigation sites or reaches.

3 Characterization of High-gradient Ephemeral and Intermittent Streams of the Appalachian Mountain Region of Eastern Kentucky and Western West Virginia

Regional subclass and reference domain

This regional assessment method was developed to assess the functions of High-gradient Ephemeral and Intermittent Streams (known collectively as High-gradient Headwater Streams of the Appalachian Mountain Region of eastern Kentucky and western West Virginia including portions of Major Land Resource Areas (MLRA), 125 – Cumberland Plateau and Mountains, and 126 – Central Allegheny Plateau 127 – Eastern Allegheny Plateau and Mountains (Figure 3) (USDA Natural Resources Conservation Service 2006). Ephemeral streams have flowing water only during, and for a short duration after, precipitation events in a typical year. Ephemeral streambeds are located above the water table year-around. Groundwater is not a significant source of water for the stream. Runoff from rainfall is the primary source of water for stream flow (Federal Register 2007). They typically have flowing water for a few hours to a few days after a storm event and have no discernable floodplain (Figure 4). In contrast, intermittent streams have flowing water during certain times of the year, when groundwater provides water for stream flow. During dry periods, intermittent streams may not have flowing water. Runoff from rainfall is a supplemental source of water for stream flow (Federal Register 2007). This guidebook is not designed to be applied to streams classified as perennial, where year-round flow throughout the channel system is the normal condition.

Development of this guidebook was initiated in part to meet the needs of federal and state agencies for a procedure to assess potential impact and mitigation reaches of streams in eastern Kentucky and western West Virginia.

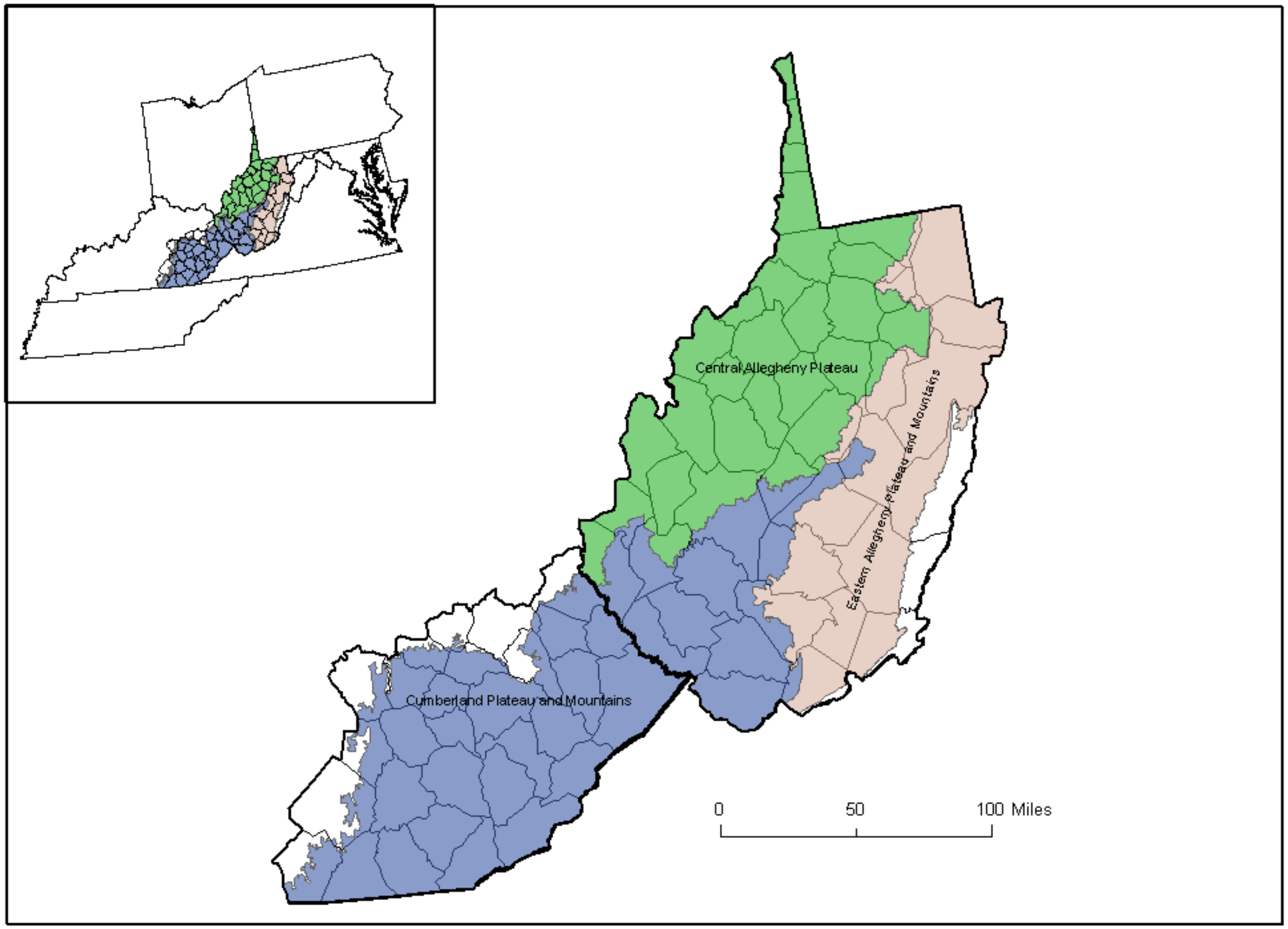


Figure 3. Map of the reference domain for high-gradient headwater streams in western West Virginia and eastern Kentucky.

Figure 4. A photo illustrating the lack of a floodplain associated with high-gradient ephemeral stream channels.

The *potential* reference domain (the maximum geographic extent of the subclass) (Smith et al. 1995) includes much of the Appalachian Plateau from Pennsylvania to Tennessee. The models in this guidebook were calibrated using data from reference stream reaches in eastern Kentucky and western West Virginia, but they may be applicable to high-gradient streams located elsewhere in the potential reference domain. Persons wishing to apply the models in other areas should verify that existing reference data adequately describe local conditions. If not, additional reference data should be collected and used to revise plant lists and recalibrate subindex graphs.

Characterization of the regional subclass

Physiography and geology

The Reference Domain is an area of hilly to mountainous terrain, ranging from 827 ft (252 m) in elevation at Huntington, WV to about 4,100 ft (1,263 m) in eastern Kentucky (Bailey 1995). This area is primarily in the

Kanawha Section of the Appalachian Plateaus Province of the Appalachian Highlands. The southern edge is in the Cumberland Plateau Section of the same province and division. The southwestern edge is in the Lexington Plain Section of the Interior Low Plateaus Province of the Interior Plains. The area has narrow, level valleys and narrow, sloping ridgetops that are separated by long, steep and very steep side slopes dissected by numerous stream channels with no or very narrow stream floodplains. Local relief is about 160 to 330 ft (50 to 100 m) (USDA Natural Resources Conservation Service 2006).

Alternating beds of sandstone, siltstone, clay, shale, and coal of Pennsylvanian age form the bedrock in this area. Similar rocks of Mississippian age occur along the southwest edge of the area in Kentucky. Unconsolidated deposits of silt, sand, and gravel are present in the major river valleys. The lower parts of many hillslopes have a thin layer of colluvium (USDA Natural Resources Conservation Service 2006).

Climate

The climate within the Reference Domain is characterized by hot, humid summers and mild winters (Bailey 1995). Average annual temperatures range from 43-54 °F (6-12 °C), with summer temperatures averaging in the 70s and winter temperatures in the 50s. Precipitation averages 34-51 in. (86-130 cm) annually and increases with elevation. Highest rainfall amounts occur in midsummer, and the lowest occur in autumn and early winter. Rainfall typically occurs as high-intensity thunderstorms in summer. Overall, this climate provides a water surplus in the reference domain, with precipitation exceeding potential evapotranspiration for much of the year. However, water deficits (evapotranspiration exceeds precipitation) usually occur in summer (June - August). Snowfall occurs annually and ranges from 35 in. (89 cm) in the southern part to more than 50 in. (127 cm) at higher elevations in the northern part of the reference domain (USDA Natural Resources Conservation Service 2006). The growing season based on soil temperatures above 41 °F (5 °C) at 20 in. (50 cm) depth (USDA Natural Resources Conservation Service 1999) is generally April through October throughout the reference domain.

Geomorphic setting

Within the reference domain, high-gradient ephemeral and intermittent streams occur primarily as linear drainages within steep to very steep upland landscapes (Figure 5). For the purpose of this guidebook, high-gradient ephemeral and intermittent streams are defined as streams in the upper portions of the drainage basin, that have channel slopes greater than 4 percent, and whose hydrologic inputs are precipitation and overland flow. Intermittent streams typically receive groundwater during a portion of the year. Stream channels have low sinuosity, but they may have common-to-many step pools and would classify as A, Aa, or Aa+ channels under the system of Rosgen (1996) with gravel- or cobble-controlled channels within Type I valleys. This guidebook is not intended to assess streams that are dominated by a bedrock substrate (in greater than 50 percent of the stream reach). The surrounding drainage basin contributing to the channels is typically forested with hardwood trees and woody shrubs on moderately steep to very steep slopes (USDA Natural Resources Conservation Service 2006). Within the reference domain, drainage basins can be small (1 acre) and many stream channels do not appear on standard 1:24,000 USGS topographic maps.

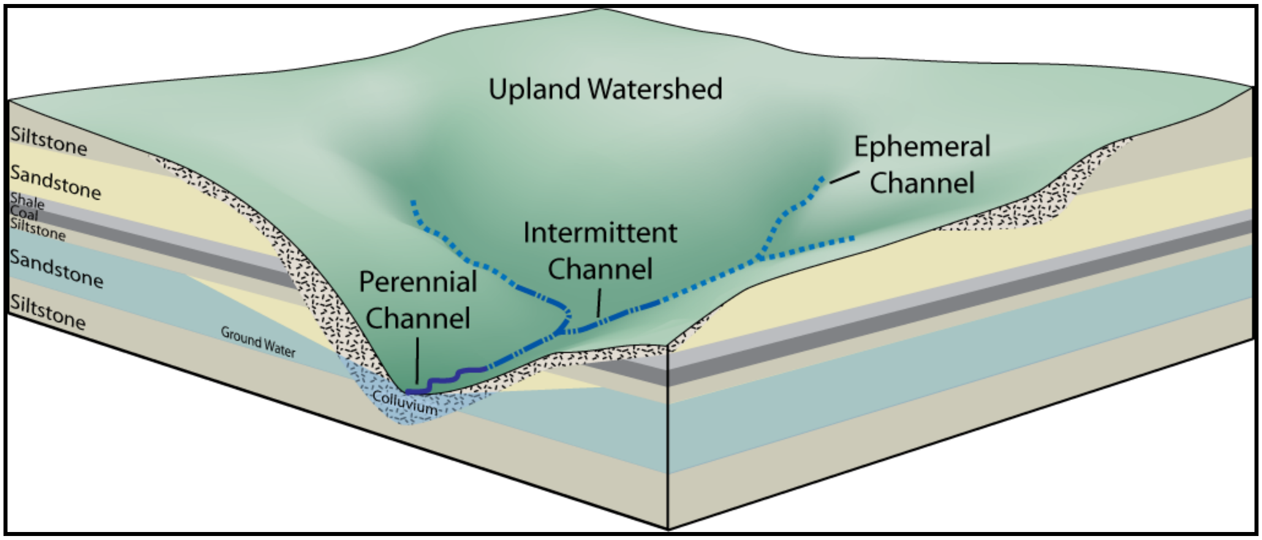


Figure 5. Illustration of ephemeral and intermittent channels within a typical landscape setting in eastern Kentucky and western West Virginia.

Hydrologic regime

Flow rates in these streams are commonly less than 0.5 cubic ft per second (cfs) (0.014 cubic m per second (cms) (Paybins 2003). Typically, ephemeral streams grade into intermittent streams, but they can flow directly into perennial streams, which have flowing water nearly all year in most years. The addition of groundwater typically increases the duration of flow in intermittent streams to several months each year, but they are usually dry during the driest months of the year (Figure 6). Intermittent streams typically flow into perennial streams. In this region ephemeral streams are nearly always first-order streams while intermittent streams are typically first- or second-order streams (Strahler 1952). Another name used to refer to high-gradient ephemeral and intermittent streams in the region is headwater streams.

Figure 6. A photo illustrating the absence of flowing water during dry periods in a high-gradient intermittent stream channel.

Soils

Soils in the drainage basin surrounding high-gradient headwater streams are extremely variable, ranging from shallow to very deep, excessively drained to somewhat poorly drained, and skeletal to clayey in texture (USDA Natural Resources Conservation Service 2006). The most current soils information for the reference domain can be found on the web soil survey at http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx

Flora

The area is dominated by deciduous forest vegetation. White oak (*Quercus alba*), northern red oak (*Quercus rubra*), scarlet oak (*Quercus coccinea*), red maple (*Acer rubrum*), sugar maple (*Acer saccharum*), mockernut hickory (*Carya alba*), red hickory (*Carya ovalis*), American beech (*Fagus grandifolia*), chestnut oak (*Quercus prinus*), black oak (*Quercus velutina*), American basswood (*Tilia americana*), eastern hemlock (*Tsuga canadensis*), shagbark hickory (*Carya ovata*), black birch (*Betula lenta*), tuliptree (*Liriodendron tulipifera*), blackgum (*Nyssa sylvatica*), white ash (*Fraxinus americana*), eastern sycamore (*Platanus occidentalis*), and sweetgum (*Liquidambar styraciflua*) are common forest species across the reference domain (Strausbaugh and Core 1978; USDA 2009).

Common shrub species associated with headwater areas include, but are not limited to; northern spicebush (*Lindera benzoin*), American witchhazel (*Hamamelis virginiana*), pawpaw (*Asmina triloba*), wild hydrangea (*Hydrangea arborescens*), flowering dogwood (*Cornus florida*), alternateleaf dogwood (*Cornus alternifolia*), possumhaw (*Ilex decidua*), southern arrowwood (*Viburnum dentatum*), hobblebush (*Viburnum alnifolium*), and great laurel (*Rhododendron maximum*) (Strausbaugh and Core 1978; USDA 2009).

Herbaceous species that are commonly found in the understory in the drainage basin of high-gradient ephemeral and intermittent streams are dogtooth violet (*Erythronium americanum*), jack in the pulpit (*Arisaema triphyllum*), white fawnlily (*Erythronium albidum*), largeflower bellwort (*Uvularia grandiflora*), white clintonia (*Clintonia umbellulata*), feathery false lily of the valley (*Smilacina racemosa*), Indian cucumber (*Medeola virginiana*), smooth Solomon’s seal (*Polygonatum biflorum*), mayapple (*Podophyllum peltatum*), bloodroot (*Sanguinaria canadensis*), Virginia wildrye (*Elymus virginicum*), rattlesnake plantain (*Goodyera pubescens*), eastern hayscented fern (*Dennstaedtia punctilobula*), marginal woodfern (*Dryopteris marginalis*), Christmas fern (*Polystichum acrostichoides*), asplenium ladyfern (*Athyrium asplenioides*), and northern maidenhair (*Adiantum pedatum*) (Strausbaugh and Core 1978; USDA 2009).

Fauna

Headwater streams provide habitat to a diverse community of macroinvertebrate and amphibian species that require water or moist soils to complete at least a portion of their life cycles. Over 300 species of insects have been identified in headwater streams within the reference domain (Pond and McMurray 2002). Stoneflies (Plecoptera), mayflies (Ephemeroptera), dragonflies (Odonata), beetles (Coleoptera), caddisflies (Trichoptera), moths (Lepidoptera), true flies (Diptera), and alderflies (Megaloptera) are insect orders that have been found in headwater streams within the Reference Domain (Lee and Samuel 1976).

Salamanders often replace fish as the primary vertebrate predators in headwater streams (Jung et al. 2004). Salamanders commonly found within the reference domain include the northern two-lined (*Eurycea b. bislineata*), mountain dusky (*Desmognathus ochrophaeus*), northern spring (*Gyrinophilus p. porphyriticus*), northern red (*Pseudotriton r. rubber*), longtail (*Eurycea longicauda*), northern dusky (*Desmognathus f. fuscus*), Appalachian seal (*Desmognathus monticola*) (Rocco and Brooks 2000), blackbelly (*Desmognathus quadramaculatus*) (Russell et. al 2004), black mountain (*Desmognathus welteri*), and southern two-lined (*Eurycea cirrigera*) salamanders (Knapp et al. 2003).

Anthropogenic alterations

Most of the forests within the drainage basin surrounding high-gradient headwater streams within the reference domain were cleared of trees before 1900 (Petranka et al. 1993). Since that time, many areas have been allowed to regrow in native hardwood trees and other areas have had additional forest clearing in the adjacent upland landscape for agricultural production or pasture. Common land-use changes that directly or indirectly impact high-gradient headwater streams in the reference domain include the construction of county, state, and interstate highways, logging access roads and bridges, urban development, and filling as part of the coal-mining process.

4 Variables, Functions, and Assessment Models

Variables

Data for this guidebook were collected on a total of 94 ephemeral and intermittent reference stream reaches within the high-gradient headwater stream subclass within the reference domain. Ten sites were identified by the A-Team to be reference standard stream reaches. The following variables are used to assess the functions that are performed by high-gradient headwater streams in eastern Kentucky and western West Virginia:

a. Channel Canopy Cover
b. Channel Substrate Embeddedness
c. Channel Substrate Size
d. Potential Channel Bank Erosion
e. Large Woody Debris
f. Riparian/Buffer Zone Tree Diameter
g. Riparian/Buffer Zone Snag Density
h. Riparian/Buffer Zone Sapling/Shrub Density
i. Riparian/Buffer Zone Species Richness
j. Riparian/Buffer Zone Soil Detritus
k. Riparian/Buffer Zone Herbaceous Cover
l. Watershed Land-use

Each variable is defined and the rationale for its selection is discussed in the following paragraphs. The relationship of each variable to functional capacity is also given, based on measurements taken in reference stream reaches in eastern Kentucky and western West Virginia. Procedures for measuring each variable in the field can be found in Chapter 5.

Channel canopy cover ($V_{CCANOPY}$)

This variable is the average percent cover of canopy over the stream channel. Stream canopy cover is determined using a visual estimate. The use of comparison charts (Figures B1 and B2) can be helpful in making visual estimates of percent canopy cover. In reference standard reaches, stream canopy cover values were ≥88 percent. Figure 7 shows a channel with >90 percent canopy cover. If $V_{CCANOPY}$ is <20 percent (Figure 8) then neither Riparian/Buffer Zone Tree Diameter (V_{TDBH}) nor Channel Canopy

Figure 7. Stream reach exhibiting greater than 90 percent canopy cover over the stream channel.

Figure 8. Stream reach exhibiting zero canopy cover over the stream channel after clear cutting.

Cover ($V_{CCANOPY}$) is used to determine functional capacity indices (FCI) and Riparian/Buffer Sapling/Shrub Density (V_{SSD}) and Riparian/Buffer Herbaceous Cover (V_{HERB}) are used to determine FCIs. $V_{CCANOPY}$ applies to the habitat function only.

Channel canopy cover affects the temperature, nutrient cycling, and habitat of riparian and stream ecosystems. Canopy coverage is inversely related to daytime surface temperature (Todd and Rothermel 2006). Reduced canopy coverage can accelerate desiccation and lead to mortality in amphibians (Rothermel and Luhring 2005) and increased surface temperature increases detrital decomposition, altering amphibian habitat. Changes in canopy cover and composition affect the quality of stream inputs from the riparian zone (Wipfli et al. 2007) and the flow of biomass from headwaters to downstream reaches. Stem flow and canopy leaching are additional sources of nutrients to riparian and aquatic systems (Mulholland 1992). Riparian plant communities provide habitat and are affected by canopy shading, with shade-tolerant species germinating below a full canopy and early successional species dominating in areas where canopy is absent (Moorhead and Coder 1994).

Channel canopy cover within the reference domain ranged from 0-100 percent. Based on data collected at reference standard stream reaches, channel canopy cover values ≥88 percent are assigned a variable subindex score of 1.0. Stream reaches lacking channel canopy cover (<20 percent) are assigned a subindex of 0.1. At 20 percent cover, trees still provide some shade and temperature moderation to the channel, but at a much reduced level reflected in the subindex score of 0.1. Below 20 percent, trees are not measured and shrubs and herbaceous cover become the primary influence on the function of the stream channel. A linear increase in the subindex score as channel canopy cover increases from 0.1 at 20 percent canopy cover to 1.0 at 88 percent canopy cover is assumed (Figure 9). The mean for data collected within the reference domain was 82 percent.

Channel substrate embeddedness (V_{EMBED})

This variable represents the average embeddedness of the stream substrate. Channel substrate embeddedness is defined as an index based on the percentage of fine soil particles (sand, silt and clay) that surround coarse (gravel, cobble, and boulder) substrate materials (Table 4). Embeddedness is a direct indication of fine soil particles delivered to the stream channel from erosion of the surrounding drainage basin and not being removed from the stream system by stream flows (Chang 2006).

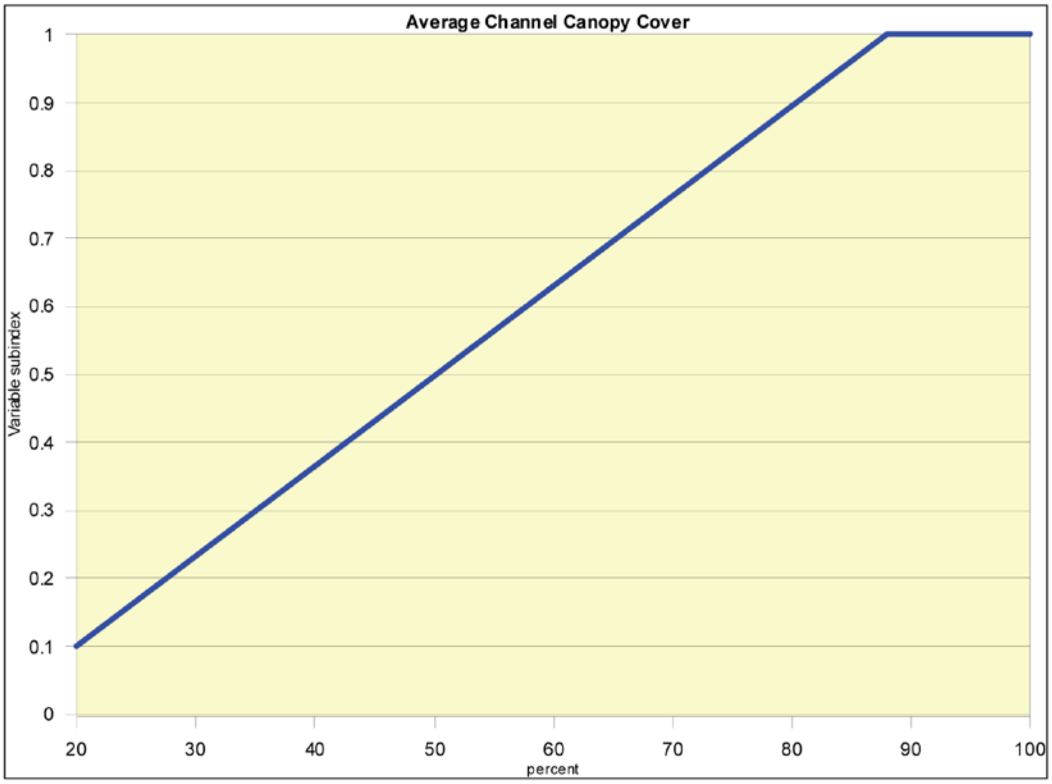


Figure 9. Relationship between average percent channel canopy cover ($V_{CCANOPY}$) and functional capacity.

Table 4: Embeddedness rating for gravel, cobble, and boulder particles (rescaled from Platts et al. 1983).

Rating	Rating Description
5	<5 percent of surface covered, surrounded, or buried by fine sediment (or bedrock)
4	5 to 25 percent of surface covered, surrounded, or buried by fine sediment
3	26 to 50 percent of surface covered, surrounded, or buried by fine sediment
2	51 to 75 percent of surface covered, surrounded, or buried by fine sediment
1	>75 percent of surface covered, surrounded, or buried by fine sediment (or artificial substrate)

Channel substrate embeddedness is important is important to stream hydrology and habitat. As the spaces around large particles (Figures 10 and B3) become filled with fine particles, streambed roughness is reduced, which reduces energy dissipation (Wilcock 1998). The reduction of voids limits the available cover for macroinvertebrates (Merrit and Cummins 1996) and salamanders, obstructs respiration, and interferes with feeding (Wiederholm 1984). The change in particle size can reduce the diversity and density of biotic communities (Lenat et al. 1981). V_{EMBED} applies to the hydrology, biogeochemical, and habitat functions.

Figure 10. Location with an embeddedness rating of 1 (>75 percent of the surface covered by fine sediments).

In high-gradient headwater streams in eastern Kentucky and western West Virginia, all reference standard reaches had average embeddedness ratings of 3.5 to 4 (Table 4). An average embeddedness rating less than 3.5 is assumed to reduce cover for macroinvertebrates and amphibians outside of the range observed under reference standard conditions. Low channel substrate embeddedness ratings are assumed to correspond to lower macroinvertebrate numbers and species diversity (Figure 10) (Snyder et al. 2003). On the other hand, average embeddedness ratings >4 (≤25 percent embeddedness) were found in constructed channels and receive a reduced subindex score (Figure 11).

Channel substrate size ($V_{SUBSTRATE}$)

For the purposes of this guidebook, channel substrate size is defined as the median size of the bed material within the stream channel (Figure 12). Substrate size is important for dissipating stream energy, and providing cover and habitat for macroinvertebrates and salamanders (Gordon et al. 2006). $V_{SUBSTRATE}$ applies to the hydrology and habitat functions.

The median size of substrate in reference standard stream reaches ranged from 2 to 6 in. (5 to 15 cm). Median substrate scores between 2 and 6 in. (5 to 15 cm) receive a variable subindex score of 1.0. Within the reference data set, the median substrate size ranged from 0 to 20 in. (51 cm). Stream reaches with a median substrate size >6 in. (15 cm) are assumed to have a linear decrease to a subindex score of 0.1 at 20 in. (51 cm) (Figure 13). This variable does not reach zero for large substrate sizes, which include bedrock. Large substrate sizes still provide energy dissipation and potential habitat. Substrate composed of concrete or other artificial channel materials is assigned a value of zero. The median substrate size for all reference stream reaches was 3.5 in. (9 cm). See Chapter 5 and Appendix B for guidance for determining channel substrate size.

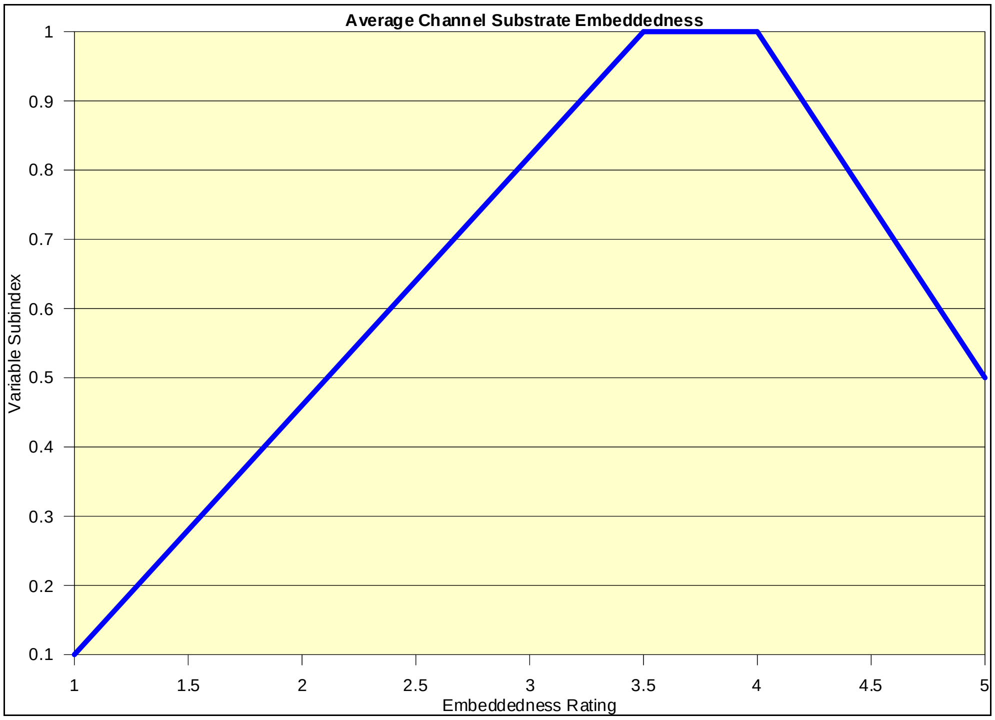


Figure 11. Relationship between average embeddedness rating (V_{EMBED}) and functional capacity.

Figure 12. Substrate in an intermittent reach within the high-gradient headwater stream subclass.

Figure 13. Relationship between median channel substrate size ($V_{SUBSTRATE}$) and functional capacity.

A median substrate size <2 in. (5 cm) represents a negative impact to the stream, because it reflects an increase in channel sedimentation due to past or current erosion of the streambank or surrounding watershed that is not being moved downstream by the current stream energy. Fine sediments fill spaces between coarse particles and reduce habitat for macroinvertebrates and salamanders. As fine sediments increase, there is a reduction in energy dissipation.

Potential channel bank erosion *(V_{BERO})*

This variable quantifies the percent of stream channel bank displaying signs of erosion or bare streambank with exposed soil that could contribute fine particles to the stream channel. Potential channel bank erosion is defined as disturbed, scoured sections of the stream channel bank. Eroded banks have exposed soil above or below the waterline that may contribute sediment to the channel and increase substrate embeddedness. The stream channel bank has been disturbed by the movement of water, the scraping of debris within the stream channel, or streambank subsidence caused by undercutting and other fluvial processes (bank failure). It is not necessary for the entire height of the stream channel bank to exhibit erosion. Any portion of the bank exhibiting erosion should be included in this measurement. Areas of erosion are recorded for each side of the stream and added together to yield a total length of stream channel bank displaying erosion for the entire stream assessment reach (SAR) or partial stream assessment reach (PSAR) (Figure 14). This value is then converted to represent the percent of streambank displaying erosion (Equation 1). V_{BERO} applies to the hydrology function only.

$$\left(\frac{\text{ft. left bank erosion} + \text{ft. right bank erosion}}{\text{stream reach length}}\right) \times 100 = \text{\% stream channel erosion} \tag{1}$$

The erosion of the stream channel bank and subsequent release of sediments change the chemistry, biology, water quality and physical form of downstream reaches. Channel bank erosion plays an important role in stream channel degradation and contributes to watershed sediment yields (Wynn and Mostaghimi 2006). Channel bank erosion and retreat also impact riparian ecosystems, floodplain residents, and threaten streamside infrastructure (Wynn and Mostaghimi 2006).

Figure 14. Intermittent stream channel with short section of eroded bank on the left channel and no bank erosion on right channel bank.

Channel bank erosion is caused by natural and anthropogenic processes. Changes in channel form result from frost action, flooding, trampling, agriculture, and other factors (Gordon et al. 2006; Lenat 1984). Channel bank erosion occurs as a result of several interrelated processes. Fluvial processes erode soil particles from the stream channel bank by direct physical action. Subaerial and other climatic processes lead to cracking and weakening of the soil, which increases the efficiency of fluvial erosion. In headwater streams, subaerial processes (e.g., soil desiccation and freeze-thaw cycling) are a major cause of streambank retreat as soils are broken into small peds and crumbs that can be easily eroded by fluvial action (Wynn and Mostaghimi 2006).

Measurements of streambank erosion within the reference domain ranged from 0 to 200 percent when banks on both sides of the channel were eroded the entire length of the stream reach. Based on data collected at reference standard stream reaches, streambank erosion values between 0 and 14 percent are assigned a variable subindex score of 1.0. Stream reaches with greater amounts of streambank erosion are assigned a lower subindex score. The subindex score is assumed to decrease linearly beyond the reference standard range as potential channel bank erosion increases (Figure 15).

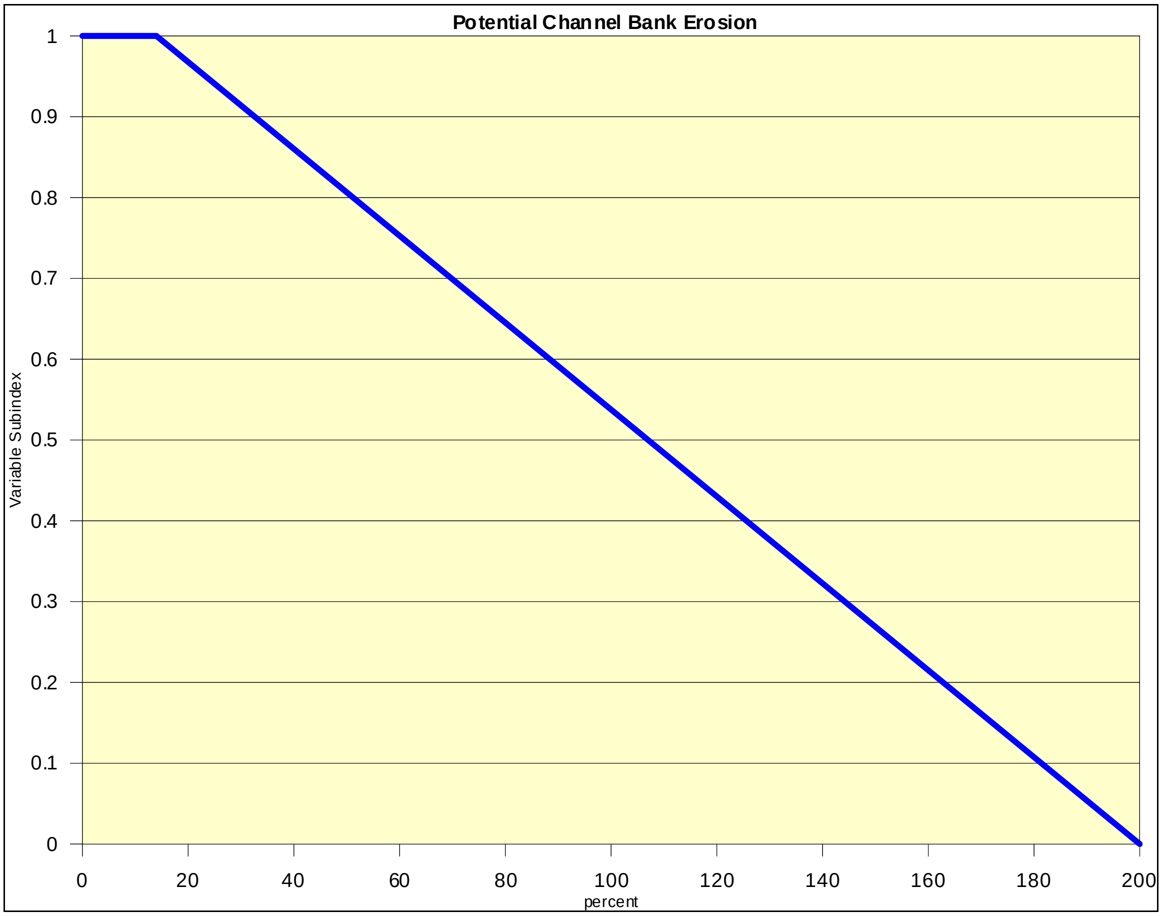


Figure 15. Relationship between percent channel bank erosion (V_{BERO}) and functional capacity.

Large woody debris (V_{LWD})

This variable is defined as the number of individual pieces of down woody stems per 100 ft (30.5 m) of stream reach within the channel and the riparian/buffer zone. The riparian buffer zone is defined as a plot that is 50 ft (15.2 m) wide (25 ft (7.6 m) on each side) perpendicular to the channel on both sides of the channel and the entire length of the SAR or PSAR. This plot includes the channel (Figure 16). V_{LWD} is defined as the number of down woody stems ≥4 in. (10 cm) in diameter and ≥36 in. (91 cm) long. V_{LWD} is measured using a count along the entire SAR or PSAR and includes materials within the stream channel and in the riparian/buffer zone (Figure 16). V_{LWD} is an indicator of long-term

Figure 16. Stream channel and riparian/buffer zone containing large woody debris (V_{LWD}).

(greater than two years) accumulation of organic matter primarily from vegetation within the riparian/buffer zone. Large woody debris is a source of food and cover for macroinvertebrates and salamanders (Lockaby et al. 2002). V_{LWD} applies to hydrology, biogeochemistry, and habitat functions.

Large woody debris provides an interface between aquatic and terrestrial ecosystems and the importance of large woody debris in temperate streams has been well documented (Hilderbrand et al. 1997). Large woody debris affects channel geomorphic processes including the formation of pools and riffles, channel roughness, and channel shifting (Montgomery and Piegay 2003; Scherer 2004). Large woody debris also dissipates the energy of water within the stream channel and decreases the power of tributaries entering the stream from the surrounding watershed. Large woody debris decreases sediment transport power in stream ecosystems (Hedman et al. 1996; Naiman et al. 1989) and creates habitat for macroinvertebrates. Removal of large woody debris has been shown to result in stream down-cutting and widening, increased transport of bedload materials, and streambank subsidence (Hilderbrand et al. 1997). Too much large woody debris can result from ice or wind storms, insects, fire, disease, or anthropogenic disturbance, such as poor forest management practices. The result of increased large woody debris is an increase in organic matter inputs to the stream system. This does not represent a natural self-sustaining ecosystem and therefore receives a reduced subindex score.

Large woody debris influences the movement, storage, and addition of organic matter into stream ecosystems (Hilderbrand et al. 1997) and is a source of particulate organic matter (Fischenich and Morrow 2000). Pools created by water currents around LWD trap and store organic matter (leaf litter, twigs, etc.) for later release (Scherer 2004). Wood in channel and stream ecosystems provides velocity refuge and overhead cover for a variety of species (Fischenich and Morrow 2000). The presence of LWD provides substrate and promotes invertebrate colonization and establishment (Hilderbrand al. 1997; Fischenich and Morrow 2000).

On reference standard reaches within the reference domain, counts of large woody debris ranged from 8 to 20 pieces per 100 ft (30.5 m) of stream reach. Stream reaches lacking large woody debris are assigned a subindex score of 0. A linear increase in subindex score is assumed for the amount of large woody debris ranging from 0 to 8. A linear decrease is assumed as the amount of large woody debris increases above 20 to a subindex score of 0.5 at 60 pieces of large woody debris per 100 ft (30.5 m) (Figure 17).

Riparian/buffer zone tree diameter (V_{TDBH})

This variable is the average diameter measured at breast height (dbh) of living woody plants within the riparian/buffer zone (Figure 18). Trees are included in this measurement when the tree is ≥4 in. (10 cm) in diameter. This variable is collected at stream reaches that contain ≥20 percent channel canopy cover ($V_{CCANOPY}$). If the channel canopy cover <20 percent, this variable is not used. Riparian/buffer zone dbh is measured by determining the diameter of all trees with dbh ≥4 in. (10 cm) located within the stream channel and riparian/buffer zone of the SAR or PSAR. The mean dbh is calculated by summing all dbh measurements recorded and dividing by the total number of trees measured. V_{TDBH} applies to the biogeochemistry and habitat functions.

The riparian/buffer zone forms a region of interaction that connects the stream channel to the surrounding root systems, tree canopy, and landscape. Riparian/buffer zone forests regulate many of the ecological functions of stream ecosystems. Chemical, physical, and biotic integrity improve with forest maturity (Rheinhardt et al. 2009). Mature forests provide structural features lacking in younger forest stands, and dbh as used in V_{TDBH} is a reasonable surrogate for successional status (Rheinhardt et al. 2009). Tree stands in the Riparian/Buffer Zone affect stream lighting, temperature, nutrient cycling, hydrology, physical structure, habitat, and food sources (Hession et al. 2000). Riparian/buffer zone forests also provide streambank structure and prevent erosion. Leaves and branches from trees in the riparian/buffer zone provide nutrients to aquatic species, and leaf litter provides a major energy base for low-order, headwater streams (Benfield et al. 1991). Fallen trees provide large woody debris (bole, limb, root wad) to the stream channel, providing an important component to the ecology and morphology of headwater streams (Hedman et al. 1996). It also has been shown that forested riparian/buffer zones promote stream stability and water quality more effectively than areas dominated by lower herbaceous strata (Osborne and Kovacic 1993).

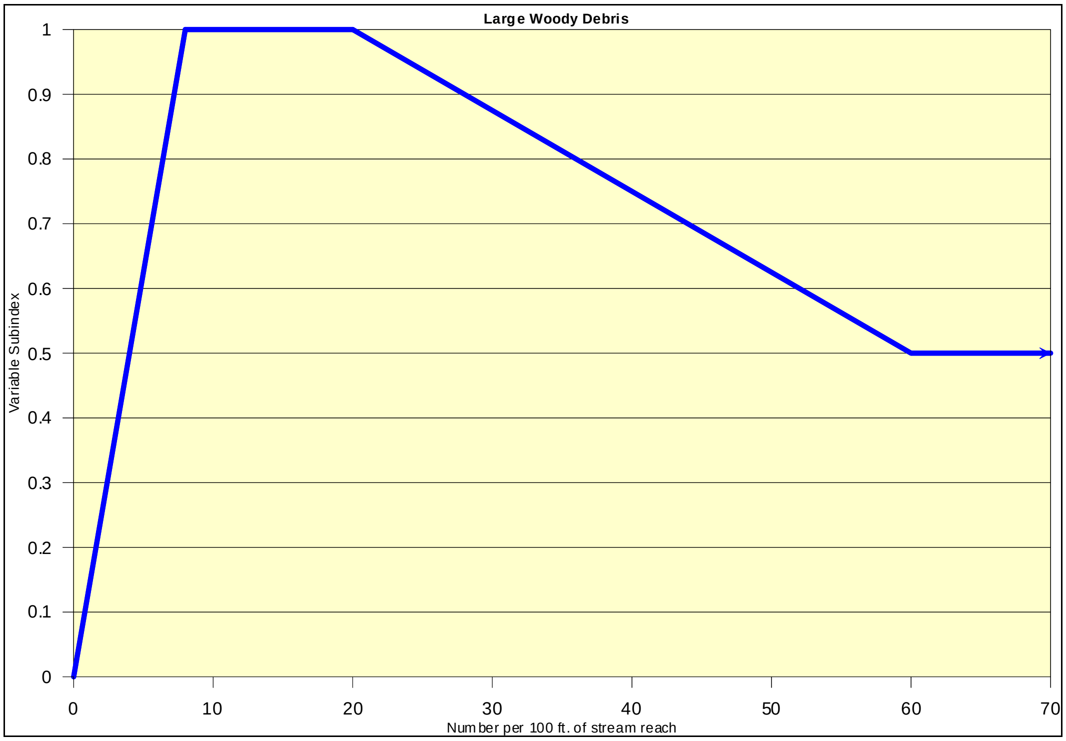


Figure 17. Relationship between large woody debris (V_{LWD}) and functional capacity.

Figure 18: Stream reaches a) with, and b) without riparian/buffer zone forest.

The mean riparian/buffer zone tree diameter within the reference domain ranged from 5 to 18 in. (12.7 to 45.7 cm). Based on data collected at reference standard stream reaches, average dbh values ≥8.7 in. (22.1 cm) are assigned a variable subindex score of 1.0. A linear decrease in the subindex score from 1.0 to 0.1 is assumed as average dbh declines from reference standard range (Figure 19). V_{TDBH} cannot receive a subindex score of zero because even trees with a minimum dbh of 4 in. (10 cm) provide some organic matter and shade, and reduce erosion.

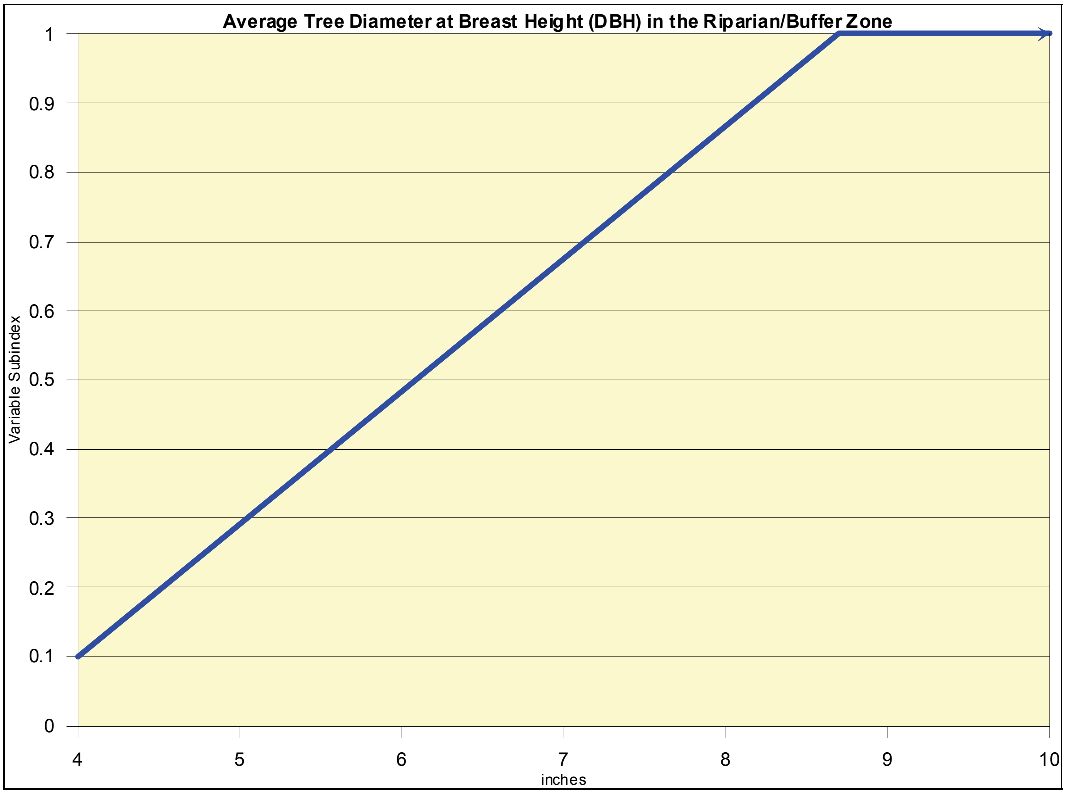


Figure 19. Relationship between average tree diameter in the riparian/buffer zone (V_{DBH}) at breast height and functional capacity.

Riparian/buffer zone snag density (V_{SNAG})

This variable is defined as the number of individual snags per 100 ft of the SAR or PSAR within the entire stream channel and riparian/buffer zone. Snags are defined as standing dead trees ≥4 in. (10 cm) in diameter and ≥36 in. (90 cm) in height (Figure 20). V_{SNAG} is standardized to a measurement of snags per 100 ft of stream reach. Snags occurring at the riparian/buffer zone boundary or falling partially in the riparian/buffer zone boundary are included in this measurement. V_{SNAG} only applies to the habitat function.

Snags are found in forests throughout the region and provide important resources to terrestrial and aquatic ecosystems (McComb and Muller 1983; Franklin et al. 1987). Snags provide habitat for many wildlife species (McComb and Muller 1983) and are an important source of nutrients and potential woody debris in riparian and stream ecosystems (Sharitz et al. 1992; Harmon et al. 1986). Snags influence channel and riparian morphology, surface runoff patterns, and decrease erosion (Franklin et al. 1987).

Figure 20. Lone snag.

The number of snags within the reference domain ranged from 0.0 to 8.0 per 100 ft of stream reach in the riparian/buffer zone. In reference standard stream reaches, the number of snags per 100 ft of stream ranged between 0.6 and 3.0. Stream reaches lacking snags within the riparian/buffer zone are assigned a subindex of 0.1. A linear increase and decrease in the subindex score as snag count diverges from the reference standard range is assumed (Figure 21), with variable subindex scores decreasing to 0.5 above 10 snags per 100 ft of stream reach.

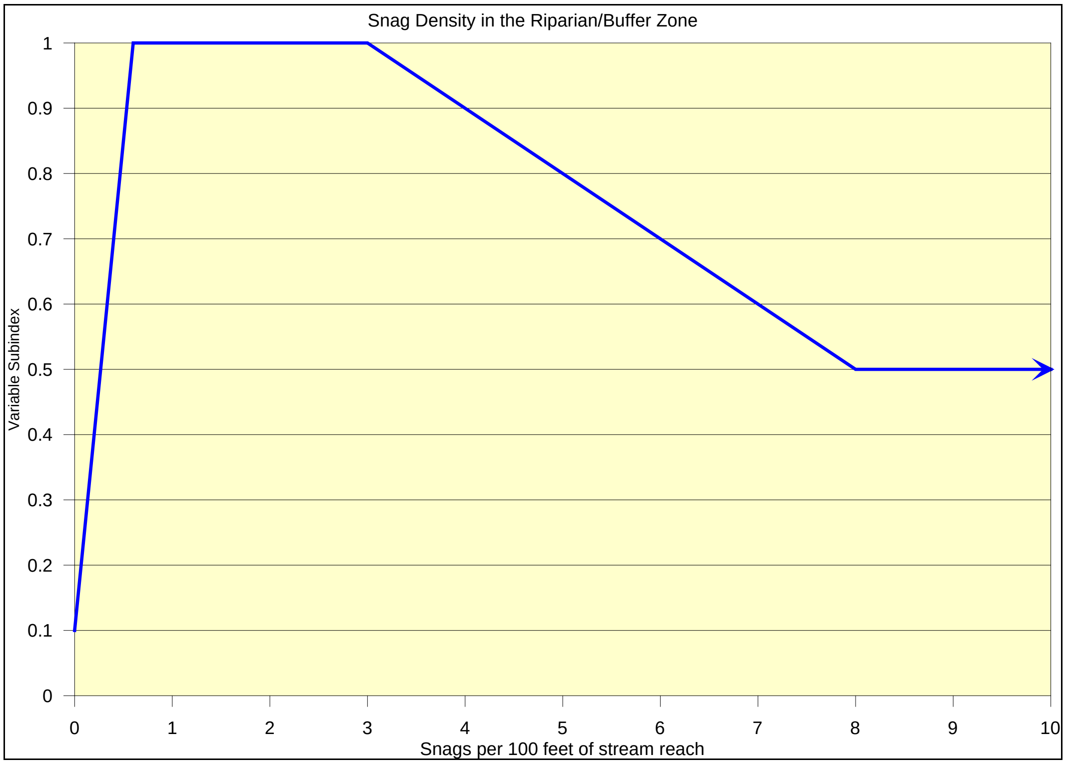


Figure 21. Relationship between density of snags in the riparian/buffer zone (V_{SNAG}) and functional capacity.

Riparian/buffer zone sapling/shrub density (V_{SSD})

This variable is defined as the number of woody stems >36 in. (90 cm) in height and <4 in. (10 cm) dbh (e.g., shrubs, saplings, and understory trees) per 100 ft (30.5 m) of stream reach. Shrubs contribute to the structure of the plant community, particularly if trees are absent. They take up nutrients, produce biomass, and provide cover and breeding sites for wildlife. Shrubs may dominate the community in high-gradient headwater stream systems during early to mid-successional stages (Figure 22). V_{SSD} applies only to the biogeochemistry and habitat functions and is only measured if channel canopy cover is <20 percent.

Figure 22. Riparian/buffer zone dominated by saplings and shrubs.

Riparian/buffer zone sapling/shrub density was highly variable in reference stream reaches, ranging from 10 to 785 stems/100 ft of stream reach. V_{SSD} is not used to evaluate high-gradient headwater streams that have a well-developed channel canopy. Instead, V_{SSD} is measured only in areas with <20 percent channel canopy cover due to recent natural or anthropogenic disturbance. In this context, V_{SSD} reflects the amount of woody regeneration on the site that contributes immediately to carbon cycling and provides habitat for wildlife, and will eventually reproduce a mature forest canopy. Therefore, higher values of sapling/shrub cover are desirable in areas with poor channel canopy cover, as saplings and shrubs become a major component of biogeochemistry and habitat functions. Sapling/shrub density along reference stream reaches with <20 percent channel canopy cover ranged from 10 to 674 stems/100 ft. Based on reference data, a subindex of 1.0 is assigned when sapling/shrub density is ≥65 stems/100 ft of stream reach (Figure 23).

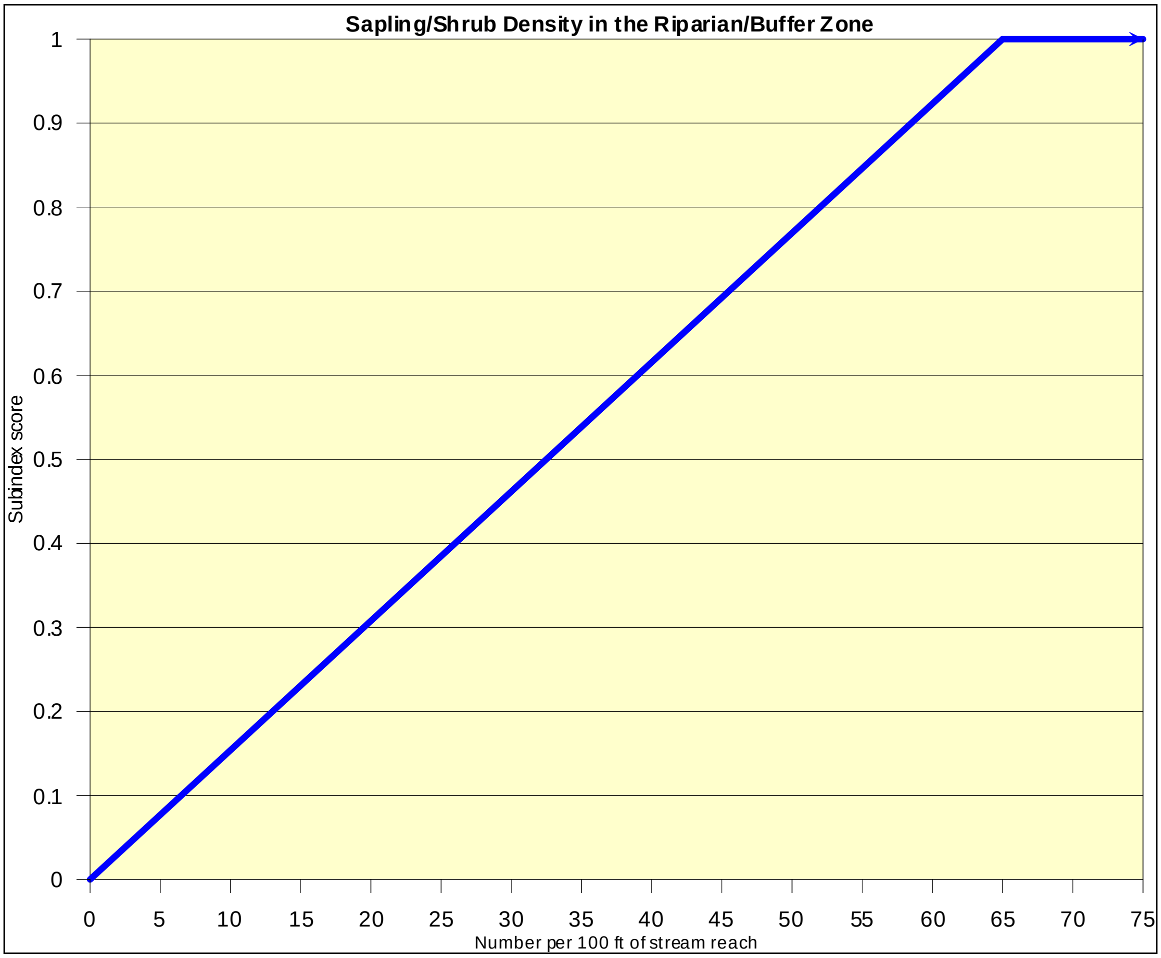


Figure 23. Relationship between riparian/buffer zone sapling/shrub density (V_{SSD}) and functional capacity.

This approach deviates from reference standard conditions because, as discussed above, reference standard stream reaches did not include areas with a poorly developed canopy. It is assumed that a cover of sapling and shrubs provides a decreased level of function from a forested community, but provides greater functionality than bare soil. Due to the form of the model algorithms, models using V_{SSD} in lieu of tree canopy cover cannot receive a functional capacity index of 1.0.

Riparian/buffer zone species richness (V_{SRICH})

This variable is defined as a measure of the native tree species diversity per 100 ft of stream reach within the riparian/buffer zone and channel of high-gradient headwater streams in the reference domain. This variable reflects a modified approach based on concepts in Andreas and Lichvar (1995), Smith and Klimas (2002), and Rheinhardt et al. (2009). The focus is on the plants occurring in the tallest stratum present, as recommended by

Smith and Klimas (2002). In reference standard high-gradient headwater streams, the tallest stratum is composed of native trees. In high-gradient headwater stream systems that have undergone recent and severe natural or anthropogenic disturbance, the tallest stratum may be dominated by exotic, invasive trees, saplings and shrubs, or herbaceous species. Implicit in this approach is the assumption that the diversity of the tallest layer is a good indicator of overall community composition and successional patterns (i.e., appropriate shrub composition indicates appropriate future canopy composition) (Rheinhardt et al. 2009). Most reference standard stream reaches within the reference domain are relatively diverse with several tree species present. Note that the tree stratum includes all trees ≥4 in. (10 cm) dbh.

Species are classified into two groups (Table 5). Group 1 consists of species that characterize relatively undisturbed high-gradient headwater streams in eastern Kentucky and western West Virginia. This list is based on species richness in reference standard stream reaches within the reference domain. Rheinhardt et al. (2009) identified several of the same species as dominant within the Piedmont region of the Ridge and Valley Physiographic Province. Any tree species occurring in more than three reference standard stream reaches was included in Group 1. Group 2 consists of non-native (exotic) species or native invasive species that usually are found on highly degraded sites. The list of exotic species in Group 2 is based on data from USDA (2009) plants database (http://plants.usda.gov/) and the West Virginia Division of Natural Resources (2003) list of invasive species (http://www.wvdnr.gov/wildlife/invasivewv.shtm).

In reference standard high-gradient headwater streams within the reference domain, vegetation composition included only species from Group 1, and the number of species observed was ≥2.1 per 100 ft (30.5 m) of stream reach (Figure 24). As species richness deviates from reference standard conditions, functional capacity is assumed to decline. The range in the number of species for all reference reaches was 0 to 7.4 per 100 ft (30.5 m). The procedure used to calculate a species richness value (SRV), which is used to determine the variable subindex for V_{SRICH}, is described in Chapter 5. V_{SRICH} applies only to the habitat function.

Table 5: Species used to calculate V_{SRICH} in the riparian/buffer zone of high-gradient headwater streams

Scientific Name	Common Name	Scientific Name	Common Name
Group 1		Group 2	
Acer rubrum	red maple	*Ailanthus altissima*	tree of heaven
Acer saccharum	sugar maple	*Albizia julibrissin*	silktree
Aesculus flava	yellow buckeye	*Alliaria petiolata*	garlic mustard
Asimina triloba	pawpaw	*Alternanthera philoxeroides*	alligatorweed
Betula alleghaniensis	yellow birch	*Aster tataricus*	tatarian aster
Betula lenta	black birch	*Cerastium fontanum*	common mouse-ear
Quercus alba	white oak	*Coronilla varia*	crownvetch
Carya alba	mockernut hickory	*Elaeagnus umbellata*	autumn olive
Carya glabra	pignut hickory	*Lespedeza bicolor*	shrub lespedeza
Carya ovalis	red hickory	*Lespedeza cuneata*	sericea lespedeza
Carya ovata	shagbark hickory	*Ligustrum obtusifolium*	border privet
Cornus florida	flowering dogwood	*Ligustrum sinense*	Chinese privet
Fagus grandifolia	American beech	*Lonicera japonica*	Japanese honeysuckle
Fraxinus americana	white ash	*Lonicera tatarica*	Tatarian honeysuckle
Liriodendron tulipifera	tuliptree	*Lotus corniculatus*	bird's-foot trefoil
Magnolia acuminata	cucumber-tree	*Lythrum salicaria*	purple loosestrife
Magnolia tripetala	umbrella-tree	*Microstegium vimineum*	Nepalese browntop
Nyssa sylvatica	blackgum	*Paulownia tomentosa*	princesstree
Oxydendrum arboreum	sourwood	*Polygonum cuspidatum*	Japanese knotweed
Prunus serotina	black cherry	*Pueraria montana*	kudzu
Quercus coccinea	scarlet oak	*Rosa multiflora*	multiflora rose
Quercus imbricaria	shingle oak	*Sorghum halepense*	Johnsongrass
Quercus prinus	chestnut oak	*Verbena brasiliensis*	Brazilian vervain
Quercus rubra	northern red oak		
Quercus velutina	black oak		
Sassafras albidum	sassafras		
Tilia americana	American basswood		
Tsuga canadensis	eastern hemlock		
Ulmus americana	American elm		

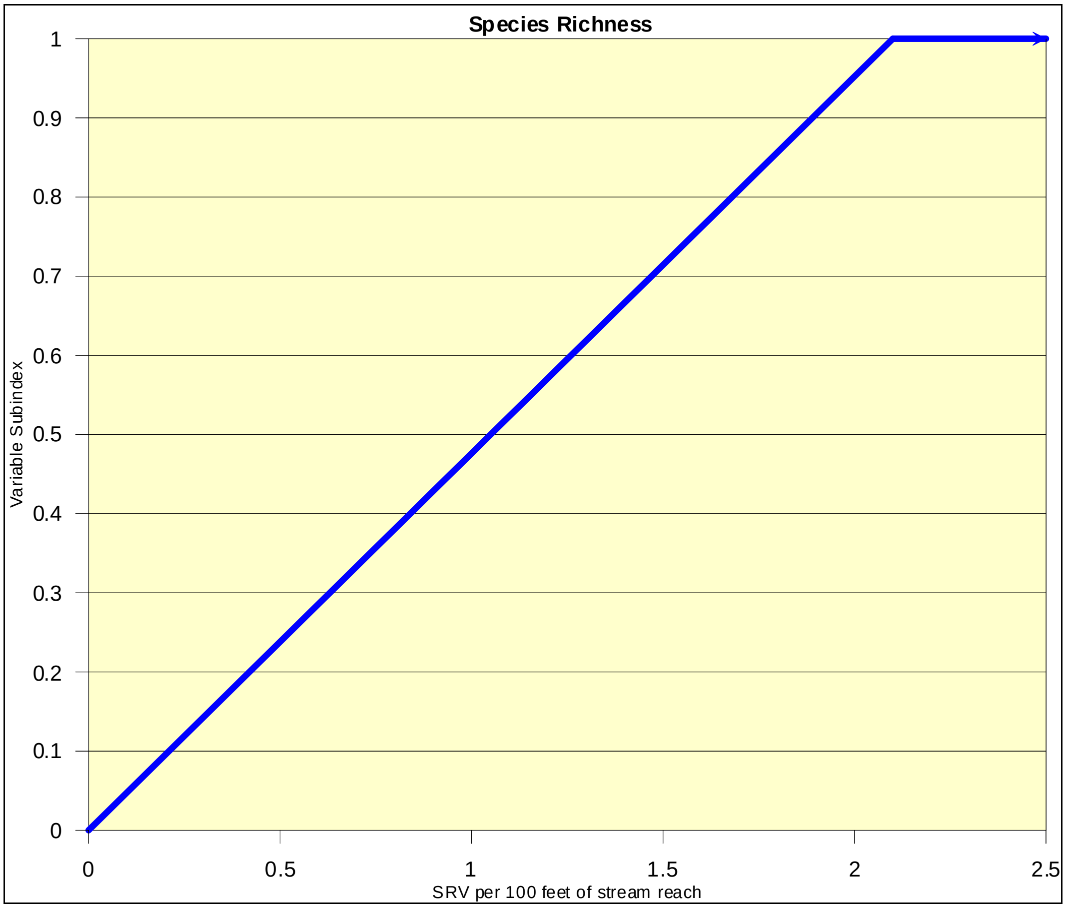


Figure 24. Relationship between riparian/buffer species richness (V_{SRICH}) and functional capacity.

Riparian/buffer zone soil detritus ($V_{DETRITUS}$)

This variable consists of the average percent cover of detrital material on the soil surface within the riparian/buffer zone. Soil detritus is defined as the soil layer dominated by partially decomposed but still recognizable organic material, such as leaves, sticks, needles, flowers, fruits, insect frass, dead moss, or detached lichens on the surface of the ground (Figure 25). Detritus includes materials <4 in. (10 cm) in diameter and <36 in. (90 cm) long and includes fibric or hemic material (peat or mucky peat). Detritus is a direct indication of short-term (one or two years) accumulation of organic matter primarily from vegetation within the riparian/buffer zone and a source of food and cover for macroinvertebrates and salamanders. The presence or absence of detritus in the channel is not considered. $V_{DETRITUS}$ applies to the biogeochemistry and habitat functions.

Figure 25. Detritus is 100 percent along the riparian/buffer zone.

Litter fall (leaves and twigs) is a primary source for organic materials in headwater streams (Wipfli et al. 2007). Leaf litter from the near-stream riparian/buffer zone has been shown to be the dominant source of stream-water dissolved organic carbon (Dalva and Moore 1991). Generation of dissolved organic carbon from leaf litter is a result of chemical leaching of soluble compounds, dissolved organic carbon released during microbial breakdown of the litter, and carbon released during invertebrate feeding on decaying leaf litter (Meyer and O'Hop 1983). All of these pathways are likely decreased when litter is absent from the stream system (Wallace et al. 1997).

Leaf litter and other organic detritus supply energy subsidies to the aquatic food web (Meyer et al. 1998; Vannote et al. 1980) and cover for macroinvertebrates and salamanders. It has been shown that less dissolved organic carbon is produced during invertebrate feeding when less leaf litter is present in the stream system due to fewer leaf-shredding invertebrates (Wallace et al. 1997). Terrestrial invertebrates occur along riparian corridors and are associated with leaf litter, and riparian soils (Allan et al. 2003). Commonly occurring groups include aphids, leafhoppers, beetles, caterpillars, sawflies, spiders, mites, springtails, small wasps, and flies, and all contribute substantially to the diets of consumers in streams (Hynes 1970; Hunt 1975; Mason and Macdonald 1982; Baxter et al. 2004, 2005).

Detritus is important for salamander habitat because stream salamanders are most active at night and hide under logs, leaves, bark, and other objects during the day (Jung et al. 2004). A barren streambank will be devoid of plethodontid salamanders regardless of other habitat characteristics. Because they are lungless, respiration in plethodontids is primarily cutaneous, making them particularly prone to desiccation. There is no physiological control over water loss, and because smaller salamanders have more evaporative surface area in relation to body volume, they desiccate faster than larger salamanders (Spotila 1972). These salamanders are primarily limited to foraging when conditions are cool and wet, and they seek refuge under objects such as leaves, bark, or woody debris (Knapp et al. 2003). With a decrease in leaf litter production and moisture, and an increase in temperatures, soil invertebrate prey is reduced and the biomass of salamanders decreases (Burke and Nol 1998).

The cover of soil detritus in high-gradient headwater streams ranged from 0 to 100 percent. Based on data from reference standard stream reaches, a variable subindex of 1.0 is assigned when detrital cover is between 82 and 100 percent. Stream reaches lacking detrital cover are assigned a subindex of 0.0. A linear increase in the subindex score as detrital cover increases from 0 to 82 percent is assumed (Figure 26).

Riparian/buffer zone herbaceous cover (V_{HERB})

This variable is defined as the average percent cover of herbaceous vegetation within the riparian/buffer zone. Herbaceous cover is defined as all herbaceous vegetation, regardless of height. Herbaceous cover does not include woody species defined as sapling/shrub. Herbaceous cover is an index that estimates abundance and biomass of low vegetation in the riparian/buffer zone, which affects the productivity and structure of habitats. V_{HERB} only applies to the biogeochemistry and habitat functions.

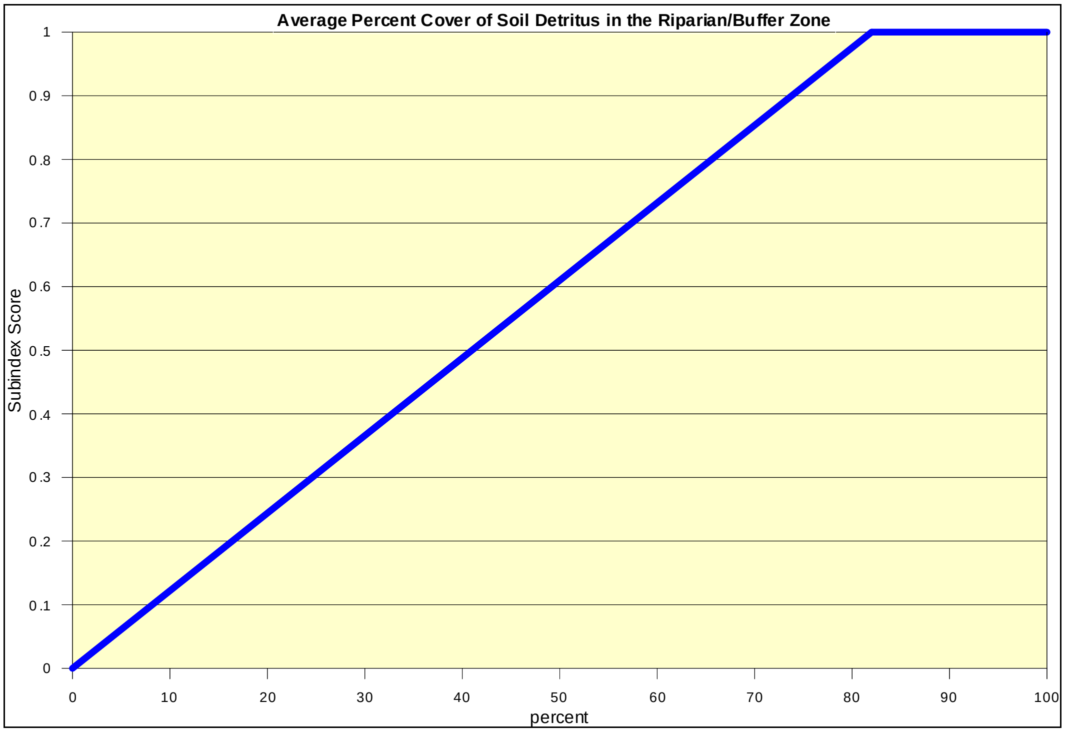


Figure 26. Relationship between riparian/buffer zone soil detritus ($V_{DETRITUS}$) and functional capacity.

V_{HERB} is not used to evaluate high-gradient headwater stream systems that have a well-developed tree canopy. Instead, V_{HERB} is measured only in areas where channel canopy cover is <20 percent. Even under these conditions, ground-layer vegetation contributes organic material to the carbon cycle, provides some cover for wildlife, reduces sediment to the stream channel, and helps produce conditions favorable to the regeneration of a woody midstory and canopy. Herbaceous vegetation cover on reference stream reaches with <20 percent channel canopy cover ranged from 75 to 100 percent. A subindex of 1.0 is assigned when herbaceous cover is ≥75 percent. A linear decrease in subindex score is assumed for <75 percent herbaceous cover to a subindex score of zero if no herbaceous cover is present (Figure 27). Models using V_{HERB} in lieu of tree canopy cover cannot receive a functional capacity index of 1.0.

Watershed land-use (V_{WLUSE})

This variable is defined as the surface runoff potential from the watershed or catchment outside the riparian/buffer zone into headwater streams. Variable scores are based upon the weighted average of the combination of percent land cover and land-use classifications. To calculate this variable subindex score, the percentage of the watershed in each of the land-use

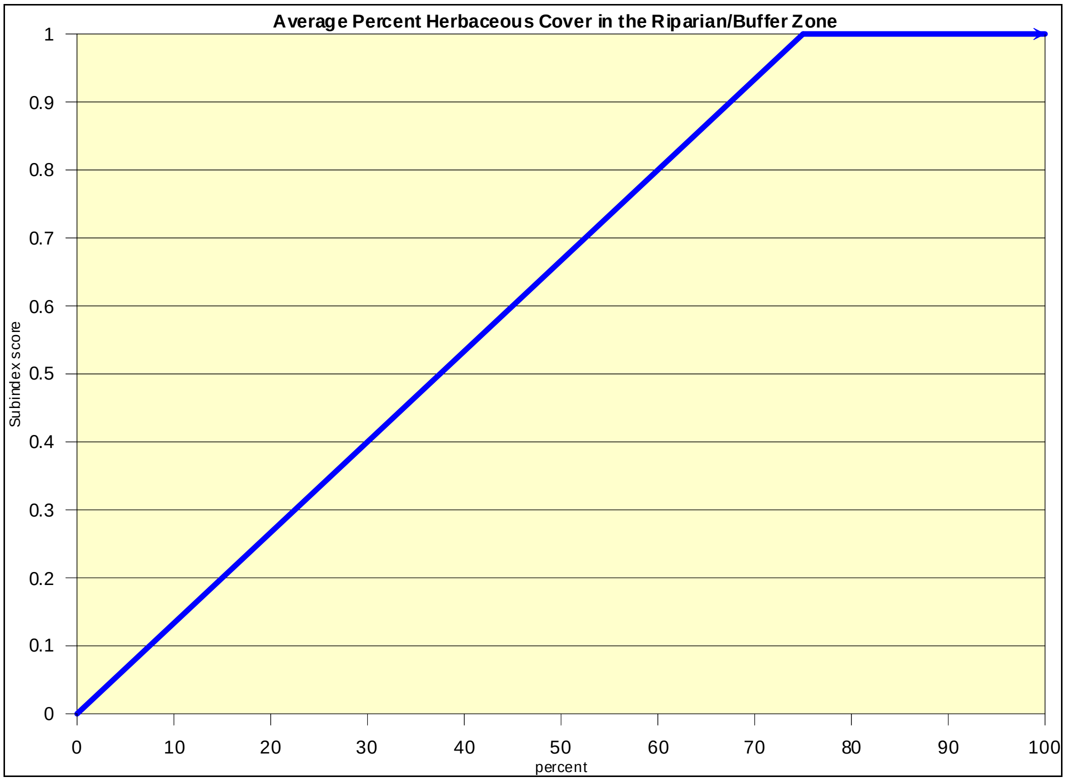


Figure 27. Relationship between riparian/buffer zone herbaceous cover (V_{HERB}) and functional capacity.

categories (forested, residential, industrial, etc.) must be calculated or estimated. This requires the use of internet resources, landscape images, and/or GIS, along with field reconnaissance and verification. V_{WLUSE} applies to the hydrology, biogeochemistry, and habitat functions.

Landscape-based metrics of land-use and land cover affect runoff quantity and water quality within watersheds (Jones et al. 2001; Rheinhardt et al. 2009). Upland land-use conditions determine the structure and function of downstream environments (Bolstad et al. 2003). With increased disturbance and decreased infiltration capacity in the surrounding watershed, more surface water enters downstream waters than under the reference condition (Simmons et al. 2008; Townsend et al. 2009; DeFries and Eshleman 2004). Increased runoff increases sediment and nutrient loading, and impacts water quality during base and peak flow events (Poor and McDonnell 2007; Herlihy et al. 1998; Bolstad and Swank 1997).

The subindex score is based on the weighted average of the runoff scores associated with the various land uses identified in the watershed catchment outside the riparian/buffer zone (see Appendix B for an example calculation).

Areas affected by naturally occurring wildfires (lightning strikes), controlled burns designed for forest management, and other burned natural areas should not receive an increased runoff score. Land use can be classified using aerial, orthographic photographs, and topographic resources, which are available from a number of Internet sources including TerraServer (http://terraserver-usa.com), Google Maps (http://maps.google.com/), and the USDA Data Gateway.

Reference standard locations within the reference domain were surrounded by native hardwood vegetative communities. Under reference standard conditions, watersheds contained a high degree of forest cover and limited agricultural, industrial, residential, and transportation infrastructure land-use classes (Simmons et al. 2008; Fraterrigo et al. 2006).

Reference standard watersheds had high percentages of lands with >75 percent native forest and native range coverage (Table 6). Reference standard reaches contained a maximum of 6 percent impervious surfaces as roads and gravel areas, and no industrial, agricultural, or residential areas. Some reference standard stream reaches were previously impacted by land clearing for agricultural, pastureland, limited road building, and forestry activities but soil conditions remained stable and displayed limited erosion (<14 percent erosion along the stream channel).

Other sites within the reference domain contained additional land uses, including large areas of grass cover, industrial coverage >70 percent, agricultural land uses, roads and gravel pads, and residential coverage, and result in decreased subindex scores. Watershed land-use scores between 0.95 and 1.0 receive a subindex score of 1.0, and decline linearly to 0 as the score drops from 0.95 to 0.0 (Figure 28).

Table 6. Watershed land use.

Land use	Runoff score
Open space (pasture, lawns, parks, golf courses, cemeteries):	
Poor condition (grass cover <50%)	0.1
Fair condition (grass cover 50% to 75%)	0.2
Good condition (grass cover >75%)	0.3
Impervious areas (parking lots, roofs, driveways, etc)	0
Gravel	0
Urban districts:	
Industrial, commercial and business (≥70% cover)	0
Residential districts by average lot size:	
1/8 acre or less (town houses and apartments) (65% cover)	0
1/4 acre to 1/3 acre (38% to 30% cover)	0.1
1/2 acre to 1 acre (25% to 20% cover)	0.2
2 acres (12% cover)	0.3
Newly graded areas (bare soil, no vegetation or pavement)	0
Forest and shrub/sapling:	
Forest and native range (<50% ground cover)	0.5
Forest and native range (50% to 75% ground cover)	0.7
Forest and native range (>75% ground cover)	1.0

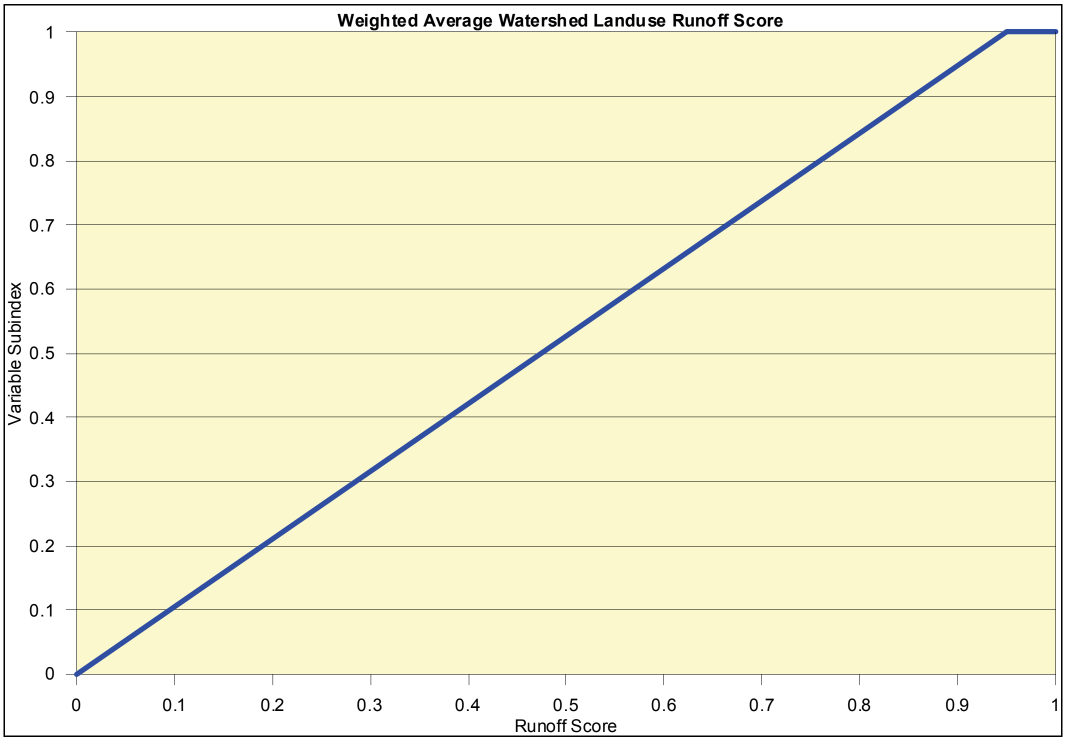


Figure 28. Relationship between watershed land use (V_{WLUSE}) and functional capacity.

Functions

The following sequence is used to present and discuss each function:

a. *Definition:* Defines the function.

b. *Rationale for selecting the function*: Provides the rationale for why a function was selected and discusses onsite and offsite effects that may occur as a result of lost functional capacity.

c. *Characteristics and processes that influence the function*: Describes the characteristics and processes of the stream and the surrounding landscape that influence the function and lay the groundwork for the description of model variables.

d. *Functional capacity index*: Describes the assessment model from which the functional capacity index is derived and discusses how model variables interact to influence functional capacity.

Function 1: Hydrology

Definition

The hydrology function is defined as the ability of the high-gradient headwater stream to dissipate energy associated with flow velocity and transport water downstream. Potential independent, quantitative measures that may be used in validating the functional index include direct measures of water flow in the channel over time (ft/sec).

Rationale for selecting the function

Water transport and energy dissipation are fundamental physical functions performed by all stream systems. The energy produced by flowing water of high-gradient headwater streams affects the amount of sediment, organic matter, and nutrients that are transported downstream (Leopold 1994; Leopold et al. 1992; Gordon et al. 2006; Chang 2006). Excess sediment can reduce habitat for macroinvertebrates and amphibians if stream energy is insufficient to remove it from the headwater system (Merritt and Cummins 1996). Headwater systems are a primary source of organic matter and nutrients, which are a source of food for macroinvertebrates and vertebrates that live in the perennial systems downstream from the headwaters (Jung et al. 2004).

Characteristics and processes that influence the function

The characteristics and processes that influence the capacity of a high-gradient headwater stream to dissipate energy and convey water have both natural and anthropogenic origins. Climate, landscape-scale geomorphic characteristics, and characteristics of the soil within the watershed are factors largely established by natural processes. However, even landscape-scale geomorphic characteristics and soils can be altered by anthropogenic alterations.

Human activities may have a profound effect on the amount of water entering the stream and the dissipation of stream energy. Modifications to the uplands surrounding the channel may affect the amount and timing of water and sediment delivery to the channel through overland flow. Land-use changes such as logging, urban development, grazing, or filling are modifications that directly affect this function (Gordon et al. 2006; Leopold and Marchand 1968).

Removing large woody debris, reducing the median size of the channel substrate, or increasing the degree of embeddedness through increased sediment deposition in the channel, will result in a reduction in energy dissipation in the channel. Conversely, if the amount of water to the channel is increased to the point where the energy in the channel is capable of removing large woody debris, or flushing fine particles from the channel increasing the median size of the substrate and reducing embeddedness, then energy dissipation will increase. Unaltered stream flow velocities recruit large woody debris into the ecosystem, flush excess fine particles downstream, and reduce embeddedness, maintaining energy dissipation at a level consistent with reference standard conditions.

Functional capacity index

The following variables are used in the assessment model for the hydrology function:

- Channel substrate embeddedness (V_{EMBED})
- Channel substrate size ($V_{SUBSTRATE}$)
- Potential channel bank erosion (V_{BERO})
- Large woody debris (V_{LWD})
- Watershed land use (V_{WLUSE})

The assessment model for calculating the FCI for the hydrology function in high-gradient headwater streams is given below. This model is only appropriate for high-gradient headwater streams and should not be applied to channels with <4 percent slope.

$$FCI = \left\{ \frac{V_{WLUSE} + \left[\frac{V_{LWD} + \min\left(V_{SUBSTRATE}, V_{EMBED}, V_{BERO}\right)}{2} \right]}{2} \right\} \tag{2}$$

In this model, changes in hydrology, including water flow and dissipation of stream energy in high-gradient headwater streams relative to reference standard conditions, depend on the roughness of the channel, and materials in the channel and riparian/buffer zone that will slow the flow of water, and the amount of water that is delivered to the channel through overland flow. The model is based on the assumption that if large woody debris and the appropriate channel substrate are in place, the channel does not have an excessive amount of sediment, the channel banks are not excessively eroded, and the surrounding watershed has not been excessively altered by anthropogenic disturbances, then channel flow, sediment transport, and stream energy are appropriate for the channel. In the first part of the equation, the amount of water from the surrounding watershed is represented by V_{WLUSE}. When the amount of forest cover in the watershed decreases, the amount of water and the timing of the delivery of water through overland flow to the stream channel will increase in relation to reference standard conditions. In the second part of the equation, the lowest value from $V_{SUBSTRATE}$, V_{EMBED}, or V_{BERO} is used to represent the effects of channel degradation from the reference standard condition. The lowest score from $V_{SUBSTRATE}$, V_{EMBED}, or V_{BERO} is averaged with V_{LWD} based on the assumption that large woody debris is independent, but equally important, in its effect on hydrologic flow and dissipation of stream energy. The amount of water delivered to the channel, represented by $V_{WLUSE,}$ is combined with the result of the second part of the equation using an arithmetic mean. This is based on the assumption that input from the surrounding watershed is of equal importance in the function of channel hydrology and the dissipation of stream energy as the average of V_{LWD} and the minimum score of $V_{SUBSTRATE}$, V_{EMBED}, or V_{BERO}.

Function 2: Biogeochemical cycling

Definition

The biogeochemical cycling function is defined as the ability of the high-gradient headwater stream ecosystem to retain and transform inorganic materials needed for biological processes into organic forms and to oxidize those organic molecules back into elemental forms through respiration and decomposition. Thus, biogeochemical cycling includes the activities of producers, consumers, and decomposers. Potential independent, quantitative measures that may be used in validating the functional index include direct measurements of net annual productivity (g/m^2), annual accumulation of organic matter (g/m^2), and annual decomposition of organic matter (g/m^2).

Rationale for selecting the function

Biogeochemical cycling is a fundamental function performed by all ecosystems (Mitsch and Gosselink 2000). A sustained supply of organic carbon in the soil provides for maintenance of the characteristic plant community including annual primary productivity, composition, and diversity (Bormann and Likens 1970; Whittaker 1975; Perry 1994). The plant community (producers) provides the food and habitat structure (energy and materials) needed to maintain the characteristic animal community (consumers) (Fredrickson 1978). In time, the plant and animal communities serve as a source of detritus that is the source of energy and materials needed to maintain the characteristic community of decomposers. The decomposers break down these organic materials into simpler elements and compounds that can reenter the nutrient cycle (Reiners 1972; Dickinson and Pugh 1974; Pugh and Dickinson 1974; Schlesinger 1977; Singh and Gupta 1977; Hayes 1979; Harmon et al. 1986; Vogt et al. 1986).

Characteristics and processes that influence the function

Biogeochemical cycling is a function of biotic and abiotic processes that result from conditions within and around the headwater stream. In high-gradient headwater stream ecosystems carbon is stored within, and cycled among, four major compartments: (a) the soil, (b) primary producers such as vascular and nonvascular plants, (c) consumers such as animals, fungi, and bacteria, and (d) dead organic matter, such as leaf litter and woody debris, collectively referred to as detritus. It is the maintenance of the characteristic primary productivity of the plant community that sets the stage for all subsequent transformations of energy and materials at each trophic level within the ecosystem. It follows that alterations to hydrologic inputs, outputs, or storage and/or changes to the characteristic plant community will directly affect the way in which the ecosystem can perform this function.

The ability of a high-gradient headwater stream ecosystem to perform this function depends upon the transfer of carbon between trophic levels, the rate of decomposition, and the flux of materials in and out of the ecosystem. A change in the ability of one trophic level to process carbon will result in changes in the processing of carbon in other trophic levels (Carpenter 1988).

The ideal approach for assessing biogeochemical cycling in a headwater riverine ecosystem would be to measure the rate at which carbon is transferred and transformed between and within trophic levels over several years. However, the time and effort required to make these measurements are well beyond a rapid assessment procedure, and so plant community structure and detrital cover are used as indirect indicators. Changes in vegetative cover directly affect the amount of organic carbon present in the ecosystem. Canopy removal, in particular, directly affects the amount and type of detritus present in the high-gradient headwater stream system. Changes in hydrology or vegetation, deposition of fill material, excavation, or recent fire can alter the amount of soil detritus. Changes to the hydrology of high-gradient headwater stream ecosystems, primarily through increased surface water flow or ponding, has a tremendous effect on biogeochemical cycling. Increased surface water flow can sweep nearly all detrital matter from the stream channel and disrupt the biogeochemical cycle. Ponding reduces the rate of decomposition and increases the accumulation of organic carbon, as well as changing the vegetative community. It is assumed that measurements of these characteristics reflect the level of biogeochemical cycling taking place within an ecosystem.

Functional capacity index

The following variables are used in the assessment model for the biogeochemical function:

- Channel substrate embeddedness (V_{EMBED})
- Large woody debris (V_{LWD})
- Riparian/buffer zone tree diameter (V_{TDBH})

- Riparian/buffer zone sapling/shrub density (V_{SSD})
- Riparian/buffer zone soil detritus ($V_{DETRITUS}$)
- Riparian/buffer zone herbaceous cover (V_{HERB})
- Watershed land use (V_{WLUSE})

Assessment models for calculating the FCI for the biogeochemical functions in high-gradient headwater streams are given below. The models depend, in part, on the vegetative cover over the stream channel. If the SAR or PSAR supports an average channel canopy cover ≥20 percent, then Equation 3 is used. If the SAR or PSAR does not support an average channel canopy cover ≥20 percent, then Equation 4 is used.

$$FCI = \left\{ V_{EMBED} \times \left[\frac{\left(\frac{V_{LWD} + V_{DETRITUS} + V_{TDBH}}{3} \right) + V_{WLUSE}}{2} \right] \right\}^{1/2} \tag{3}$$

$$FCI = \left\{ V_{EMBED} \times \left[\frac{\left(\frac{V_{LWD} + V_{DETRITUS} + V_{SSD} + V_{HERB}}{4} \right) + V_{WLUSE}}{4} \right] \right\}^{1/2} \tag{4}$$

In these models, changes in the biogeochemical cycling capacity of high-gradient headwater stream ecosystems relative to reference standard conditions depend on the relative roughness of the channel and the potential to trap and hold organic matter, increased inflow of water from the surrounding watershed or on reductions in water inflows, organic matter, or the quantity of vegetation. The models are based on the assumption that if organic matter and vegetation are in place, and anthropogenic hydrologic disturbance is not present in the stream channel or the surrounding watershed, then biogeochemical cycling will occur at an appropriate rate. In the first part of each equation, organic matter retention in the channel is represented by V_{EMBED}. In the second part, V_{LWD} is used as an indicator of long-term organic matter accumulation within the channel and immediately adjacent to the channel, while $V_{DETRITUS}$ is used as an indicator of recent organic input and accumulation. If vegetation has been removed from the riparian/buffer zone during the previous year or two, then the amount of detritus will likely be reduced or absent. Also, if the hydrology of the surrounding watershed has been altered to the point that detritus is being flushed from the headwater ecosystem, then this alteration should be reflected in the amount of detrital cover and large woody debris in the stream system. Also, if fill material has been placed in the stream or adjacent watershed or soil excavation has taken place, the organic matter in the previous condition will have been buried by the fill or removed in excavation. These variables, V_{LWD}, $V_{DETRITUS}$, and V_{TDBH} or V_{SSD} and V_{HERB}, depending on the presence of an average channel canopy cover of ≥20 percent, are combined using an arithmetic mean. This is based on the assumption that large woody debris, detritus, and vegetation are of equal importance in biogeochemical cycling. If the amount of vegetation, represented by percent cover, is reduced, then it is assumed that carbon cycling will be reduced. In Equation 4, the two parts are divided by a factor of 4 to reflect the assumption that stream reaches dominated by saplings/shrubs or herbaceous vegetation do not produce or cycle carbon at the same rate as a mature forest. For sapling/shrub-dominated riparian/buffer zone, the maximum FCI is 0.7.

Function 3: Habitat

Definition

This function is defined as the capacity of a high-gradient headwater stream ecosystem to provide critical life requisites to selected components of the vertebrate and invertebrate wildlife community. Ecosystems within the subclass provide habitat for numerous species of macroinvertebrates, amphibians, reptiles, birds, and mammals. Amphibians and macroinvertebrates were selected as the focus of this function. Amphibians were chosen because of the importance of streams as breeding habitat. Various species of salamanders and frogs breed in shallow streams, temporary ponds, and moist leaf litter. In the adult stages, they often disperse into suitable habitat in the adjacent landscape.

A potential independent, quantitative measure of this function that could be used to validate the assessment model (Wakeley and Smith 2001) is the combined species richness of macroinvertebrates and amphibians that use high-gradient headwater stream ecosystems in the reference domain throughout the annual cycle. Data requirements for model validation include direct monitoring of animal communities using appropriate techniques for each taxon. Gibbons and Semlitsch (1981) described procedures for sampling small animals including reptiles and amphibians. Heyer et al. (1994) and Dodd (2003) described monitoring procedures for amphibians.

Rationale for selecting the function

Headwater streams and the surrounding landscape are recognized as valuable habitats for a diversity of animal species including both vertebrates and invertebrates. However, amphibians can be particularly important. Burton and Likens (1975) reported that amphibians constitute the single largest source of vertebrate biomass in some ecosystems. Because many amphibians require both aquatic and adjacent terrestrial habitats, they serve as a conduit for energy exchange between the two systems (Mitchell et al. 2004). Wharton et al. (1982), Johnson (1987), Mitsch and Gosselink (2000), and Bailey et al. (2006) are all good sources of information regarding these communities.

Many animal species associated with streams have experienced serious population declines. In West Virginia and Kentucky, high-gradient headwater stream channels and the adjacent riparian/buffer zone areas constitute a relatively small percentage of the landscape; therefore, these areas are likely important for the maintenance of local populations of many species (Meyer et al. 2007).

Characteristics and processes that influence the function

Hydrologic alteration of high-gradient headwater stream ecosystems has the potential to impact a number of animal species, but the most serious on-site impacts would be to invertebrates and amphibians. Animals with direct dependence on aquatic habitats, including those that use seasonally ponded micro-depressions within high-gradient headwater stream ecosystems for reproduction, are highly vulnerable to hydrologic alteration. Even partial alteration could impact breeding activity because of the length of time needed for egg development and maturation of the young. There is considerable variability in development time among species. Most anurans require the presence of water for 2-3 months (Duellman and Trueb 1986). Some species, however, require substantially shorter periods of time. Conversely, artificially increasing the amount of time that surface water is present in the ecosystem by altering channel runoff can potentially reduce the suitability for amphibians by allowing fish populations to become established. Bailey et al. (2006) noted that predatory fish prey on breeding amphibians, their eggs, and tadpoles. They recommended that wherever ecosystems free of fish exist, efforts should be made to avoid accidental or deliberate fish introductions.

Besides the direct effects of hydrologic change on animals, indirect effects can occur through changes in the plant community. Streams with unaltered hydrology that have not been subjected to significant disturbance for long periods support a characteristic vegetation composition and structure (e.g., tree size, density, stratification, etc.). Animal species have evolved with and adapted to these conditions. Thus, altering the hydroperiod has the potential to change the composition and structure of the animal community. Other factors including droughts and catastrophic storms, competition, disease, browsing pressure, shade tolerance, community succession, and natural and anthropogenic disturbances, also affect the plant and animal communities. Below is an overview of the relationships between specific characteristics of the plant community and animal utilization of forested ecosystems, including streams. Wharton et al. (1982), Hunter (1990), and Morrison et al. (1992) are all useful sources of information on this subject.

Habitat structure is an important determinant of wildlife species composition and diversity (Meyer et al. 2007). Undisturbed high-gradient headwater stream ecosystems in eastern Kentucky and western West Virginia contain multiple strata. This structural complexity provides a myriad of habitat conditions for animals and allows numerous species to coexist in the same area (Schoener 1986).

While the structure of the riparian forest in the immediate vicinity of a high-gradient headwater stream is an important determinant of animal habitat availability, the characteristics of adjacent terrestrial habitat are equally critical to many species. Although tied to wetlands and other aquatic habitats for breeding, many frogs and some salamanders spend the remainder of the year in terrestrial habitats, often in hardwood forests (Mitchell et al. 2004). Semlitsch and Jensen (2001) noted that suitable terrestrial habitat surrounding the breeding site is critical for feeding, growth, maturation, and maintenance of juvenile and adult populations of pond-breeding salamanders. Bailey et al. (2006) concurred, stating that “a seasonal wetland without appropriate surrounding terrestrial habitat will lose its amphibian and reptile fauna.” Semlitsch and Jensen (2001) suggested that the terrestrial habitat be referred to as part of the “core habitat” used by the animals, because it is as essential as the breeding site itself. This is different from the traditional concept of the “buffer zone” commonly recommended to protect various functions (Boyd 2001).

Semlitsch and Bodie (2003) reviewed the literature on terrestrial habitats used by amphibians. Habitat features such as leaf litter, coarse woody debris (i.e., logs), boulders, small mammal burrows, cracks in rocks, spring seeps, and rocky pools were important for foraging, refuge, or overwintering. A well-developed canopy (for shade) and coarse woody debris and litter (for refuge and food) were considered to be essential habitat features. The abundance of litter is related to the age of forest stands. The litter layer in an older forest usually is much thicker than in a younger forest due to the differential amount of foliage produced. Young stands do not begin to contain significant amounts of litter and coarse woody debris until natural thinning begins. Such a pattern probably also exists in upland forests. Shade, which is critical to some amphibian species in slowing or preventing dehydration (Spight 1968; Rothermel and Semlitsch 2002), is provided to some extent in all forest stands but likely is not effective until tree canopies begin to close (Rothermel and Semlitsch 2002). Thus total canopy cover is an important consideration in evaluating amphibian habitat in forest ecosystems.

Terrestrial areas immediately adjacent to streams also are important to the integrity of the stream ecosystem itself. Such areas serve to reduce the amounts of silt, contaminants, and pathogens that enter the stream, and to moderate physical parameters, such as temperature (Rohde et al. 1980; Young et al. 1980; Hupp et al. 1993; Snyder et al. 1995; Daniels and Gilliam 1996; Semlitsch and Jensen 2001; Semlitsch and Bodie 2003). These functions affect amphibians and macroinvertebrates through improved water quality and provide benefits to the entire wildlife community.

Functional capacity index

The following variables are used in the assessment model for the provide characteristic wildlife habitat function:

- Channel canopy cover ($V_{CCANOPY}$)
- Channel substrate embeddedness (V_{EMBED})
- Channel substrate size ($V_{SUBSTRATE}$)
- Large woody debris (V_{LWD})
- Riparian/buffer zone tree diameter (V_{TDBH})
- Riparian/buffer zone snag density (V_{SNAG})
- Riparian/buffer zone sapling/shrub density (V_{SSD})
- Riparian/buffer zone species richness (V_{SRICH})
- Riparian/buffer zone soil detritus ($V_{DETRITUS}$)

- Riparian/buffer zone herbaceous cover (V_{HERB})
- Watershed land-use (V_{WLUSE})

The model used for deriving the functional capacity index for the wildlife habitat function in high-gradient headwater stream ecosystems depends, in part, on the vegetative cover over the stream channel. If the SAR or PSAR supports an average channel canopy cover $\geq$20 percent, then Equation 5 is used. If the SAR or PSAR does not support an average channel canopy cover $\geq$20 percent, then Equation 6 is used.

$$FCI = \left\langle \left[\frac{V_{CCANOPY} + \min\left(V_{EMBED}, V_{SUBSTRATE}\right)}{2} \right] \times \left\{ \frac{\left(\frac{V_{LWD} + V_{DETRITUS}}{2} \right) + \left[\frac{\left(\frac{V_{SNAG} + V_{TDBH} + V_{SRICH}}{3} \right) + V_{WLUSE}}{2} \right]}{2} \right\} \right\rangle^{1/2} \quad (5)$$

$$FCI = \left\langle \min\left(V_{EMBED}, V_{SUBSTRATE}\right) \times \left\{ \frac{\left(\frac{V_{LWD} + V_{DETRITUS}}{2} \right) + \left[\frac{\left(\frac{V_{SNAG} + V_{SSD} + V_{HERB} + V_{SRICH}}{6} \right) + V_{WLUSE}}{4} \right]}{2} \right\} \right\rangle^{1/2} \quad (6)$$

This model is assumed to reflect the ability of high-gradient headwater stream ecosystems to provide critical life requisites for wildlife, with an emphasis on macroinvertebrates and amphibians. If the components of this model are similar to those found under reference standard conditions, then it is likely that the entire complement of amphibians and macroinvertebrates characteristic of high-gradient headwater stream ecosystems within the reference domain will be present.

The first part of each equation is an expression of the structural components in the stream channel that directly relate to macroinvertebrate and amphibian habitat. The second part of each equation contains variables that reflect seral stage, food production potential, availability of dispersal habitat, and other factors that depend on stand structure, maturity, and connectivity. Riparian/buffer zone tree diameter (V_{TDBH}) is used when the ecosystem is dominated by trees (channel canopy cover is ≥20 percent). Riparian/buffer zone sapling/shrub density (V_{SSD}) and riparian/buffer zone herbaceous vegetation (V_{HERB}) are both used when channel canopy cover is <20 percent. Other features of forested high-gradient headwater stream ecosystems, such as snags, are also important habitat for many species. Channel integrity is critical to the maintenance of wildlife habitat; therefore, the channel components are used as a multiplier in each equation. Watershed land use (V_{WLUSE}) reflects the characteristic hydrologic regime that is essential as a source of water for breeding amphibians and macroinvertebrates. Watershed land use (V_{WLUSE}) along with riparian/buffer zone species richness (V_{SRICH}) attempts to capture plant community and offsite conditions on which the animal community depends. The variables in the second part of the equations are assumed to be partially compensatory (i.e., a low value for one term will be partially compensated by a high value for the other(s)). In a high-gradient headwater stream ecosystem where channel canopy cover is ≥20 percent, the maximum possible FCI is 1.0. In high-gradient headwater streams where channel canopy cover is <20 percent, the maximum FCI is 0.8.

5 Assessment Protocol

Introduction

Previous chapters of this Regional Guidebook provide background information on the HGM approach and document the variables, measures, and models used to assess the functions of high-gradient headwater streams. This chapter outlines a protocol for collecting and analyzing the data necessary to assess the functional capacity of a high-gradient headwater stream in the context of a Section 404 permit review or similar assessment scenario. The typical assessment scenario is a comparison of pre-project and post-project conditions that impact the stream. In practical terms, this translates into an assessment of the functional capacity of the stream reach under both pre-project and post-project conditions and the subsequent determination of how FCIs have changed or are expected to change as a result of the project. Data for the pre-project assessment are collected under existing conditions at the project stream reach, while data for the post-project assessment are normally based on the conditions expected to exist following proposed project impacts. A skeptical, conservative, and well-documented approach is required in defining post-project conditions. This recommendation is based on the often-observed lack of similarity between predicted or engineered post-project conditions and actual post-project conditions. This chapter discusses each of the following tasks required to complete an assessment of high-gradient headwater streams:

a. Define assessment objectives

b. Characterize the project area

c. Screen for red flags

d. Define the stream assessment reach

e. Determine the stream subclass

f. Collect the data

g. Analyze the data

h. Apply assessment results

Define assessment objectives

Begin the assessment process by unambiguously identifying the purpose of the assessment. This can be as simple as stating, “The purpose of this assessment is to determine how the proposed project will impact stream functions.” Other potential objectives could be as follows:

a. Compare several streams as part of an alternatives analysis.

b. Identify specific actions that can be taken to minimize project impacts.

c. Document baseline conditions at a stream reach.

d. Determine mitigation requirements.

e. Determine mitigation success.

f. Determine the effects of a stream management technique.

Frequently, multiple reasons are identified for conducting an assessment. Carefully defining the purpose(s) facilitates communication and understanding among the people involved in the assessment, and makes the goals of the study clear to interested parties. In addition, defining the purpose helps to clarify the approach that should be taken. The specific approach will vary to some degree depending upon whether the project is a Section 404 permit review, or a component of an advanced identification (ADID), special area management plan (SAMP), or some other scenario.

Characterize the project area

Characterizing the project area involves describing the area in terms of climate, surficial geology, geomorphic setting, surface and groundwater hydrology, vegetation, soils, land use, proposed impacts, and any other characteristics and processes that have the potential to influence how streams in the project area perform functions. The characterization should be written and accompanied by maps and figures, including photographs, that show project area boundaries, jurisdictional boundaries, the boundaries of the stream assessment reach (discussed later in this chapter), proposed impacts, roads, mining, buildings, soil types, plant communities, threatened or endangered species habitat, and other important features. Some sources of information useful in characterizing a project area are aerial photographs, topographic and national wetland inventory (NWI) maps, and soil surveys.

Screen for red flags

Red flags are features within or in the vicinity of the project area that might warrant special recognition or protection based on objective criteria (Table 7). Many red flag features, such as those based on national criteria or programs, are similar from region to region. Other red flag features are based on regional or local criteria. Screening for red flag features represents a proactive attempt to determine if the stream or other natural resources in and around the project area require special consideration or attention that may preempt or postpone an assessment of stream functions. An assessment of stream functions may not be necessary if the project is unlikely to occur as a result of a red flag feature. For example, if a proposed project has the potential to impact a threatened or endangered species or habitat, an assessment of stream functions may be unnecessary because the project may be denied or modified strictly on the basis of the impacts to threatened or endangered species or habitat.

Define the stream assessment reach

The stream assessment reach (SAR) is an area of the stream within a project area that belongs to a single regional stream subclass and is relatively homogeneous with respect to the site-specific criteria used to assess stream functions (hydrology, biogeochemical cycling, and habitat). In many project areas, there will be just one SAR representing a single stream subclass, as illustrated in Figure 29A. However, as the size and heterogeneity of the project area increase, it may be necessary to define and assess multiple SARs or partial stream assessment reaches (PSARs) within the project area.

Various other situations may necessitate defining and assessing multiple SARs or PSARs within a project area. Several examples are provided here. The first situation exists when more than one regional stream subclass occurs within a project area. This would include project areas containing ephemeral and intermittent stream reaches (Figure 29B). Another situation exists when separated stream reaches of the same regional subclass occur in the project area (Figure 29C). This occurs when the project area contains several stream reaches or lobes. These lobes may be ephemeral or intermittent, and should be assessed separately. The situation may exist

Table 7. Red flag features and respective program/agency authority.

Red Flag Features	Authority[1]
Native Lands and areas protected under American Indian Religious Freedom Act	A
Hazardous waste sites identified under CERCLA or RCRA	I
Areas protected by a Coastal Zone Management Plan	E
Areas providing critical habitat for species of special concern	B, C, F
Areas covered under the Farmland Protection Act	K
Floodplains, floodways, or floodprone areas	J
Areas with structures/artifacts of historic or archeological significance	G
Areas protected under the Land and Water Conservation Fund Act	K
Areas protected by the Marine Protection Research and Sanctuaries Act	B, D
National wildlife refuges and special management areas	C
Areas identified in the North American Waterfowl Management Plan	C, F
Areas identified as significant under the RAMSAR Treaty	H
Areas supporting rare or unique plant communities	C, H
Areas designated as Sole Source Groundwater Aquifers	I, L
Areas protected by the Safe Drinking Water Act	I, L
City, County, State, and National Parks	D, F, H, L
Areas supporting threatened or endangered species	B, C, F, H, I
Areas with unique geological features	H
Areas protected by the Wild and Scenic Rivers Act	D
Areas protected by the Wilderness Act	D
State listed special use waters (High Quality Waters or Trout Waters)	F, I

[1] Program Authority / Agency

A = Bureau of Indian Affairs
B = National Marine Fisheries Service
C = U.S. Fish and Wildlife Service
D = National Park Service
E = State Coastal Zone Office
F = State Departments of Natural Resources, Fish and Game, etc.
G = State Historic Preservation Office
H = State Natural Heritage Offices
I = U.S. Environmental Protection Agency
J = Federal Emergency Management Agency
K = Natural Resources Conservation Service
L = Local Government Agencies

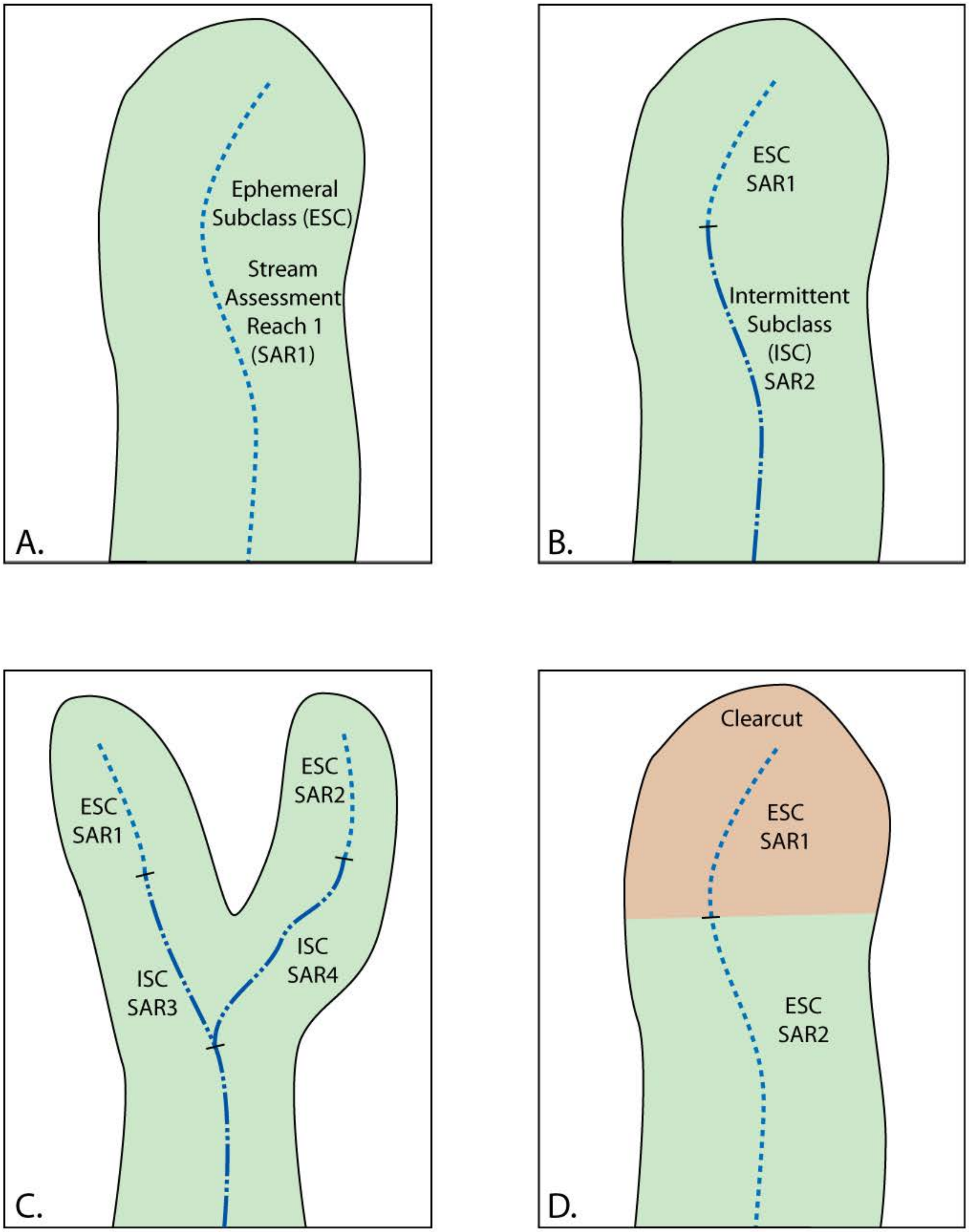


Figure 29. Example of possible SARs and PSARs for high-gradient stream assessments.

when a physically contiguous stream reach of the same regional subclass exhibits spatial heterogeneity with respect to hydrology, vegetation, soils, disturbance history, or other factors that translate into a significantly different value for one or more of the site-specific variable measures.

These differences may be a result of natural variability (e.g., windthrow, insect activity, ice storms) or cultural alteration (e.g., logging, surface mining, hydrologic alterations) (Figure 29D). This example focuses on an ephemeral stream reach in which the upper portion of the reach has been clear-cut. The disturbed and undisturbed section of stream should be assessed separately as independent SARs or PSARs.

There are elements of subjectivity and practicality in determining what constitutes a significant difference in portions of the SAR. Field experience with the regional subclass under consideration provides a sense of the range of variability that typically occurs, and the understanding necessary to make reasonable decisions about defining multiple PSARs. For example, in high-gradient streams, recent logging in a portion of a watershed may be a criterion for designating two PSARs (Figure 29D). The presence of relatively minor differences resulting from natural variability (e.g., change in the average tree DBH, percent cover of detritus, or percent bank erosion) should not be used as a basis for dividing a contiguous stream reach into multiple PSARs. However, disturbances caused by rare and destructive natural events (e.g., flooding, ice storms, etc.) should be used as a basis for defining PSARs. A sketch of the proposed project area can be helpful in determining the extent of SARs and PSARs.

Determine the subclass

This guidebook describes high-gradient headwater streams found in eastern Kentucky and western West Virginia. Determining the correct subclass is essential to completing a meaningful assessment. Subclasses are based on hydrogeomorphic characteristics. High-gradient headwater streams in the reference domain were defined previously as first- and second-order headwater streams that are supported by precipitation and groundwater inputs from the surrounding landscape and are not dominated by riverine processes. The subclass includes both ephemeral and intermittent stream reaches. Current aerial photographs, topographic maps, soils maps, NWI maps, local knowledge, sketches, or other available information can be used to help identify high-gradient headwater streams and distinguish them from perennial riverine systems. In some cases, however, it will not be possible to determine the stream subclass from remotely sensed data or maps, and on-site investigation will be necessary. Some extremely disturbed streams will be difficult or impossible to evaluate even during an on-site examination. In these cases, historical aerial photographs or knowledge of local experts may be helpful in determining the stream subclass.

Collect the data

The first step in data collection is to identify and delineate the project area and SAR or PSARs on aerial photographs and topographic maps. Always use the most recent and highest quality images and maps available. It usually will be necessary to verify decisions made from photo interpretation in the field during field reconnaissance.

Many methods or devices can be used to measure each of the variables need to complete an assessment. The following list of equipment will be helpful.

- 300-ft measuring tape
- Densitometer or spherical densitometer
- Tally meter or counter
- Tape recorder
- Large calipers or DBH tape
- Laser rangefinders
- Small calipers
- Pin flags
- Flagging tape
- GPS receiver

Variables used in the models to assess stream functions were defined and discussed in Chapter 4. Information needed to determine the variable subindex score is collected at various spatial scales. Four variables ($V_{CCANOPY}$, V_{EMBED}, $V_{SUBSTRATE}$, and V_{BERO}) describe conditions in the stream channel. The next five variables (V_{LWD}, V_{SNAG}, V_{TDBH}, V_{SSD}, and V_{SRICH}) are collected in the riparian/buffer zone, which includes the channel. $V_{DETRITUS}$ and V_{HERB} are collected in subplots within the riparian/buffer zone. The remaining variable (V_{WLUSE}) is evaluated through aerial photo interpretation of the upland watershed outside the riparian/buffer zone and verified in the field during field reconnaissance (Figure 30). The data sheet shown in Figure 31 is organized to facilitate data collection at each spatial scale. Instructions for measuring each variable are given below.

Stream channel variables

Data on vegetation, structure, and condition of the stream channel zone of high-gradient headwater streams are collected within the stream channel and represent the conditions observed along the entire SAR (Figure 30). Measurements of SAR length are required to determine a number of model variables. SAR length can be determined using a measuring tape, which will assist in determining spacing for the measurement of several variables. Several model variables require the repeated measurement of a single parameter at approximately equally spaced, representative points

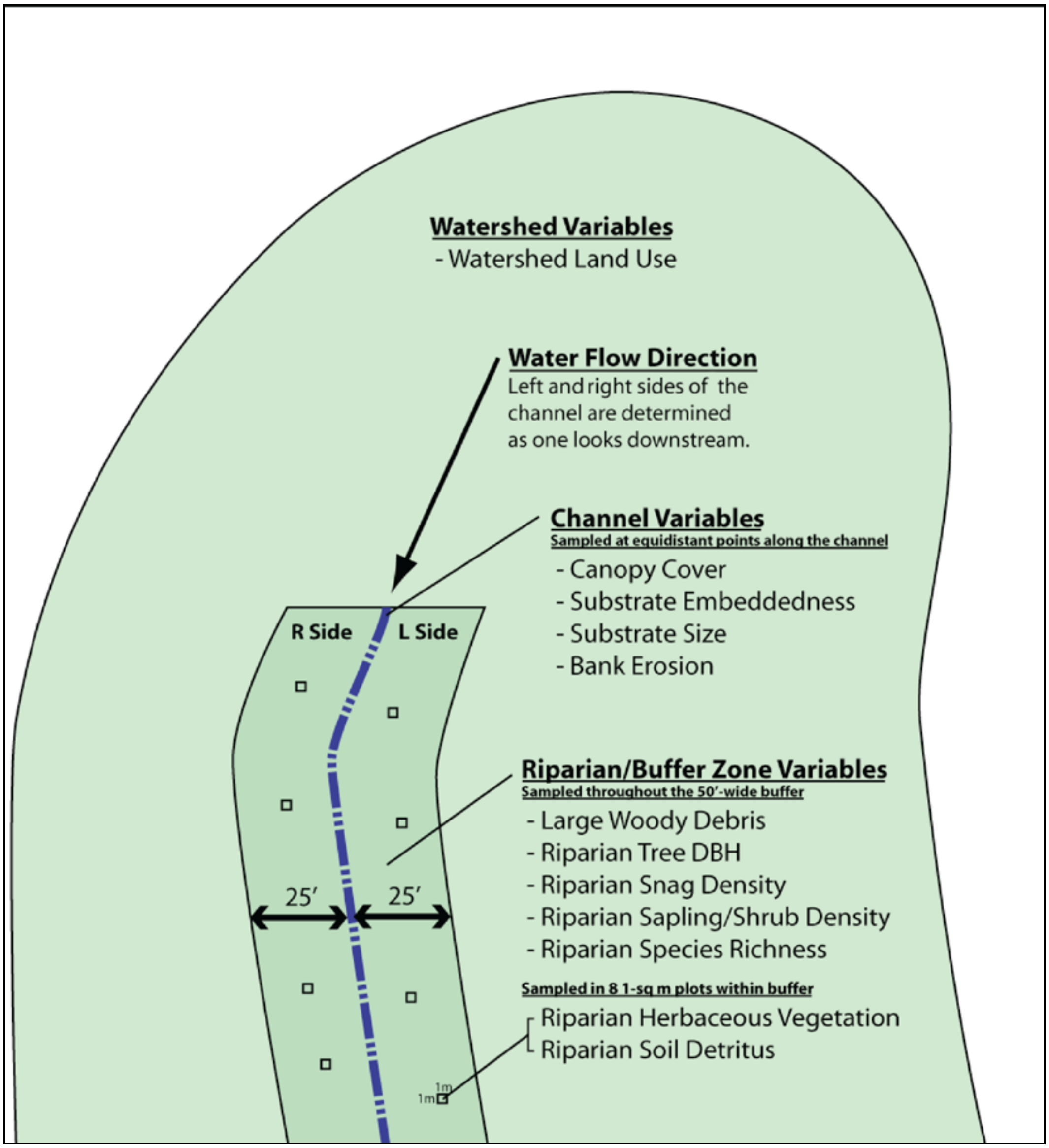
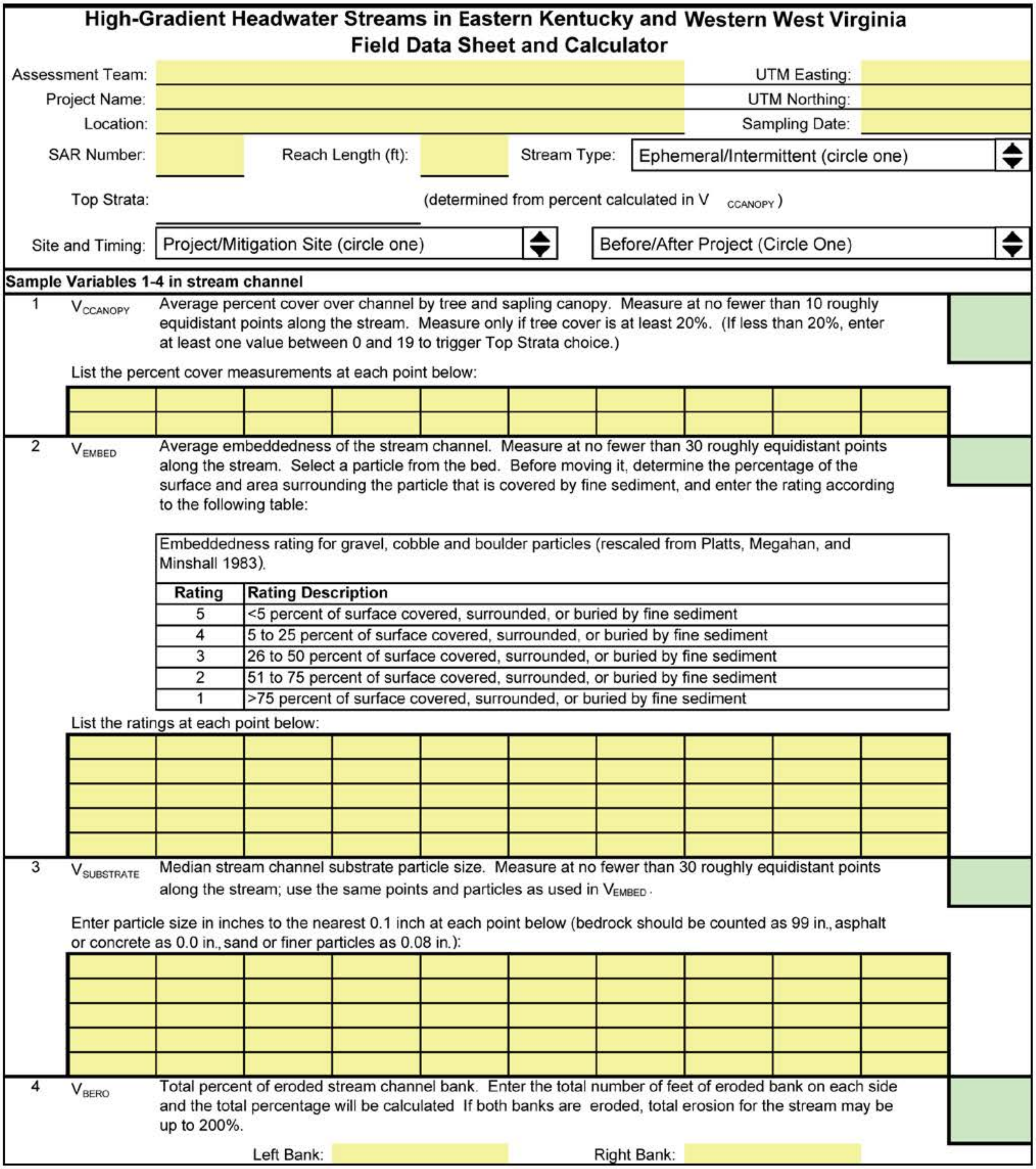


Figure 30. Example of site layout for sampling a high-gradient headwater stream.



High-Gradient Headwater Streams in Eastern Kentucky and Western West Virginia
Field Data Sheet and Calculator

Assessment Team:
UTM Easting:
Project Name:
UTM Northing:
Location:
Sampling Date:
SAR Number:
Reach Length (ft):
Stream Type: Ephemeral/Intermittent (circle one) ⬍
Top Strata: (determined from percent calculated in $V_{CCANOPY}$)
Site and Timing: Project/Mitigation Site (circle one) ⬍ Before/After Project (Circle One) ⬍

Sample Variables 1-4 in stream channel

1 $V_{CCANOPY}$ Average percent cover over channel by tree and sapling canopy. Measure at no fewer than 10 roughly equidistant points along the stream. Measure only if tree cover is at least 20%. (If less than 20%, enter at least one value between 0 and 19 to trigger Top Strata choice.)

List the percent cover measurements at each point below:

2 V_{EMBED} Average embeddedness of the stream channel. Measure at no fewer than 30 roughly equidistant points along the stream. Select a particle from the bed. Before moving it, determine the percentage of the surface and area surrounding the particle that is covered by fine sediment, and enter the rating according to the following table:

Embeddedness rating for gravel, cobble and boulder particles (rescaled from Platts, Megahan, and Minshall 1983).

Rating	Rating Description
5	<5 percent of surface covered, surrounded, or buried by fine sediment
4	5 to 25 percent of surface covered, surrounded, or buried by fine sediment
3	26 to 50 percent of surface covered, surrounded, or buried by fine sediment
2	51 to 75 percent of surface covered, surrounded, or buried by fine sediment
1	>75 percent of surface covered, surrounded, or buried by fine sediment

List the ratings at each point below:

3 $V_{SUBSTRATE}$ Median stream channel substrate particle size. Measure at no fewer than 30 roughly equidistant points along the stream; use the same points and particles as used in V_{EMBED}.

Enter particle size in inches to the nearest 0.1 inch at each point below (bedrock should be counted as 99 in., asphalt or concrete as 0.0 in., sand or finer particles as 0.08 in.):

4 V_{BERO} Total percent of eroded stream channel bank. Enter the total number of feet of eroded bank on each side and the total percentage will be calculated If both banks are eroded, total erosion for the stream may be up to 200%.

Left Bank:
Right Bank:

Figure 31. Field data sheet for high-gradient headwater streams in eastern Kentucky and western West Virginia.

Sample Variables 5-9 within the entire riparian/buffer zone adjacent to the stream channel (25 ft from each bank).

5 V_{LWD} Number of down woody stems (at least 4 in. in diameter and 36 in. in length) per 100 ft of stream reach. Enter the number from the entire 50-ft-wide buffer and within the channel, and the amount per 100 ft of stream will be calculated.

Number of downed woody stems:

6 V_{TDBH} Average dbh of trees (measure only if total tree cover is at least 20%). Trees are at least 4 in. (10 cm) in diameter. Enter DBHs in inches.

List the dbh measurements of individual trees (at least 4 in.) within the buffer on each side of the stream below:

Left Side					Right Side				

7 V_{SNAG} Number of snags (at least 4 in. dbh and 36 in. tall) per 100 ft of stream. Enter number of snags on each side of the stream, and the amount per 100 ft will be calculated.

Left Side: Right Side:

8 V_{SSD} Number of saplings and shrubs (woody stems up to 4 in. dbh) per 100 ft of stream (measure only if tree cover is <20%). Enter number of saplings and shrubs on each side of the stream, and the amount per 100 ft of stream will be calculated.

Left Side: Right Side:

9 V_{SRICH} Riparian vegetation species richness per 100 ft of stream reach. Check all species present from Group 1 in the tallest stratum. Check all exotic and invasive species present in all strata. Species richness per 100 ft and the subindex will be calculated from these data.

Group 1 = 1.0

☐ *Acer rubrum*
☐ *Acer saccharum*
☐ *Aesculus flava*
☐ *Asimina triloba*
☐ *Betula alleghaniensis*
☐ *Betula lenta*
☐ *Carya alba*
☐ *Carya glabra*
☐ *Carya ovalis*
☐ *Carya ovata*
☐ *Cornus florida*
☐ *Fagus grandifolia*
☐ *Fraxinus americana*
☐ *Liriodendron tulipifera*
☐ *Magnolia acuminata*
☐ *Magnolia tripetala*
☐ *Nyssa sylvatica*
☐ *Oxydendrum arboreum*
☐ *Prunus serotina*
☐ *Quercus alba*
☐ *Quercus coccinea*
☐ *Quercus imbricaria*
☐ *Quercus prinus*
☐ *Quercus rubra*
☐ *Quercus velutina*
☐ *Sassafras albidum*
☐ *Tilia americana*
☐ *Tsuga canadensis*
☐ *Ulmus americana*

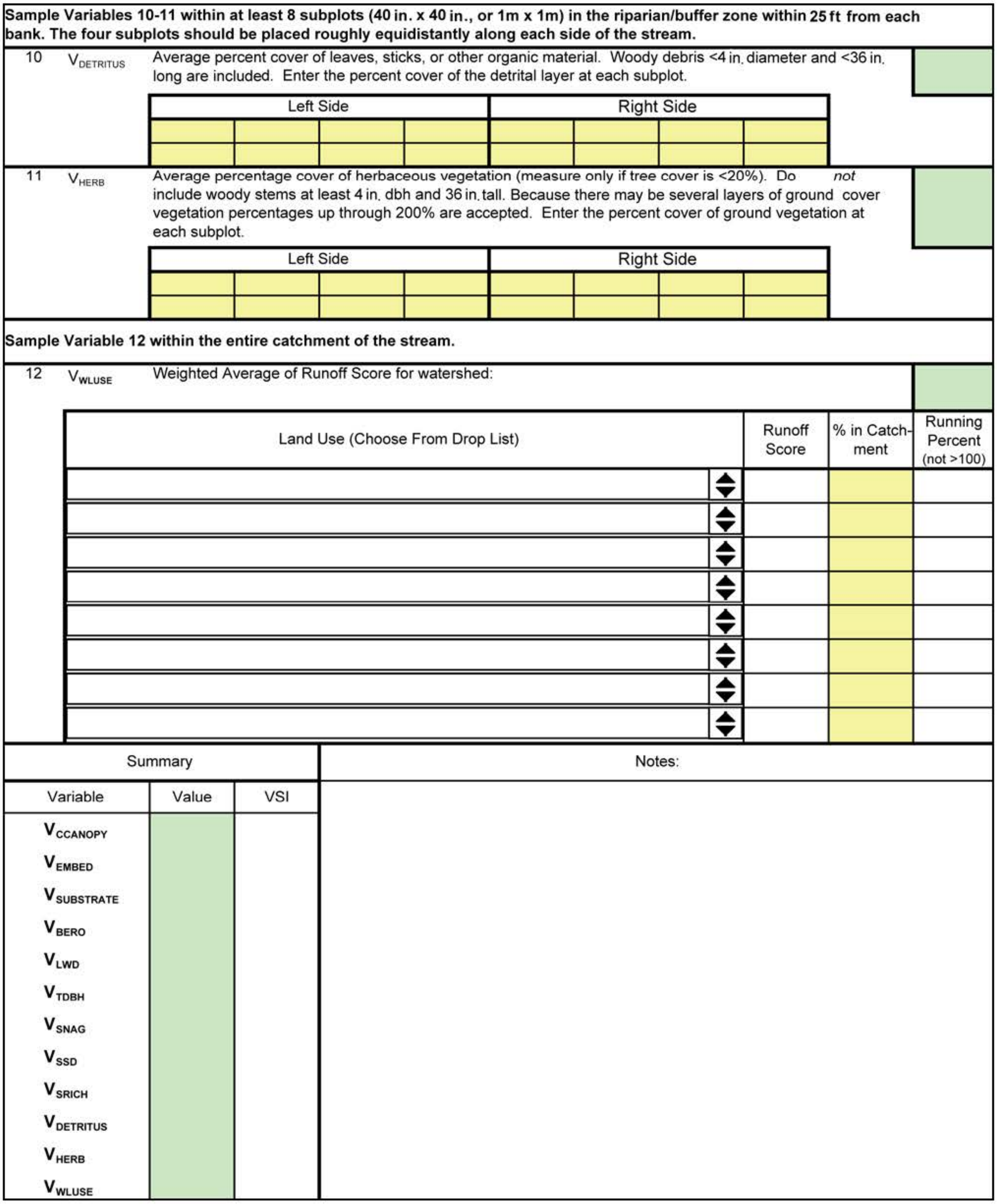
0 Species in Group 1

Group 2 (-1.0)

☐ *Ailanthus altissima*
☐ *Albizia julibrissin*
☐ *Alliaria petiolata*
☐ *Alternanthera philoxeroides*
☐ *Aster tataricus*
☐ *Cerastium fontanum*
☐ *Coronilla varia*
☐ *Elaeagnus umbellata*
☐ *Lespedeza bicolor*
☐ *Lespedeza cuneata*
☐ *Ligustrum obtusifolium*
☐ *Ligustrum sinense*
☐ *Lonicera japonica*
☐ *Lonicera tatarica*
☐ *Lotus corniculatus*
☐ *Lythrum salicaria*
☐ *Microstegium vimineum*
☐ *Paulownia tomentosa*
☐ *Polygonum cuspidatum*
☐ *Pueraria montana*
☐ *Rosa multiflora*
☐ *Sorghum halepense*
☐ *Verbena brasiliensis*

0 Species in Group 2

Figure 31. Field data sheet for high-gradient headwater streams in eastern Kentucky and western West Virginia (Continued).



Sample Variables 10-11 within at least 8 subplots (40 in. x 40 in., or 1m x 1m) in the riparian/buffer zone within 25 ft from each bank. The four subplots should be placed roughly equidistantly along each side of the stream.

10 $V_{DETRITUS}$ Average percent cover of leaves, sticks, or other organic material. Woody debris <4 in. diameter and <36 in. long are included. Enter the percent cover of the detrital layer at each subplot.

Left Side				Right Side			

11 V_{HERB} Average percentage cover of herbaceous vegetation (measure only if tree cover is <20%). Do *not* include woody stems at least 4 in. dbh and 36 in. tall. Because there may be several layers of ground cover vegetation percentages up through 200% are accepted. Enter the percent cover of ground vegetation at each subplot.

Left Side				Right Side			

Sample Variable 12 within the entire catchment of the stream.

12 V_{WLUSE} Weighted Average of Runoff Score for watershed:

Land Use (Choose From Drop List)	Runoff Score	% in Catch-ment	Running Percent (not >100)
⬍			
⬍			
⬍			
⬍			
⬍			
⬍			
⬍			
⬍			

Summary

Variable	Value	VSI
$V_{CCANOPY}$		
V_{EMBED}		
$V_{SUBSTRATE}$		
V_{BERO}		
V_{LWD}		
V_{TDBH}		
V_{SNAG}		
V_{SSD}		
V_{SRICH}		
$V_{DETRITUS}$		
V_{HERB}		
V_{WLUSE}		

Notes:

Figure 31. Field data sheet for high-gradient headwater streams in eastern Kentucky and western West Virginia (Concluded).

along the stream channel (e.g., $V_{CCANOPY}$, V_{EMBED}, $V_{SUBSTRATE}$). V_{BERO} requires the measurement of the number of feet of bare or scoured channel bank that could provide fine sediment to the stream channel. All variables should be recorded in English units on the data form. During periods of leaf fall or snow, it may be required to examine the stream channel and adjacent areas below these materials, brushing leaves and snow out of the way to accurately measure model parameters.

The data sheets are available as Excel spreadsheets, which can be printed and taken into the field. They are also calculators, and entering the data into them will allow any averages, variable subindex scores, and functional capacity indices to be calculated automatically. The directions below offer the means to perform these same calculations by hand.

The following variables are measured within the channel banks of the SAR:

Channel canopy cover ($V_{CCANOPY}$)

Measure/Units: Average percent cover of the canopy over the stream channel. Use the following procedure to measure $V_{CCANOPY}$:

1. If no trees or saplings are present within the riparian/buffer zone or stream channel, then the variable would not be used, and the following steps can be skipped.
2. Using a densitometer, spherical crown densiometer, or equivalent device designed for estimating percent canopy cover, estimate the amount of light obscured by tree branches and leaves. Follow all manufacturers' instructions. This is done while standing in the stream channel within the SAR or PSAR. Only the contribution from leaves, branches, and other canopy constituents should be included in the measurement. Do not include shadows from surrounding hills, or manmade structures when estimating percent canopy cover.
3. Examine the sky directly above.
4. Estimate the percentage of the canopy above that is obscured by tree branches and leaves. This number is the estimate of canopy cover. Estimating percent canopy cover can be difficult in winter when there are no leaves on the trees. However, with practice a reasonable estimate can be made by visualizing the trees with leaves. If necessary, revisit the site when the trees have leaves.
5. Record the percent canopy cover estimate on the data sheet.

6. Repeat the process a minimum of nine times at locations approximately evenly spaced along the SAR. This will result in a minimum of ten measurements. Longer SARs or those with a diverse canopy may require additional data points.
7. Average all of the estimates of percent canopy cover.
8. Using Figure 9, determine the subindex score for $V_{CCANOPY}$.

Substrate embeddedness (V_{EMBED})

Measure/Units: This variable is the average embeddedness value of the stream substrate. Embeddedness is a measure of the degree to which coarse substrates (gravel, cobble, and boulders) are covered, surrounded, or buried by fine sediments. Fine sediments include sand, silt, and clay size (≤0.08 in. (0.2 cm)) particles. The purpose of the V_{EMBED} and $V_{SUBSTRATE}$ values is to characterize the substrate of the channel. Use the following procedure to measure V_{EMBED}:

1. Emdeddedness is measured concurrently with $V_{SUBSTRATE}$ using the same substrate particle.
2. At 30 or more evenly spaced points along the length of the SAR or PSAR select at random (i.e., blind) a substrate particle. For example, with eyes closed reach into the stream and evaluate the first particle (sand, silt, clay, gravel, cobble, or boulder) that is touched. It is important not to intentionally select substrate particles only from pools, runs, center of the channel, or other channel feature. Before each particle is removed and measured for size, visually estimate the percentage of the particle that is covered, surrounded, or buried with fine materials and assign the appropriate rating using Table 8.
3. Substrate particles consisting of sand, silt, and clay receive an embeddedness score of 1. Concrete or other artificial substrate would also receive an embeddedness score of 1. Areas of bedrock receive an embeddedness score of 5.
4. Record the embeddedness rating based on Table 8 on the datasheet. Do NOT record the percent embeddedness.
5. Average the embeddedness rating score for all substrate particles measured.
6. Using Figure 11, determine the subindex score for V_{EMBED}.

Table 8. Embeddedness rating for gravel, cobble, and boulder size particles (rescaled from Platts et al. 1983)

Rating	Rating Description
5	<5 percent of surface covered, surrounded, or buried by fine sediment (or bedrock)
4	5 to 25 percent of surface covered, surrounded, or buried by fine sediment
3	26 to 50 percent of surface covered, surrounded, or buried by fine sediment
2	51 to 75 percent of surface covered, surrounded, or buried by fine sediment
1	>75 percent covered, surrounded, or buried by fine sediment (or artificial substrate)

Substrate ($V_{SUBSTRATE}$)

Measure/Units: This variable is the median size of the stream substrate. Use the following procedure to measure $V_{SUBSTRATE}$:

1. Using the same particles selected for V_{EMBED}, measure to the nearest 0.1 in. (3 mm) the size of the particle along the longitudinal (intermediate) axis (See Appendix B).
2. Bedrock should be counted as 99 in. (251 cm).
3. Concrete or asphalt should be counted as zero.
4. Sand or finer size particles can be recorded as 0.08 in. (0.2 cm).
5. Calculate the median value for all particles measured.
6. Use Figure 13 to determine the subindex score for $V_{SUBSTRATE}$:

Potential channel bank erosion (V_{BERO})

Measure/Units: Percentage of the total length of streambank that shows signs of erosion along the SAR or PSAR. Potential channel bank erosion is defined as disturbed, scoured sections of streambank that have exposed soil above or below the waterline. These areas are often vertical, and can range from a few inches to several feet high and have little or no vegetative or detrital cover. Exposed roots along the streambank can help identify eroded areas. Do not include undercut banks that have a stable overhang of roots and soil and no evidence of active collapse. V_{BERO} is standardized to a percent. The percent could potentially reach 200 percent if both the left and right channel banks were eroded along the entire length of the SAR. Use the following procedure to measure V_{BERO}:

1. While standing in the channel of the SAR or PSAR, measure the length of both the left and right streambanks that display signs of erosion. Note that the entire height of the channel bank is not required to exhibit erosion.

Any portion of the bank exhibiting erosion should be included in this measurement.

2. Record separately the number of feet of left channel bank erosion and right channel bank erosion on the data sheet.
3. Total the number of feet of left and right channel bank erosion and divide by the length of the stream channel; then multiply by 100 (Equation 7).

$$\left(\frac{\text{feet left bank erosion} + \text{feet right bank erosion}}{\text{stream reach length}}\right) \times 100 = \%\ \text{stream channel erosion} \tag{7}$$

4. Use Figure 15 to determine the subindex score for V_{BERO}.

Riparian/buffer zone variables

Data for some variables within the riparian/buffer zone (V_{LWD}, V_{SNAGS}, V_{TDBH}, and V_{SSD}) of high-gradient headwater streams are collected within the entire riparian/buffer zone, extending 25 ft from each bank of the stream and including the channel (Figure 30). Other variables are collected in 40-in. x 40-in. (1-m x 1-m) plots within the riparian/buffer zone ($V_{DETRITUS}$ and V_{HERB}). These plots do not include the stream channel. Data collected within the riparian/buffer zone can be subdivided into left and right sections for the convenience of data collection (Figure 30). The right and left portions of the sample area are always determined while facing downstream (Figure 30). The data from all subplots must be combined to determine the subindex score for each variable.

Large woody debris (V_{LWD})

Measure/Units: This variable consists of the number of individual pieces of down woody stems per 100 ft of stream reach within the channel and riparian/buffer zone. LWD is defined as down woody stems ≥ 4 in. (10 cm) in diameter and ≥ 36 in. (91.4 cm) long (tree size). Use the following procedure to measure V_{LWD}:

1. Count each individual piece of LWD along the entire SAR or PSAR. This includes all LWD located in the riparian/buffer zone and within the stream channel. In some cases pieces of LWD will extend outside the riparian/buffer zone. Pieces extending outside the riparian/buffer zone should be counted if a section at least 36 in. (91.4 cm) long and 4 in. (10 cm) in diameter extends into the riparian/buffer zone or the stream

channel. Distinct pieces of LWD located within log jams or piles should be counted individually. Sections of downed wood or logs that are broken, but are obviously sections of the same tree, should be counted as one piece.

2. Record the total number of LWD on the data sheet.
3. Divide the total number of LWD by the length of the SAR or PSAR, then multiply by 100 to determine the number of LWD per 100 ft of stream reach.
4. Use Figure 17 to determine the subindex score for V_{LWD}.

Riparian/buffer tree diameter (V_{TDBH})

Measure/Units: Average diameter at breast height (dbh) for all trees within the riparian/buffer zone. DBH is measured at 55 in. (1.4 m) above the ground. For the purpose of this guidebook, a tree is defined as a living woody plant with dbh ≥ 4 in. (10 cm). If channel canopy cover is <20 percent, the tree stratum is ignored, the following steps related to V_{TDBH} can be skipped, and data for V_{SSD} and V_{HERB} must be collected. Use the following procedure to measure V_{TDBH}:

1. Measure the dbh of all trees within the entire riparian/buffer zone, including any trees that occur in the stream channel of the SAR or PSAR. Measurements should be made using tree calipers, dbh tape, or equivalent device. The National Forestry Handbook (USDA Natural Resources Conservation Service (2004) is a good source of information regarding tools and methods for measuring tree diameter. All manufacturers' instructions should be followed. The tree should be measured if any part of the stem is within the sample area.
2. Calculate the average tree diameter by summing dbh measurements and dividing by the total number of trees measured.
3. Use Figure 19 to determine the subindex score for V_{TDBH}.

Riparian/buffer zone snag density (V_{SNAG})

Measure/Units: The total number of snags per 100 ft of SAR or PSAR. Snags are defined as standing dead trees. In order to be considered, snags must be woody species ≥4 in. (10 cm) in diameter and ≥36 in. (91.4 cm) in height. If the snag is not standing at the time of site evaluation, it is not measured and should be included in the measure of V_{LWD}. V_{SNAG} is standardized to a measurement of snags per 100 ft of stream reach. Use the following procedure to measure V_{SNAG}:

1. Count all snags within the entire riparian/buffer zone, including any snags that occur in the stream channel of the SAR or PSAR. Snags should be counted if any part of the stem is within the sample area.
2. Divide the total number of snags by the length of the SAR or PSAR; then multiply by 100 to determine the number of snags per 100 ft of stream reach.
3. Use Figure 21 to determine the subindex score for V_{SNAG}.

Riparian/buffer zone sapling/shrub density (V_{SSD})

Measure/Units: The number of shrubs and saplings per 100 ft of stream reach within the riparian/buffer zone including the channel. Saplings and shrubs are defined as all woody species <4 in. (10 cm) in dbh and >36 in. (90 cm) in height. They do *not* include soft-tissued, herbaceous plants or woody vines. Measure this variable only when a channel canopy cover is <20 percent. If the channel canopy cover is ≥20 percent, the following steps can be skipped. Use the following procedure to measure V_{SSD}:

1. Count each woody stem within the entire riparian/buffer zone and the stream channel. In cases where multiple stems arise from the same plant, count all stems above a height of 6 in. (15 cm) from the ground surface. Stems that originate outside of the riparian buffer zone are not counted. Record the total number of stems for the left side and right side of the sample reach on the datasheet.
2. Total the number of stems within the riparian/buffer zone.
3. Divide the total number of stems by the length of the SAR or PSAR, then multiply by 100 to determine the number of sapling/shrub stems per 100 ft of stream reach.
4. Use Figure 23 to determine the variable subindex for V_{SSD}.

Riparian/buffer zone species richness (V_{SRICH})

Measure/Units: This variable is a measure of species richness and composition. This measurement consists of the number of species from Group 1 in the tallest stratum present minus any species from Group 2 regardless of the stratum in which they occur (Table 5). For Group 1 species, the tree stratum is used if channel canopy cover ($V_{CCANOPY}$) is ≥20 percent. If channel canopy cover ($V_{CCANOPY}$) is <20 percent, then the sapling/shrub stratum is used. If the tree stratum is <20 percent and there is no sapling/shrub stratum, then the variable subindex score equals zero and the following steps can be skipped. Use the following procedure to measure V_{SRICH}:

1. On the data form, place a check mark beside each species in Group 1 or 2 (Table 5) that is observed in the riparian/buffer zone, including the channel.
2. Total the number of species checked in Groups 1 and 2 separately. Subtract the number of observed species in Group 2 from the number observed in Group 1. If the number from Group 2 is larger than that from Group 1, then the subindex score equals zero for V_{SRICH} and the following steps can be skipped.
3. If the result of Group 1 – Group 2 is ≥ 8, then the subindex score is 1.0 regardless of the reach length and the following steps can be skipped.
4. For both Group 1 and Group 2, divide the number of species by the length of the SAR or PSAR being assessed; then multiply by 100 to determine the number of species per 100 ft of stream reach for each group. The result is the standardized totals for Group 1 and Group 2 (Equation 8).

$$\text{Group 1 per 100 ft} = \left(\frac{\text{Group 1 total}}{\text{total length of SAR or PSAR}}\right)\times 100 \tag{8}$$

5. Use Equation 9 to determine the Species Richness Value (SRV):

$$\text{SRV} = \left[\text{Group 1 per 100 ft of SAR - Group 2 per 100 ft SAR}\right]\times\left[1\text{-}(0.1\times\text{Group 2 per 100 ft SAR})\right] \tag{9}$$

6. Use Figure 24 to determine the subindex score for V_{SRICH}.

Riparian/buffer zone soil detritus ($V_{DETRITUS}$)

Measure/Units: This variable is the average percent cover of detrital material on the soil surface within the riparian/buffer zone. Soil detritus is defined as the soil layer dominated by partially decomposed, but still recognizable organic material, such as leaves, sticks, needles, flowers, fruits, insect frass, dead moss, or detached lichens on the surface of the ground. Detrital materials do *not* include living vegetative ground cover. Detrital materials include woody debris that have diameters <4 in. (10 cm) and are <36 in. (91.4 cm) long. Detrital material includes soil material that would classify as fibric or hemic material (peat or mucky peat). Percent detrital cover is determined using a visual estimate. Use the following procedure to measure $V_{DETRITUS}$:

1. Visually estimate the percent cover of leaves, sticks, or other organic material (Appendix B, Figures B1 and B2) within eight or more 40-in. x 40-in. (1-m x 1-m) plots in representative locations of the riparian/buffer zone (four plots on each side of the channel).
2. Average the percent cover estimates of all plots.
3. Report the average cover of detritus as a percent.
4. Use Figure 26 to determine the subindex score for $V_{DETRITUS}$.

Riparian/buffer zone herbaceous cover (V_{HERB})

Measure/Units: Average percent cover of living herbaceous plant material. Herbaceous plants are the lowest strata on a site and do *not* include woody species ≤4 in. (10 cm) in dbh and >36 in. (90 cm) in height. Measure this variable only when the channel canopy cover is <20 percent. If the channel canopy cover ($V_{CCANOPY}$) is ≥20 percent, the following steps can be skipped. Use the following procedure to measure V_{HERB}:

1. Using the same eight or more representative 40-in. x 40-in. (1-m x 1-m) plots used to estimate $V_{DETRITUS}$, visually estimate the percent absolute cover of herbaceous plant material (Appendix B, Figures B1 and B2).
2. Average all estimates.
3. Use Figure 27 to determine the subindex score for V_{HERB}.

Watershed variables

Data gathered within watershed or catchment of high-gradient headwater streams is interpreted from aerial photos or publicly available GIS data, and verified during field reconnaissance of the area above the riparian/buffer zone and within the watershed of the high-gradient headwater stream.

Watershed land use (V_{WLUSE})

Measure/Units: Weighted average land-use score for the catchment that provides water to the high-gradient headwater stream. If the watershed has a closed forest canopy (100 percent cover), then the variable subindex score equals 1.0 and the following steps can be skipped. Use the following procedure to measure V_{WLUSE}:

1. Use topographic maps, GIS data, or other sources to delineate the catchment or watershed above the lowest point of the SAR. Do not include areas from which water is being diverted away from the SAR: include any adjacent catchment area from which water is being imported into the watershed.
2. Use GIS techniques or aerial photographs along with field reconnaissance to determine the percentage of each land-use category (Table 6) in the watershed.
3. Determine a weighted average (by area) of land-use categories for the catchment. An example can be found in Appendix B.
4. Use Figure 28 to determine the subindex score for V_{WLUSE}.

Analyze the data

The first step in analyzing the field data is to transform the field measure of each assessment variable into a variable subindex on a scale of 0 to 1.0. This can be done using the graphs and tables in Chapter 4. The second step is to insert the variable subindices into the equations for each assessment model and calculate the FCIs using the relationships defined in the models. This can be done manually or automatically using a spreadsheet. Finally, multiply the FCI for each function by the total length of the SAR to calculate the number of functional capacity units (FCUs) for each function (Smith et al. 1995).

Apply assessment results

Once the assessment and analysis phases are complete, the results can be used to compare the level(s) of function in the same SAR at different points in time or in different SARs at the same point in time. The information can be used to address the specific objectives identified at the beginning of the study, such as (a) determining project impacts, (b) comparing project alternatives, (c) determining mitigation requirements, and (d) evaluating mitigation success.

To evaluate project-related impacts, at least two assessments will generally be needed. The first assesses the number of FCUs provided by the stream reach in its pre-project condition. The second assesses the number of FCUs provided by the stream reach in a post-project state, based on proposed project plans and the associated changes to each of the model variables. The difference between pre-project and post-project conditions, expressed in numbers of FCUs, represents the potential loss or gain of functional capacity due to the project. Similarly, in a mitigation scenario, the difference between the current condition and future condition of a stream, with mitigation actions implemented and successfully completed, represents the potential gain in functional capacity as a result of restoration activities. However, since the mitigation project is unlikely to become fully functional immediately upon completion, a time lag must be incorporated in the analysis to account for the time necessary for the mitigation site to achieve full functional development.

For more information on the calculation of FCUs and their use in project assessments, see Smith et al. (1995). Spreadsheets that can be used to help evaluate project impacts and estimate mitigation requirements are available on the web at http://el.erdc.usace.army.mil/wetlands/datanal.html. The spreadsheets were developed by Frank Hanrahan based on concepts presented by the U. S. Fish and Wildlife Service (1980) and King and Adler (1992).

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Appendix A: Glossary

Anurans: An amphibian such as a frog or toad that does not have a tail as an adult and has long powerful hind legs.

Assessment model: A model that defines the relationship between ecosystem and landscape scale variables and functional capacity of an ecosystem. The model is developed and calibrated using reference sites from a reference domain.

Assessment Objective: The reason an assessment of functions is conducted. Assessment objectives normally fall into one of three categories: documenting existing conditions, comparing different sites at the same point in time (e.g. alternatives analysis), and comparing the same site at different points in time (e.g., impacts analysis or mitigation success).

Assessment team (A-Team): An interdisciplinary group of regional and local scientists responsible for classification of streams within a region, identification of reference stream reaches, construction of assessment models, definition of reference standards, and calibration of assessment models.

Bedrock: Underlying geology of the stream channel. Many high-gradient headwater streams are formed on bedrock channels where stream flow is confined to rock outcrops (Gordon et al. 2006).

Buffer zone: See riparian/buffer zone.

Catchment: The geographic area above a specific point on a stream where surface water would flow or run off into the stream.

Diameter at breast height (DBH): Tree diameter measured at 55 in. (1.4 m) above the ground.

Direct measure: A quantitative measure of an assessment model variable.

Embeddedness: An index used to measure the degree to which coarse substrates (boulders, large cobbles) are surrounded or buried by finer sediments (Gordon et al. 2006).

Ephemeral stream: A stream, or any portion thereof, that has flowing water only during, and for a short duration after, precipitation events in a typical year. Ephemeral stream beds are located above the water table year-round. Groundwater is not a source of water for the stream. Runoff from rainfall is the primary source of water for streamflow (Federal Register 2007). Ephemeral streams typically have flowing water for a few hours to a few days after a storm event and have no discernable floodplain. Ephemeral streams are typically first-order streams and are located near the upward edge of the headwater reach (Gordon et al. 2006).

Exotics: See invasive species.

Floodplain: A relatively flat valley floor formed by the repeated influence of floods and overbank flow. High-gradient ephemeral and intermittent streams display little/no floodplain topography (Gordon et al. 2006).

Functional assessment: The process by which the capacity of an ecosystem to perform a function is measured. This approach measures capacity using an assessment model to determine a functional capacity index.

Functional capacity: The rate or magnitude at which an ecosystem performs a function. Functional capacity is dictated by characteristics of the ecosystem and the surrounding landscape, and interaction between the two.

Functional capacity index (FCI): An index of the capacity of an ecosystem to perform a function relative to other ecosystems in a regional subclass. Functional capacity indices are by definition scaled from 0.0 to 1.0. An index of 1.0 indicates the ecosystem is performing a function at the highest sustainable functional capacity, the level equivalent to an ecosystem under reference standard conditions in a reference domain. An index of 0.0 indicates the system does not perform the function at a measurable level, and will not recover the capacity to perform the function through natural processes.

Functional capacity units (FCUs): Measure of functional capacity incorporating length of the assessment reach (FCU = FCI x length of assessment reach).

Headwater stream: The most upstream, "young" reach of a watershed or the section of stream channel furthest from the stream mouth. The headwaters are located near the upper edge of the watershed boundary and occupy V-shaped valleys and encompass ephemeral and intermittent stream sections (Gordon et al. 2006).

Herbaceous layer: The lowest level of vegetative strata on a site made up of non-woody plant species (herbs). Herbaceous plants are defined as all plant materials on the ground layer ≤ 3 in. dbh and ≤ 36 in. tall. Herbaceous species do not include woody species ≤ 3 in. dbh and greater than 36 in. tall.

High-gradient Streams: Streams with channel slope greater than 4 percent. Typically small first-and second-order systems located in the headwater regions of a watershed.

Hydrogeomorphic unit: Areas within an assessment area that are relatively homogeneous with respect to ecosystem scale characteristics such as microtopography, soil type, vegetative communities, or other factors that influence function. Hydrogeomorphic units may be the result of natural or anthropogenic processes.

Indicator: Observable characteristics that correspond to identifiable variable conditions in a stream or the surrounding landscape.

Intermittent stream: A stream that has flowing water during certain times of the year when groundwater provides water for stream flow. During dry periods, intermittent streams may not have flowing water. Runoff from rainfall is a supplemental source of water for stream flow (Federal Register 2007). These systems are typically located in the headwater region and flow only when they receive water from springs or surface water runoff. These streams are typically first or second order and are located below ephemeral stream segments near the upper edge of the watershed boundary (Gordon et al. 2006).

Invasive species: Generally, exotic species without natural controls that out-compete native species.

Mitigation: Restoration or creation of a stream reach to replace functional capacity that is lost as a result of project impacts.

Model variable: A characteristic of the ecosystem or surrounding landscape that influences the capacity of an ecosystem to perform a function.

Organic matter: Plant and animal residue in the soil in various stages of decomposition.

Organic soil material: Soil material that is saturated with water for long periods or artificially drained and, excluding live roots, has an organic carbon content of 18 percent or more with 60 percent or more clay, or 12 percent or more organic carbon with 0 percent clay. Soils with an intermediate amount of clay have an intermediate amount of organic carbon. If the soil is never saturated for more than a few days, it contains 20 percent or more organic carbon.

Partial stream assessment reach (PSAR): A portion of an SAR that is identified a priori, or while applying the assessment procedure to an area relatively homogeneous and different from the rest of the SAR with respect to one or more variables. Differences may be natural or result from anthropogenic disturbance.

Perennial Stream: A stream that has flowing water year-round during a typical year (Federal Register 2007). Perennial streams are typically third order or higher systems (Gordon et al. 2006).

Pool: A segment of a stream reach where water depths are greater than in the surrounding area and streamflow velocity is reduced.

Potential reference domain: The maximum geographic extent of the subclass in the landscape.

Project alternative(s): Different ways in which a given project can be done. Alternatives may vary in terms of project location, design, method of construction, amount of fill required, and other ways.

Project area: The area that encompasses all activities related to an ongoing or proposed project.

Project target: The level of functioning identified for a restoration or creation project. Conditions specified for the functioning are used to judge whether a project reaches the target and is developing toward site capacity.

Red flag features: Features of a stream or surrounding landscape to which special recognition or protection is assigned on the basis of objective criteria. The recognition or protection may occur at a Federal, State, regional, or local level and may be official or unofficial.

Reference domain: All streams within a defined geographic area that belong to a single regional subclass.

Reference standards: Conditions exhibited by a group of reference streams that correspond to the highest level of functioning (highest sustainable capacity) across the suite of functions of the regional subclass. By definition, highest levels of functioning are assigned an index of 1.0.

Reference streams: Streams that encompass the variability of a regional subclass in a reference domain. Reference streams are used to establish the range of conditions for construction and calibration of functional indices and to establish reference standards.

Region: A geographic area that is relatively homogeneous with respect to large-scale factors such as climate and geology that may influence how streams function.

Riffle: A shallow stretch of stream where small rippled waves are formed above the stream channel substrate.

Riparian/buffer zone: A terrestrial area directly adjacent to the stream.

Runoff: Water flowing on the surface either by overland sheet flow or by channel flow in rills, gullies, streams, or rivers.

Sapling/shrub cover: A measurement of the abundance of sapling/shrubs. Sapling/shrub cover is measured from ground level as a count.

Sapling/shrub layer: For the purposes of this guidebook, the vegetation layer consisting of self-supporting woody plants greater than 39 in. (1 m) in height but less than 4 in. (10 cm) in diameter at breast height.

Site potential: The highest level of functioning possible, given local constraints of disturbance history, land use, or other factors. Site capacity may be equal to or less than levels of functioning established by reference standards for the reference domain, and it may be equal to or less than the functional capacity of an ecosystem.

Soil surface: The soil surface is the top of the mineral soil; or, for soils with an O horizon, the soil surface is the top of the part of the O horizon that is at least slightly decomposed. Fresh leaf or needle fall that has not undergone observable decomposition is excluded from soil and may be described separately (Carlisle 2000).

Stratum/Strata: See vegetative stratum.

Stream assessment reach (SAR): A section of the stream within a project area that belongs to a single regional stream subclass and is relatively homogeneous with respect to the site-specific criteria used to assess stream functions (i.e., hydrologic regime, vegetation structure, topography, soils, successional stage).

Streambank erosion: Changes in the channel resulting in the removal of streambank/streambed materials due to frost action, flooding, trampling, vegetation removal, bulldozing, or other factors (Gordon et al. 2006). Erosion includes disturbed, scoured sections of streambank that have exposed soil above or below the waterline.

Stream channel: The natural bed and banks formed by fluvial processes of accumulating/degrading mineral and organic materials. The natural depression which conveys water within defined banks.

Stream function: The normal activities or actions that occur in stream ecosystems, or simply, the things that streams do. Stream functions result directly from the characteristics of a stream ecosystem and the surrounding landscape and their interactions.

Stream order: A means of ranking relative sizes of streams and drainage area. First-order streams are small and normally dry, while larger, second-order streams are formed by the junction of two first-order streams; third-order streams are formed by the junction of two second-order streams (Gordon et al. 2006).

Stream reach: Representative homogenous units within a stream segment. A stream reach may encompass the entire length of an ephemeral stream, or may represent a subsection of the stream. Stream reaches are often comprised of riffles and pools and are used to partition the stream into homogenous sections based on topography, geology, slope, streamflow, and biological characteristics (Gordon et al. 2006).

Subindex graphs: A graphical representation of parameter quality based on data collected within the reference domain. Subindex values can range from 0.0 to 1.0.

Substrate: The particles of organic and inorganic material located on the streambed (Gordon et al. 2006).

Variable: An attribute or characteristic of an ecosystem or the surrounding landscape that influences the capacity of the ecosystem to perform a function.

Variable condition: The condition of a variable as determined through quantitative or qualitative measure.

Variable subindex: A measure of how an assessment model variable in an ecosystem compares to the reference standards of a regional subclass in a reference domain.

Watershed: See Catchment.

Appendix B: Supplementary Materials

This appendix contains additional guidance on measuring model variables. It is designed to provide tools and direction to aid in collection of model variables. The following pages contain:

a. Comparison charts for visual estimates of channel canopy cover, soil detritus, and herbaceous cover – Figures B1 and B2

b. Substrate embeddedness – page 100

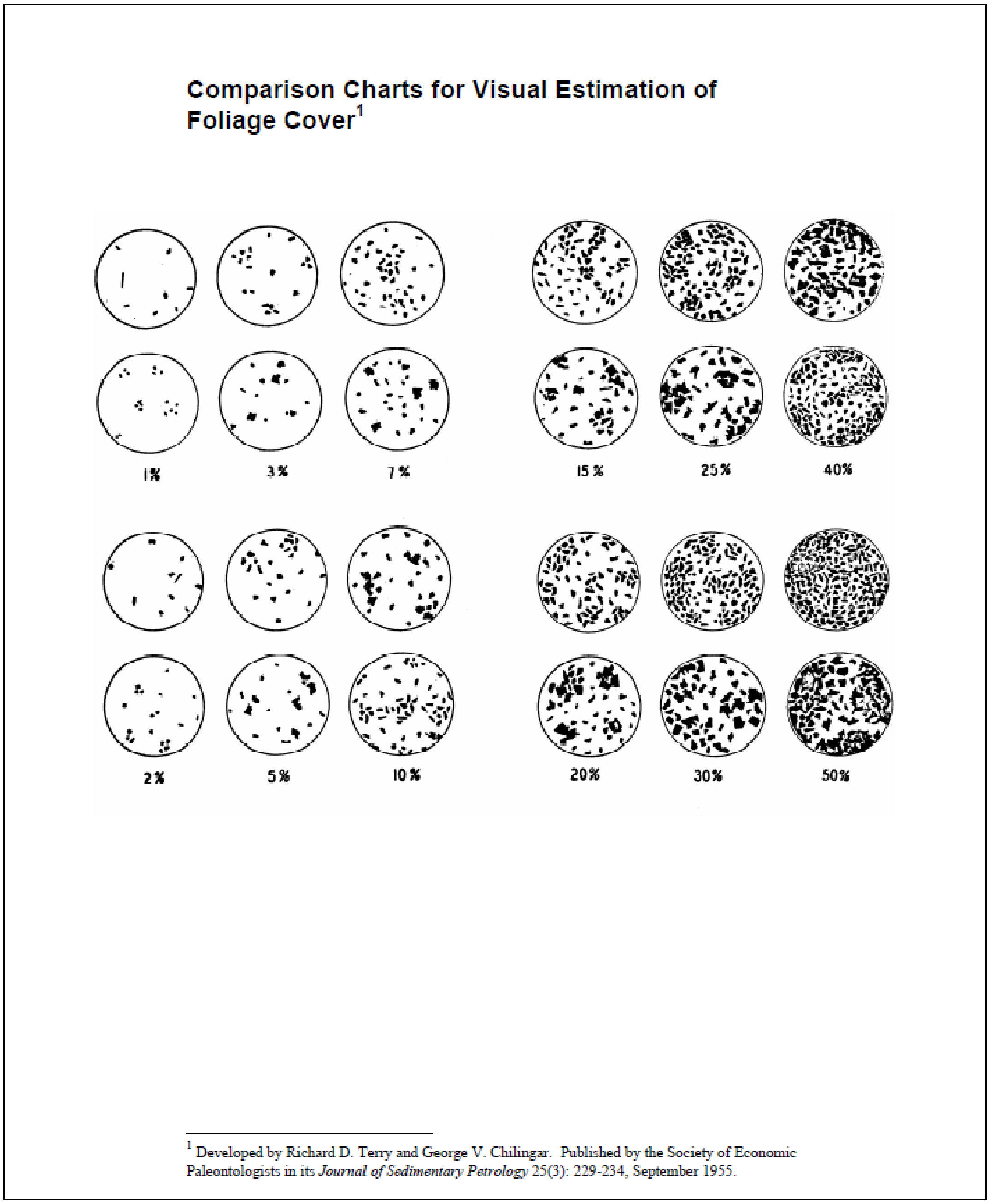
c. Substrate size – page 101

d. Tree species observed on reference sites – page 103

e. Watershed land-use measurements – page 104

Visual estimation of cover

The following charts and diagrams contain guidance on estimating percent cover values. The following tools can be used to aid in the estimation of channel canopy cover ($V_{CCANOPY}$), herbaceous cover (V_{HERB}), and detrital cover ($V_{DETRITUS}$). The estimation of cover can be difficult and requires practice to achieve repeatable results. The tools provided below can be used to improve accuracy and repeatability.



Comparison Charts for Visual Estimation of Foliage Cover[1]

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[1] Developed by Richard D. Terry and George V. Chilingar. Published by the Society of Economic Paleontologists in its *Journal of Sedimentary Petrology* 25(3): 229-234, September 1955.

Figure B1. Comparison charts for visual estimation of foliage cover.

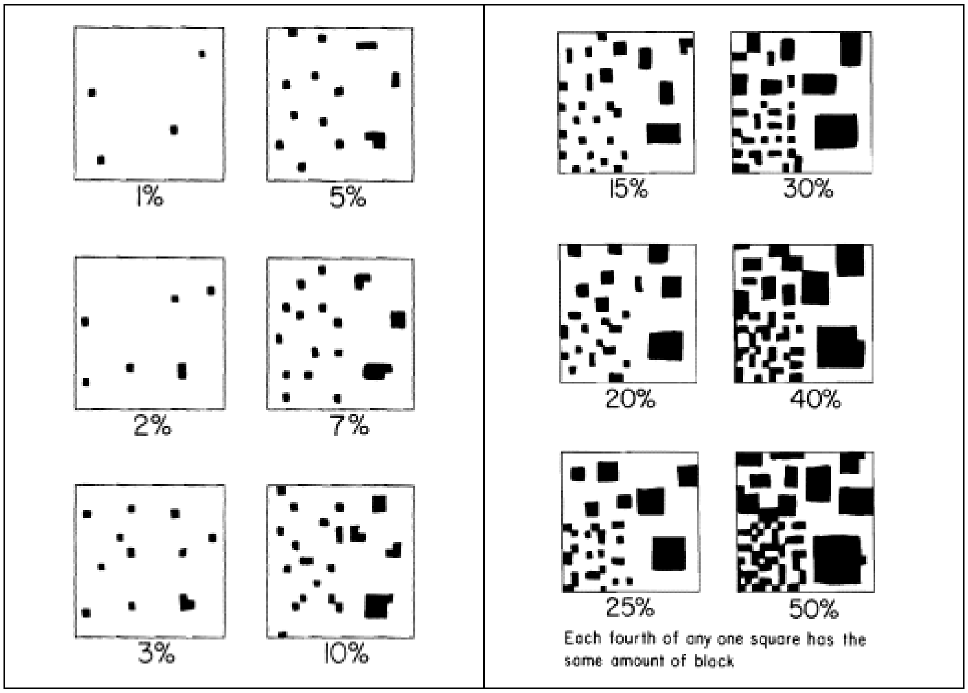

Figure B2. Comparison charts for visual estimates of soil detritus and herbaceous cover. (Gretag/Macbeth 2000).

Measuring substrate embeddedness

Embededdness can be defined as "the degree that the larger particles (e.g., boulder, cobbles, gravel) are surrounded or covered by fine sediment" or "the amount of fine sediment that is deposited in the interstices between larger stream substrate particles." Embeddedness values are estimated as a percent and recorded on a scale based on the work of Platts et al. (1983). For additional guidance on measuring embeddedness, see Sylte and Fischenich (2002) (http://www.wes.army.mil/el/emrrp).

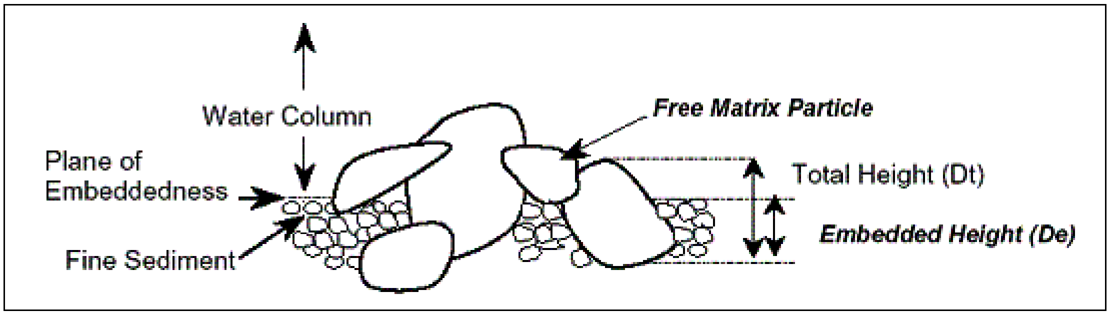

Figure B3. Schematic representation of embeddedness.

Measuring substrate size

Stream particle size (substrate size) is measured according to the procedures outlined in Chapters 4 and 5. The axis of measurement is displayed in Figure B4. In all cases, the substrate should be measured along the median axis. This axis is represented by axis b in Figure B4.

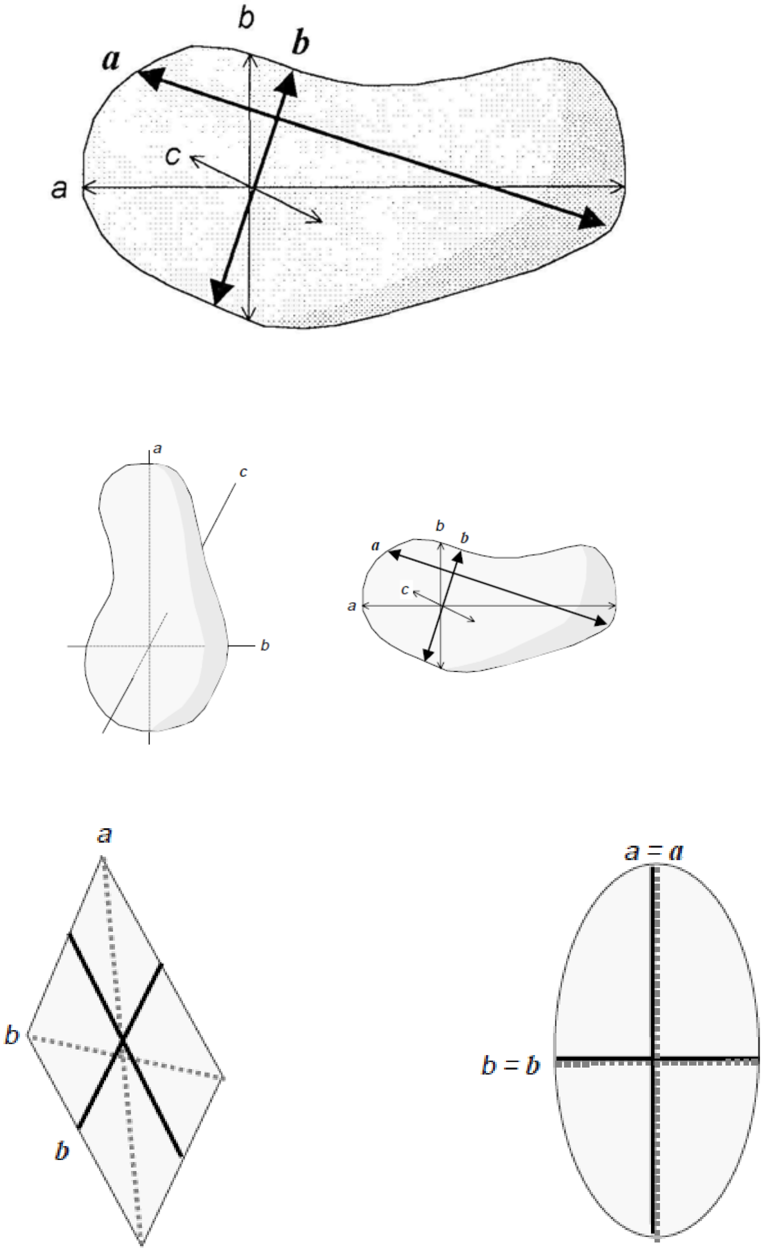

Figure B4. Diagrams of the b-axis measurement of a given stream substrate particle for use in the Wolman Pebble Count method (Bunte and Abt 2001).

Plant list

Table B1 is a list of tree species identified during the data collection for the high-gradient headwater stream guidebook. This list represents the variability occurring within the reference domain and can be used to aid in species identification. Common names are from USDA Plants Data Base (http://plants.usda.gov/)

Table B1: Comprehensive list of tree species

Scientific Name	Common Name	Scientific Name	Common Name
Acer negundo	boxelder	*Magnolia tripetala*	umbrella-tree
Acer pensylvanicum	striped maple	*Nyssa sylvatica*	blackgum
Acer rubrum	red maple	*Ostrya virginiana*	hophornbeam
Acer saccharum	sugar maple	*Oxydendrum arboreum*	sourwood
Aesculus flava	yellow buckeye	*Paulownia tomentosa*	princesstree
Ailanthus altissima	tree of heaven	*Picea rubens*	red spruce
Amelanchier arborea	common serviceberry	*Pinus rigida*	pitch pine
Asimina triloba	pawpaw	*Pinus strobus*	eastern white pine
Betula alleghaniensis	yellow birch	*Pinus virginiana*	Virginia pine
Betula lenta	sweet birch	*Platanus occidentalis*	American sycamore
Betula papyrifera	paper birch	*Populus deltoides*	eastern cottonwood
Carpinus caroliniana	American hornbeam	*Populus grandidentata*	bigtooth aspen
Carya alba	mockernut hickory	*Prunus serotina*	black cherry
Carya cordiformis	bitternut hickory	*Quercus alba*	white oak
Carya glabra	pignut hickory	*Quercus coccinea*	scarlet oak
Carya ovata	shagbark hickory	*Quercus imbricaria*	shingle oak
Celtis occidentalis	common hackberry	*Quercus muehlenbergii*	chinkapin oak
Cercis canadensis	eastern redbud	*Quercus palustris*	pin oak
Cornus florida	flowering dogwood	*Quercus prinus*	chestnut oak
Elaeagnus umbellata	autumn olive	*Quercus rubra*	northern red oak
Fagus grandifolia	American beech	*Quercus velutina*	black oak
Fraxinus americana	white ash	*Robinia pseudoacacia*	black locust
Fraxinus pennsylvanica	green ash	*Salix nigra*	black willow
Hamamelis virginiana	American witchhazel	*Sassafras albidum*	sassafras
Ilex opaca	American holly	*Tilia americana*	American basswood
Juglans cinerea	butternut	*Tsuga canadensis*	eastern hemlock
Juglans nigra	black walnut	*Ulmus americana*	American elm
Liquidambar styraciflua	sweetgum	*Ulmus parvifolia*	Chinese elm
Liriodendron tulipifera	tuliptree	*Ulmus rubra*	slippery elm
Magnolia acuminata	cucumber-tree	*Ulmus thomasii*	rock elm

Watershed land-use (V_{WLUSE})

The following example shows how to estimate the weighted average runoff score for V_{WLUSE}:

Identify the different land-use types within the catchment of the SAR using recent aerial photography. Estimate the percentage of the catchment in each land-use type. Verify during onsite reconnaissance. Use the spreadsheet provided (example given below) to calculate the functional index score for V_{WLUSE}.

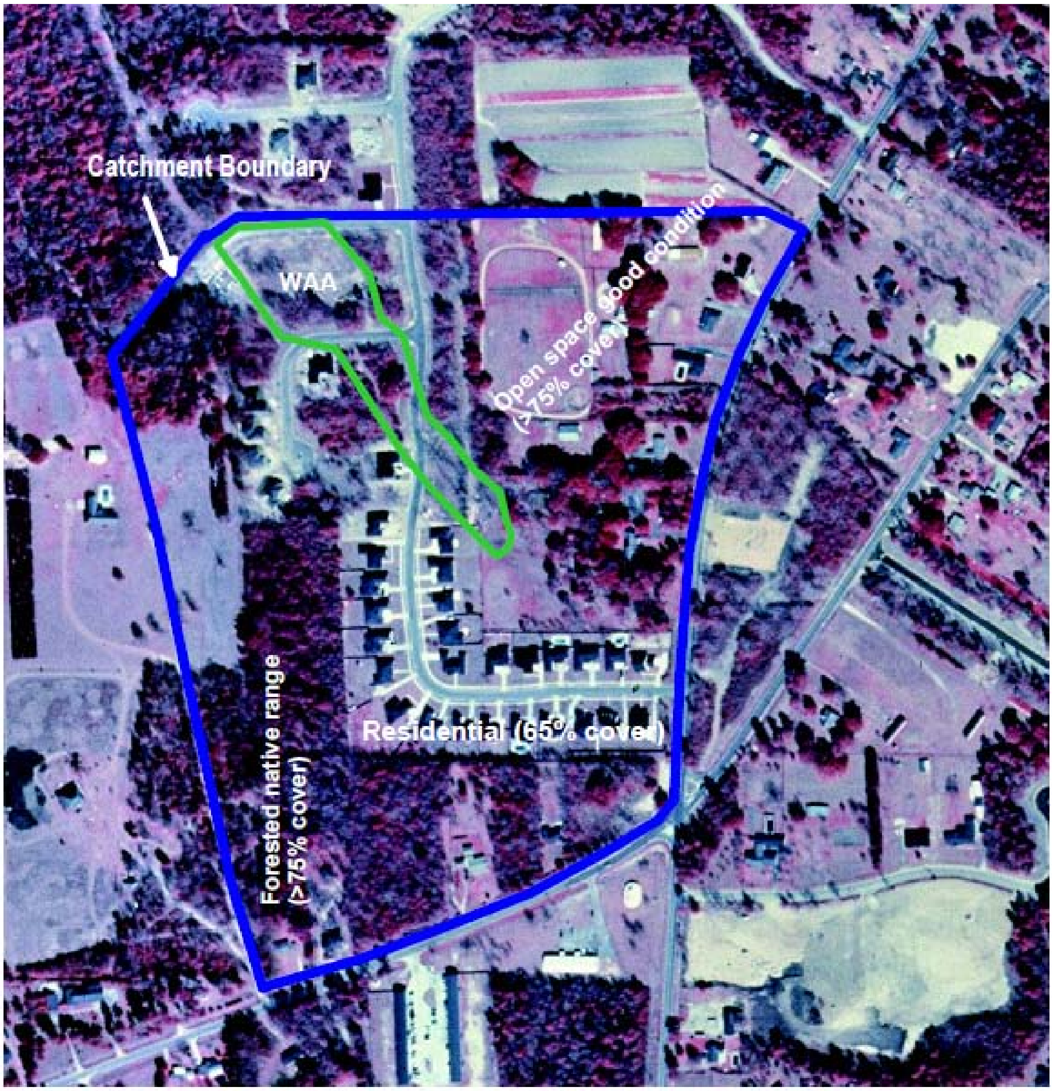

Figure B5. Aerial photograph illustrating the cover types found within a catchment.

12	V_{WLUSE}	Weighted Average of Runoff Score for watershed:			0.76
		Land-use (Choose From Drop List)	Runoff Score	% in Catch-ment	Running Percent (not >100)
		Open space (pasture, lawns, parks, etc.), grass cover >75% ▼ 4	0.5	20	20
		Forest and native range (>75% ground cover) ▼ 16	1	60	80
		Residential districts, 1/4 - 1/3 ac (38% to 30% cover) ▼ 10	0.3	20	100

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14. ABSTRACT

The Hydrogeomorphic (HGM) Approach is a method for developing functional indices and the protocols used to apply these indices to the assessment of ecosystem functions at a site-specific scale. The HGM Approach was initially designed to be used in the context of the Clean Water Act Section 404 Regulatory Program permit review to analyze project alternatives, minimize impacts, assess unavoidable impacts, determine mitigation requirements, and monitor the success of compensatory mitigation. However, a variety of other potential uses have been identified, including the determination of minimal effects under the Food Security Act, design of restoration projects, and management of wetlands.

This report uses a modified HGM Approach to develop a Regional Guidebook to (a) characterize high-gradient ephemeral and intermittent headwater streams, known collectively as high-gradient headwater streams in eastern Kentucky and western West Virginia, (b) provide the rationale used to select functions for the headwater subclasses, (c) provide the rationale used to select model variables and metrics, (d) provide the rationale used to develop assessment models, (e) provide data from reference streams and document their use in calibrating model variables and assessment models, and (f) outline the necessary protocols for applying the functional indices to the assessment of stream functions.

15. SUBJECT TERMS Clean Water Act Compensatory Mitigation	Functional indices Hydrogeomorphic (HGM) Approach Section 404 Regulatory Program	

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