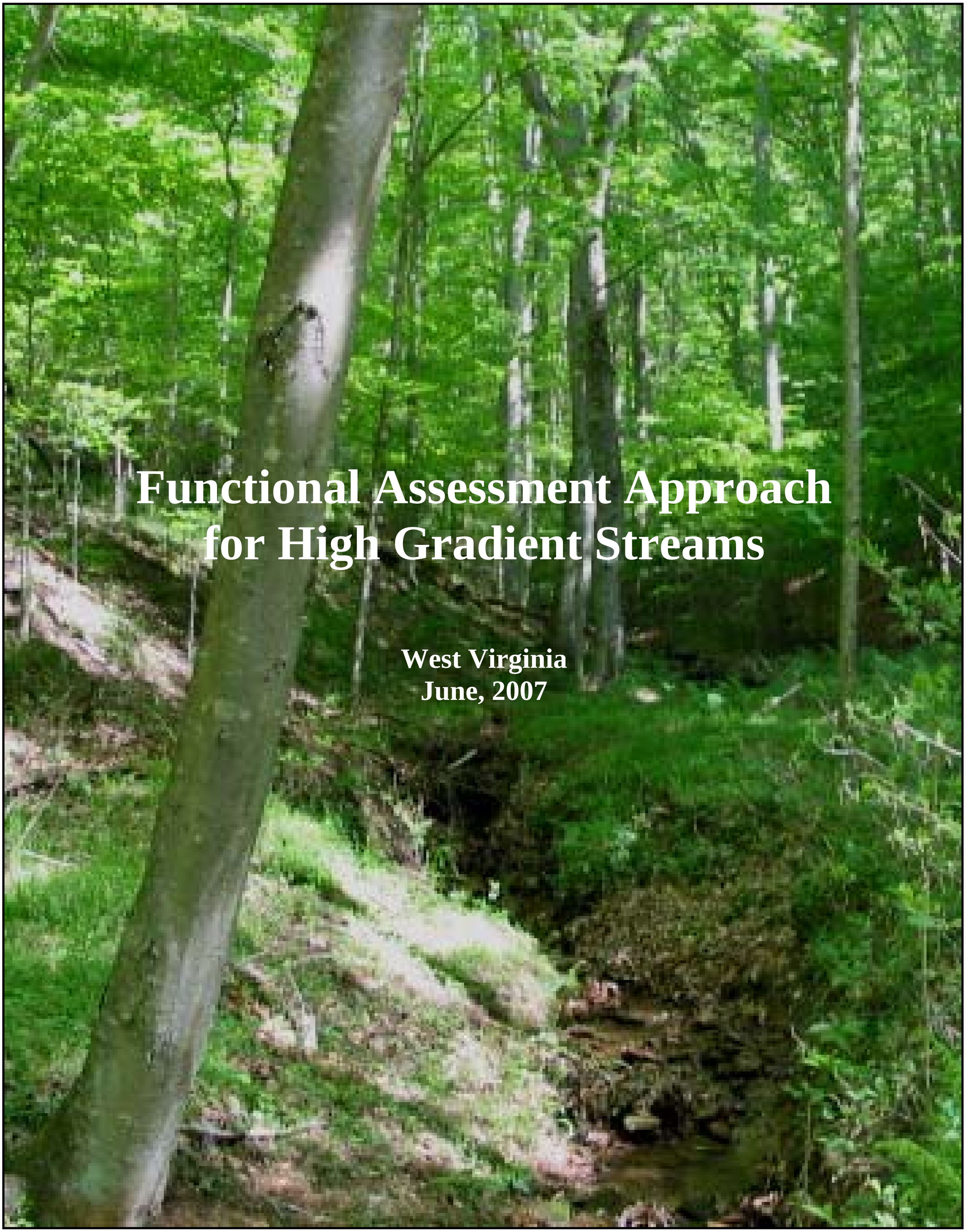


# Functional Assessment Approach for High Gradient Streams

**West Virginia**
**June, 2007**

## INTRODUCTION

This document describes the components and application of a method for assessing the condition of headwater streams and riparian areas in the mountains of West Virginia. It is specifically designed to address the typical impacts and likely mitigation proposals considered in the context of processing Clean Water Act Section 404 permit applications. The focus of this assessment method is on high gradient, headwater streams in West Virginia. These streams can be characterized as first and second order ephemeral and intermittent stream with a channel slope that ranges from 4 percent to greater than 10 percent. The stream channel sinuosity is low, but has common to many step pools and would classify as A, Aa, or Aa+ (Rosgen 1998) with a gravel, cobble or bolder controlled channel within a Type I valley. Flow rates in these streams are typically less than 7 cubic feet per second (cfs). The surrounding watershed contributing to the channel is forested with hardwood trees and woody shrubs, on moderately steep to very steep slopes (USDA 2004).

This approach, like various similar assessment tools developed for other regions and ecosystems, is based on the proposition that the condition of aquatic and wetland systems depends on a suite of physical and biological processes. These processes generally reflect the position of the system in the landscape, which controls how it interacts with geology, hydrology, and soils. These in turn influence vegetation, which further interacts with physical processes such as sediment movement, provides many elements of on-site animal habitat, and contributes nutrients and organic materials to the aquatic system on-site and downstream. Therefore, rapid assessment systems such as this one are designed to evaluate the extent to which key processes are operating or have been disrupted.

The approach involves visual evaluation of the physical and biological structure of the assessment site, or rating of the site as to the extent that it is functionally compromised by various stressors. These evaluations or ratings are formulated as simple equations, or models, where the condition assessments of a set of indicators are combined into an overall index of functionality for each of four functional categories: hydrology, biogeochemistry, plant communities, and wildlife habitat.

A set of eleven indicators are used in the models, where they are variously combined to reflect key elements of the functional category being assessed. The indicators are scaled from zero to 1.0, where 1.0 represents the fully functional (or reference), condition. The specific reason for using each indicator and the structure of the rating scale are explained further in the following sections of this document. Generally, however, the indicators (also called variables) are scaled based on a combination of field observations within a range of sites in the region, professional judgment, published literature, and rating scales developed for the same types of indicators in other regions and ecosystems. No field studies have been conducted in the region specifically to calibrate the indicators used here, therefore all scaling is approximate.

The method presented here is intended to be applied to potential or actual impact and mitigation sites by one experienced person in half a day or less. It is designed to produce consistent results across the range of headwater stream conditions typically encountered in the region.

## PROCEDURE

1. Identify the Assessment Site on a topographic map. The Assessment Site includes the affected stream reach, and the watershed that drains to that reach.

2.  Assemble any required materials and information, such as a camera, slope measuring device, a distance measuring tape, a ruler, and similar equipment.  Review the data forms in the context of the size and accessibility of the Assessment Area to determine if you will require aerial photos and a soil survey.  Bring any pertinent descriptions and maps of proposed impacts or mitigation plans.  Make sufficient copies of data sheets from this document.

3.  At each assessment area, assign a site identifier, take photos and keep notes concerning the orientation and principal subject of each photo (e.g., "channel looking downstream from midpoint of impact reach").  Complete the data sheets, consulting the individual variable descriptions for specific directions regarding the assignment of scores.  Note that each indicator is scored using a weighted approach, where the percent of the assessment area in each score range is estimated and recorded.

4.  If the average percent cover of either trees or shrubs is more than 10 percent the cover of herbaceous vegetation does not need to be determined.

5.  Copy the basic spreadsheet and name the copy with the same site identifier recorded on the datasheets.  Transfer values from data sheets to the spreadsheet and calculate Function Scores.  Save and label all digital photos.  Save the spreadsheet and all digital photos in a folder labeled with the same site identifier as used on the datasheets.  Print hard copies of the spreadsheet, photos, and photo descriptions, and any other pertinent materials, and attach original data sheets.

6.  Summarize the assessment.  Depending on the scenario being investigated, the calculated index scores can be used in various ways.  Typically, they should be converted to Functional Units by multiplying the index for each function by the stream length.  Decisions about how to use the numbers are a matter of policy, and are not specified here.  Normally, subsequent analyses are done without combining the four functions (i.e., the total habitat functional units lost to an impact are compared to the total habitat functional units gained by a mitigation action).  However, some users of assessment systems find it convenient and more understandable to add all functional units together, or to average them, despite the obvious logic problems with this approach.  Others base decisions on the "most impacted function."  Similarly, impacts and mitigation credits can be calculated based on some target year (i.e., 5 years after impact) or on a projected average condition over the life of the project, or on some other criterion.

## Variables

**Stream channel alterations (*CHANNELALT*).** This variable reflects alterations to the natural hydrology of the stream due to activities within the channel itself. Both natural and man-induced alterations can affect the hydrology of high gradient, ephemeral and intermittent streams. Examples in West Virginia include ditches, dams, culverted and unculverted road crossings, and downcutting or entrenchment of the channel. The intent of this variable is to capture those impacts that alter the hydrograph of the headwater stream system. This variable differs from *SLOPE* and *LANDUSE* in that the impacts occur within the stream channel and not in the surrounding landscape.

*CHANNELALT* is used in calculating the hydrology, biogeochemical, plant community, and habitat functional indices.

This variable is quantified by the type of structure or alteration to the stream channel. Measure *CHANNELALT* using the following procedure:

1) If stream is unaltered or no obstructions to natural water flow, and there is no excessive ponding within the channel, the score for this variable is 1.0.

2) If hydrology has been altered, identify the percentage of the stream affected by any permanent obstructions to channel flow such as dams, roads or fill, or by any deepening or straightening intended to speed flows, or any deepening or sedimentation that apparently resulted from land uses in the watershed, such as timber harvests. Do not include such changes if they appear to be the result of natural phenomena, such as increased incision following a forest fire or ponding by beaver.

3) Use Table 1 to determine the variable score for each of the alterations identified to the natural hydrology. Determine the weighted average for the entire stream reach impacted.

**Table 1**
**Stream channel alterations (*CHANNELALT*)**

| **Type of alteration** | **Score** |
|---|---|
| unaltered | 1.0 |
| restored | 0.75 |
| incised, or excess sediment in channel | 0.5 |
| dammed | 0.1 |
| channelized/straightened | 0.1 |
| channel >50% filled | 0.0 |

**Average percent slope of the watershed (*SLOPE*).** This variable reflects anthropogenic alterations to the natural slope of the headwater watershed. Under natural conditions in West Virginia, headwater stream systems form within moderately steep to extremely steep mountain coves, where average slope exceeds 45 percent. Steep slopes facilitate movement of water downslope to the stream channel, and removal of detrital material downstream to perennial streams. The intent of this variable is to capture changes to the watershed slope that can alter the movement of water and nutrients downstream at a reduced rate. This variable differs from *CHANNELALT* in that the impacts occur within the surrounding watershed and not directly in the stream channel.

*SLOPE* is used in calculating the hydrology and biogeochemical functional indices.

This variable is quantified by measuring alterations to slopes draining to the stream reach being assessed. Measure *SLOPE* using the following procedure:

1) If the watershed slope is unaltered, regardless of slope, then the score for this variable is 1.0.

2) Using topographic maps, soil survey maps, digital elevation maps, clinometers, Abney hand level, or other appropriate tools for measuring slope, determine the average percent slope of the watershed surrounding the stream reach being assessed. If the watershed slope is extremely variable (contains 3 or more categories identified in Table 2) determine a weighted average using the percent of the watershed for each category.

3) Use Table 2 to determine the variable score for the watershed slope.

**Table 2**
**Average percent slope of the watershed (*SLOPE*)**

| **Percent slope** | **Score** |
|---|---|
| 30 to 45 or unaltered | 1.0 |
| (20 to 29) or (45 to 65) | 0.75 |
| 10 to 19 | 0.5 |
| (5 to 9) or (66 to 90) | 0.25 |
| less than 5 | 0.1 |

**Stream Sediment Size (*SED*)**. Stream sediment size is the predominant particle size of materials comprising the surface of the streambed. Sediment size is based on USDA texture classes for coarse and fine soil particles (USDA 1993). The composition of the streambed has a direct impact on the dissipation of water energy in the stream channel and influences habitat for vertebrates and invertebrates.

*SED* is used in calculating habitat functional indices.

Using the following procedure, determine the score for *SED*:

(1) During field reconnaissance, visually estimate the size of the predominant bed material in the stream channel.

(2) Use Table 3 to determine the variable score for Stream Sediment Size.

(3) If Stream Sediment Size is extremely variable in the watershed being assessed, determine a weighted average for this variable.

In West Virginia minimally altered headwater stream systems stream sediment is dominated by cobbles, stones, and boulders.

**Table 3**
**Stream Sediment Size (*SED*)**

| USDA Soil Texture | Score |
|---|---|
| boulders, stones, cobbles (>3 in.) | 1.0 |
| Gravel (3/4 to 3 in.) | 0.75 |
| sand | 0.5 |
| silt | 0.1 |
| clay/pavement/bedrock | 0.1 |

**Land Cover within the Watershed (*COVER*)**. This variable is defined as the surface water runoff potential from the watershed into the stream. With increased disturbance and increased impervious surface surrounding the stream, more surface water enters the channel and it enters more quickly than under undisturbed conditions.

For headwater stream assessments in West Virginia, this variable is scored based on land cover that can be observed on aerial photographs and verified during field reconnaissance. Under undisturbed conditions, the watershed surrounding headwater slope streams is dominated by hardwood forest. Aerial photographs depicting land cover are available from a number of internet sources including TerraServer (http://terraserver.homeadvisor.msn.com/), Google Maps (http://maps.google.com/), and Web Soil Survey (http://websoilsurvey.nrcs.usda.gov/). The score for *COVER* is based on the weighted average of scores for types of land cover identified in the upland and riparian areas within the catchment of the headwater stream being assessed. Areas affected by natural fire should be scored the same as undisturbed forest. Mined areas that have been reclaimed according to regulatory standards are considered to be highly, though not entirely, functional with respect to this variable.

*COVER* is used in calculating the hydrology, biogeochemistry, and habitat functional indices.

Using the following procedure, determine the score for *COVER*:

(1) Visually estimate the percent of the watershed and riparian zone covered by the cover types identified in Table 4.

(2) Calculate the weighted average for the watershed to determine the score for *COVER*.

**Table 4**
**Land Cover Within the Watershed (*COVER*)**

| Land cover | Score |
|---|---|
| forest | 1.0 |
| shrub | 0.75 |
| orchards | 0.5 |
| pasture or hay | 0.25 |
| urban, roads | 0.0 |

**Average Percent Cover of Trees (*TREE*).** This variable is defined as the average percent cover of trees in the watershed surrounding the headwater stream. Trees are defined as woody plants greater than or equal to 3 inches (≥8 cm.) dbh. Percent cover of trees is only measured if percent tree cover is 10 percent or greater. Tree cover is a measure of the dominance and biomass of trees in a forest stand. Trees capture water in the canopy and reduce rainfall impact to the soil which reduces soil erosion and slows water runoff from the watershed to the stream. Trees are also the primary source for large woody debris and detritus in undisturbed high gradient, headwater riverine systems in West Virginia.

*TREE* is used in the assessment of all functions when tree or shrub cover is greater than 10 percent.

This variable is quantified by the average percent cover of trees. Measure *TREE* using the following procedure:

1) During a field reconnaissance of the watershed and riparian area, or using aerial photographs or other remote sensing data and verified during a field reconnaissance visually estimate the percent cover of trees. If the site is unaltered and the percent cover of trees is 90 percent or more the score for *TREE* would be 1.0.

2) If the site had been disturbed and percent cover of trees in some areas is less than 90 percent, estimate the percent cover of trees for each area.

3) Use Table 5 to determine the variable score for each area of the watershed or riparian area that differs in percent cover of trees. Determine the weighted average for *TREE*.

In reference standard sites, average percent cover of trees in the watershed and adjacent riparian area was greater than 90 percent.

**Table 5**
**Average Percent Cover of Trees (*TREE*)**

| Percent | Score |
|---|---|
| greater than 90 | 1.0 |
| 70 to 90 | 0.75 |
| 50 to 69 | 0.5 |
| 20 to 49 | 0.25 |
| 10 to 19 | 0.1 |
| less than 10 | 0.0 |

A score of 0.0 is assigned to severely altered sites that average less than 10 percent cover of trees.

**Shrub cover (*SHRUB*)**. This variable is defined as the average percent cover of woody vegetation greater than 39 inches (>1 m) in height and less than 3 inches (8 cm) dbh (e.g., shrubs and small trees). Shrubs reduce erosion, slow runoff, take up nutrients, produce biomass, and provide cover and breeding sites for wildlife. Shrubs may dominate the community in headwater areas during early to mid-successional stages. In this context, *SHRUB* reflects the amount of woody vegetation in the understory and woody regeneration on the site that influences runoff directly to the headwater stream, affects nutrient cycling, and will eventually be the source of a mature forest canopy. Therefore, higher values of sapling/shrub cover are assumed to contribute more to these functions.

*SHRUB* is used in calculating the hydrology, biogeochemical, and plant community functional indices when tree or shrub cover is greater than 10 percent.

Use the following procedure to measure *SHRUB:*

1. During a field reconnaissance visually estimate the percent cover of shrubs within the watershed. If percent cover is extremely variable, develop a weighted average across the site.

2. Report the average shrub cover as a percent.

3. Use Table 6 to determine the variable score for *SHRUB.*

**Table 6**
**Average Percent Cover of Shrubs (*SHRUB*)**

| Percent | Score |
|---|---|
| Greater than 50 | 1.0 |
| 20 to 50 | 0.5 |
| 10 to 19 | 0.25 |
| Less than 10 | 0.0 |

A score of 0.0 is assigned to severely altered sites that average less than 10 percent cover of shrubs.

**Average Percent Cover of Herbaceous Vegetation (*HERB*).** This variable is defined as the average percent cover of ground vegetation. Ground vegetation is defined as all herbaceous vegetation, regardless of height, and woody vegetation less than 39 inches (1 m) in height. Ground vegetation cover is an index to the biomass of low vegetation in headwater areas, which affects the productivity and structure of these habitats.

*HERB* applies to the hydrology, biogeochemical, plant community, and habitat functions and only when canopy tree cover and shrub cover are each less than 10 percent.

If tree and shrub cover are each less than 10 percent, estimate average percent cover of herbaceous vegetation as follows:

1. During field reconnaissance visually estimate the percent cover of herbaceous vegetation in the watershed. If percent cover is extremely variable determine the weighted average of herbaceous vegetation by estimating the percentage of the Assessment Area in each cover class.

2. Use Table 7 to determine the score for *HERB*.

**Table 7**
**Average Percent Cover of Herbaceous Vegetation (*HERB*)**

| Percent | Score |
|---|---|
| 70 to 100 | 0.1 |
| less than 70 | 0.0 |

Average percent cover of herbaceous vegetation is not used to evaluate headwater riverine systems in West Virginia that have a well-developed tree or shrub canopy. Instead, *HERB* is measured only in areas where tree and shrub cover are both less than 10 percent due to severe natural or anthropogenic disturbance. Even under these conditions, ground-layer vegetation contributes some reduction in erosion, organic material to the wetland's carbon cycle, provides some benefits for wildlife, and helps produce conditions favorable to the regeneration of a woody midstory and canopy. Because fully functional headwater areas typically are dominated by woody vegetation, even with 100 percent cover of herbaceous vegetation the maximum score that can be achieved is 0.1.

**Vegetation composition and diversity (*COMP*).** This variable reflects the "floristic quality" of the woody plant community based on concepts in Andreas and Lichvar (1995) and Smith and Klimas (2002). In undisturbed high gradient, headwater riverine systems in West Virginia, the tallest vegetation stratum is composed of native trees of a variety of species. In headwater riverine systems that have undergone recent and severe natural or anthropogenic disturbance, the tallest stratum may be dominated by 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). Note that the tree stratum includes all trees greater than 3 inches (8 cm) dbh, and the shrub layer includes all woody species at least 39 inches (1 m) tall but less than 3 inches (8 cm) dbh. There must be at least 10 percent tree cover to consider the tree stratum to be present and the focus of this evaluation. If tree cover is less than 10 percent, assess the composition of the sapling layer instead.

*COMP* applies to the plant community function and only when canopy tree or shrub cover is greater than 10 percent.

1. If tree cover is greater than 10 percent count the number of different species on the site being assessed during field reconnaissance.

2. If tree cover is less than 10 percent and shrub cover is greater than 10 percent, count the number of different woody species in the shrub stratum.

3. If both tree and shrub cover are each less than 10 percent then *COMP* would receive a score of zero.

4. Use Table 8 to determine the score for *COMP*.

In fully functional headwater areas in West Virginia, the number of native woody species present in the tallest stratum typically is 5 or more.

**Table 8**
**Number of Native Species (*COMP*)**

| Number | Score |
|---|---|
| 5 or more species | 1.0 |
| 4 species | 0.75 |
| 3 species | 0.5 |
| 2 species | 0.25 |
| 1 species | 0.1 |
| 0 species | 0.0 |

**Soil Detritus (*DETRITUS*)**. The soil detrital layer is defined as the soil layer dominated by partially decomposed, but still recognizable organic material such as leaves, sticks (less than 3 inches in diameter), needles, flowers, fruits, dead moss, or detached lichens on the surface of the ground. Detritus is a direct indication of short term (one or two years) accumulation of organic matter primarily from vegetation within the watershed and the potential source for organic export to downstream systems.

*DETRITUS* is used in calculating the biogeochemical and habitat functional indices when tree or shrub cover is greater than 10 percent.

Using the following procedure to determine the score for *DETRITUS*:

(1) Visually estimate the percent of the ground surface covered by leaves, sticks (less than 3 inches in diameter or other organic material within the watershed.

(2) Use Table 9 to determine the subindex score for Soil Detritus

In West Virginia, minimally altered watersheds of headwater stream systems were observed to have soil detritus cover of greater than 75 percent.

**Table 9**
**Soil Detritus (*DETRITUS*)**

| **Percent cover** | **Score** |
|---|---|
| greater than 75 | 1.0 |
| 50 to 75 | 0.75 |
| 25 to 49 | 0.5 |
| 10 to 24 | 0.25 |
| less than 10 | 0.1 |

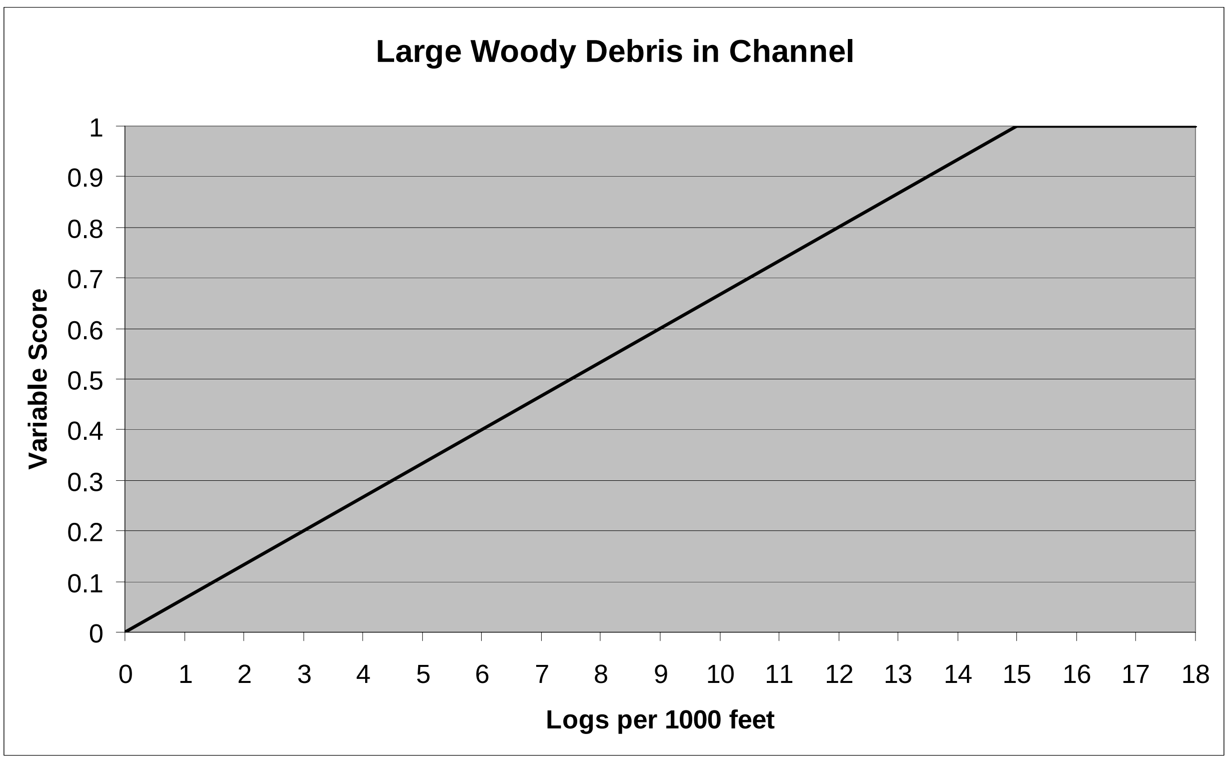
**Large woody debris in channel (*LWDEBRIS*).** This variable is defined as the number of down logs in the headwater stream channel per 1000 feet. Logs are defined as whole or partial dead tree stems. The portion of the log that is within the channel must be at least 39 inches (1 m) long, or if the channel is narrower than 39 inches (1 m), it must span the channel completely. The portion of the log that is within the channel must have a diameter greater than or equal to 3 inches (8 cm) at the widest point. Large woody debris is a measure of the dead biomass of trees within the high gradient, headwater stream ecosystem. Decomposing wood in the channel reduces channel erosion by dissipating stream energy, provides habitat for vertebrates and invertebrates, and contributes nutrients and organic matter to the downstream ecosystem.

*LWDEBRIS* is used in calculating the hydrology, biogeochemical, and habitat functional indices.

This variable is quantified by the number of logs in the stream channel per 1000 feet of channel length. Measure *LWDEBRIS* using the following procedure:

1) Measure the length of the stream channel being assessed and count the number of logs that are completely or partially lying in the channel.

2) Use Figure 1 to determine the variable score for the headwater stream. If the channel length is less than or greater than 1000 feet the number of logs needed to receive a variable score of 1.0 is proportional to the length.




In fully functional headwater stream systems in West Virginia the number of logs in the stream channel is 15 or more per 1000 feet of stream channel.

**Stream channel geomorphology (*CHANNGEO*).** This variable reflects direct alterations to the natural geomorphology of the stream channel. Examples in West Virginia include straightening, removal of the natural step-pool geomorphology, and reducing or increasing the slope or steepness of the stream channel. The intent of this variable is to capture those impacts that alter the slope and shape of natural headwater stream systems. This variable differs from *CHANNELALT* in that the impacts occur within the stream channel without affecting the amount of water in the channel, but do affect the energy of flows and how nutrients are retained within the headwater stream system.

This variable is quantified by the average channel slope and the frequency of step-pools within the stream channel. Measure *CHANNGEO* using the following procedure:

1) If stream is unaltered or the channel slope is greater than 4 percent and has many step-pools, then the subindex score for this variable is 1.0 and the following steps may be skipped.

2) If the channel has been altered or restored, use Table 10 to determine the variable score for stream channel geomorphology. Determine the weighted average for the entire stream reach impacted.

In reference standard sites, there were no alterations to the natural geomorphology of headwater stream channels.

**Table 10**
**Stream channel geomorphology (*CHANNGEO*)**

| Slope and pools | Score |
|---|---|
| Greater than 4% slope with many step pools | 1.0 |
| 2 to 4% slope with common step pools | 0.5 |
| 1 to 1.9% slope with few step pools | 0.1 |
| Less than 1% slope with no step pools | 0.0 |

## Functions

### Function 1: Hydrology

### Definition

The Hydrology function is defined as the capacity of the high gradient, headwater riverine ecosystem to store water within the soil for a few days to several weeks and slowly release this water to streams down slope as well as to transport nutrients and organic matter through surface runoff. A potential independent, quantitative measure for validating the functional index is a direct measurement of the amount of surface water that runsoff as well as the water that is dynamically stored within the soil over a portion of the year.

### Rationale for selecting the function

The annual water budget of high gradient headwater riverine streams in West Virginia is controlled mainly by precipitation and upland runoff and secondarily by interception of groundwater. Performance of the Hydrology function causes the ecosystem to retain water inputs for a sufficient period of time to develop other wetland characteristics (e.g., hydric soils, hydrophytic vegetation). Water storage also moderates the pulse of runoff that occurs following a storm event and prolongs the period of discharge into streams maintaining baseflow.

In addition to direct effects of water storage on the stream hydrograph, this function plays a role in all other wetland functions associated with headwater stream systems. Water storage has a significant effect on biogeochemical cycling in the stream. Prolonged saturation leads to anaerobic soil conditions and initiates chemical reactions that are highly dependent upon the redox capacity of the soil (Mausbach and Richardson 1994). The oxygen concentration in wetland soils greatly affects the redox potential and the chemical cycling properties of elements and compounds, particularly nutrients. This function also has important impacts on invertebrate and vertebrate populations. For example, some invertebrates, such as midges, have very short life cycles and are highly adapted to ephemeral systems.

### Characteristics and processes that influence the function

The characteristics and processes that influence the capacity of a headwater ecosystem to store water have both natural and anthropogenic origins. Climate and landscape-scale geomorphic characteristics within and around the headwater system are factors largely established by natural processes. Anthropogenic alterations to these ecosystems (e.g., filling, logging) also influence the way the stream system stores and ultimately transports water. Such effects may occur due to changes in the dominant land cover in and near the watershed and stream and whether the stream channel has been hydrologically modified through filling or damming.

In West Virginia, rain is fairly evenly distributed throughout the year. Summer thunderstorms are common and tropical storms and hurricanes occasionally affect the area. Surface soil saturation and runoff can occur during any month and, in some sites, is evident all year. In others, saturation to the surface in the riparian zone is most evident in late winter and early spring before trees have completely leafed out.

In addition to geomorphic and climatic processes, human activities may also have a profound effect on the storage of water within a high gradient, headwater riverine ecosystem. Modifications to the uplands surrounding the stream or directly to the stream itself may affect the receipt and retention of water. Land-use changes, such as filling, soil compaction, road construction, urban development, and changes in evapotranspiration that result from logging are modifications that directly affect this function.

Filling for the purpose of mine spoil disposal and damming to provide stormwater retention have modified many headwater streams, converting them to depressions, lakes, or even uplands. Such modifications so significantly affect the natural short-term water storage of the headwater stream that they lose their natural characteristics and hydrologic functions.

**Functional Capacity Index**

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

- Channel Alterations (*CHANNELALT*)
- Channel Geomorphology (*CHANNELGEO*)
- Large Woody Debris (*LWDEBRIS*)
- Land Cover (*COVER*)
- Watershed Slope (*SLOPE*)
- Tree Cover (*TREE*)
- Shrub Cover (*SHRUB*)
- Herbaceous Cover (*HERB*)

The basic assessment model for calculating the functional capacity index (FCI) for the Hydrology function in forested or shrub-dominated headwater stream systems is as presented in equation 1, below. Equation 2 presents a modified version for application in systems dominated by herbaceous vegetation:

$$\left[\left(CHANNELALT \times \left\{\frac{CHANNELGEO + LWDEBRIS}{2}\right\}\right)^{1/2} \times \left(\frac{COVER + SLOPE + \left\{\frac{TREE + SHRUB}{2}\right\}}{3}\right)\right]^{1/2} \quad (1)$$

$$\left[\left(CHANNELALT \times \left\{\frac{CHANNELGEO + LWDEBRIS}{2}\right\}\right)^{1/2} \times \left(\frac{COVER + SLOPE + HERB}{3}\right)\right]^{1/2} \quad (2)$$

In this model (equation 1), the Hydrology function of high gradient, headwater streams depends on inputs of water from surface runoff from the surrounding upland. Water is removed from the system in surface outflow and evapotranspiration. The model assumes that, if natural hydrologic inputs from runoff from the surrounding uplands are unaltered, outflow is not reduced by filling or increased by downcutting or blocked by anthropogenic obstructions such as dams, and a mature forest is present to disperse runoff at characteristic rates, then the stream is functioning at reference standard condition.

This model addresses three main factors that influence water storage. The first part of the equation reflects natural or anthropogenic alterations to the stream channel (*CHANNELALT*) that affect its capacity move water to other channels downstream. However, storage of atypically large amounts of surface water due to damming the stream results in a decrease in function. The second part is a combination of physical features that slow water flow in the stream channel and relate to the stability of the channel (*CHANNELGEO* and *LWDEBRIS*). The third part of the equation is a combination of factors affecting the supply of water from the surrounding uplands (*COVER* and *SLOPE*) through runoff, and the effect of a mature forest (*TREE* and *SHRUB*) on surface water runoff and erosion of excessive fine sediment into the stream. The first two parts are combined using a geometric mean, the result being that if *CHANNELALT* equals zero the functional capacity index will equal zero for the hydrologic function. Variables in the third part of the equation are averaged using an arithmetic mean.

The three parts of the equation are combined using a geometric mean based on the assumption that *CHANNELALT* is as important as the combination of the other variables in relation to water storage. In other words, if the stream system is drained to the point that it no longer has riverine hydrology and has been changed from a headwater stream to a depressional, upland, or lacustrine system, then the subindex score for *CHANNELALT* would be 0.0 and the functional capacity for water storage would be zero as well. For herbaceous dominated ecosystems (equation 2), the maximum FCI is 0.67.

## Function 2:  Biogeochemical cycling

### Definition

The biogeochemical function is defined as the ability of the high gradient, headwater 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 decomposition.  Thus, biogeochemical cycling includes the biogeochemical processes 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 (gm/m$^2$), annual accumulation of organic matter (gm/m$^2$), and annual decomposition of organic matter (gm/m$^2$).

### Rationale for selecting the function

Biogeochemical cycling is a fundamental function performed by all ecosystems, but tends to be accomplished at particularly high rates in many wetland systems (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) (Crow and MacDonald 1978, Fredrickson 1978, Wharton et al. 1982).  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 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 or woody debris, 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.

Abiotic processes affecting retention and cycling of carbon are dependent primarily on the adsorption of materials to soil particles, the amount of water that passes through the wetland carrying dissolved carbon, the hydroperiod or retention time of water, and the importation of materials from surrounding areas (Grubb and Ryder 1972, Federico 1977, Beaulac and Reckhow 1982, Ostry 1982, Shahan 1982, Strecker et al. 1992, Zarbock et al. 1994).  Natural soils, hydrology, and vegetation are important factors in maintaining these characteristic processes.

The ability of a high gradient, headwater ecosystem to perform this function depends upon the transfer of carbon between trophic levels within the ecosystem, the rate of decomposition, and the flux of materials in and out of the wetland.  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 instead we use plant community structure and detrital loading as indirect indicators. Reference data from other ecosystems suggest that land-use practices and forest management have great effect on plant community structure (species composition and coverage), diversity, and primary productivity. Changes in the 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 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 headwater ecosystems through drainage, 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 ecosystem and disrupt the biogeochemical cycle. Drainage, over time, changes the vegetative composition and, therefore, the type and amount of detrital matter. 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 Alterations (*CHANNELALT*)
- Channel Geomorphology (*CHANNELGEO*)
- Soil Detritus (*DETRITUS*)
- Large Woody Debris (*LWDEBRIS*)
- Land Cover (*COVER*)
- Watershed Slope (*SLOPE*)
- Tree Cover (*TREE*)
- Shrub Cover (*SHRUB*)
- Herbaceous Cover (*HERB*)

The assessment models for calculating the FCI for the biogeochemical functions in high gradient, headwater riverine systems are given below. The models depend, in part, on the characteristics of the tree and shrub stratum of vegetation within the watershed, including the riparian area. If the site supports a tree or shrub layer (≥10% total cover), then equation 3 is used. If the site is unvegetated or dominated by herbaceous vegetation (<10% canopy cover of trees or shrubs), then equation 4 is used.

$$\left[ (CHANNELALT \times CHANNELGEO)^{1/2} \times \frac{\left(\frac{COVER + SLOPE}{2}\right) + \left(\frac{TREE + SHRUB}{2}\right) + \left(\frac{DETRITUS + LWDEBRIS}{2}\right)}{3} \right]^{1/2} \quad (3)$$

$$\left[ (CHANNELALT \times CHANNELGEO)^{1/2} \times \left\{ \frac{HERB + LWDEBRIS + \left(\frac{COVER + SLOPE}{2}\right)}{3} \right\} \right]^{1/2} \quad (4)$$

In these models, changes in the biogeochemical cycling capacity of high gradient, headwater riverine ecosystems relative to reference standard conditions depend on increased outflow of water, or on reductions in water inflows, organic matter, or 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 carbon cycling will occur at an appropriate rate. In the first part of each equation, removal or retention of surface water is represented by *CHANNELALT* and *CHANNGEO*. In the second part, *COVER* and *SLOPE* are averaged and represent inputs related to water quality and time that water and particulates are delivered to the stream system. *DETRITUS* is used as an indicator of recent organic input and accumulation. If vegetation has been removed from the watershed, including the riparian area during the previous year or two, then the amount of detritus will likely be reduced or absent. Also, if the hydrology of the wetland or adjacent 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. Large Woody Debris (*LWDEBRIS*) loading within the channel is an indicator of long-term organic matter accumulation within the watershed as a whole. If hydrology or vegetation has been altered for more than a few years, then the amount of Large Woody Debris should be reduced, reflecting a decrease in organic matter content 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 two variables, *DETRITUS* and *LWDEBRIS* are combined using an arithmetic mean. This is based on the assumption that detritus and large woody debris are of equal importance in biogeochemical cycling. Headwater riverine ecosystem vegetation is represented by the combination of *TREE* and *SHRUB*, or herbaceous vegetative cover (*HERB*). If the amount of vegetation, represented by percent cover, is reduced, then it is assumed that carbon cycling will be reduced.

In equation 3, the variables that directly relate to the channel and variables related to inputs to the stream are combined using a geometric mean. The implications are that if all of the variables in any part of the model equal zero, then the function would receive an FCI of zero. For watersheds where both tree and shrub strata have less than 10 percent cover the maximum FCI is 0.76 (equation 4).

## Function 3:  Plant Community functions

### Definition

This function is defined as the degree to which a high gradient, headwater riverine ecosystem supports a plant community that is similar in structure and composition to that found on the least disturbed sites in West Virginia.  Various approaches have been developed to describe and assess plant community characteristics that might be appropriately applied in developing independent measures of this function.  However, none of these approaches alone can supply a "direct independent measure" of plant community function, because they are tools that are employed in more complex analyses that require familiarity with regional vegetation and collection of appropriate sample data.

### Rationale for selecting the function

The ability to maintain a characteristic plant community is important in part because of the intrinsic value of the species found there.  In the West Virginia landscape, the dominant community type is hardwood forest, and the high gradient, headwater riverine subclass constitutes a small percentage of the overall area.  The presence of a characteristic plant community also is critical in maintaining various biotic and abiotic processes occurring in wetlands.  For example, plant communities are the source of primary productivity, produce carbon and nutrients that may be exported to other ecosystems, and provide habitats and refugia necessary for various animal species (Harris and Gosselink 1990).

### Overview of the plant community

The plant communities of headwater ecosystems are complex and vary across the State and even locally.  Except immediately following severe disturbances, forest is the dominant community type in these ecosystems.  Sites that have been relatively undisturbed for decades or hundreds of years support trees of various sizes and ages.  Depending on the species that initially occupy a site after a major disturbance, succession can progress along different paths, but because of small-scale disturbances (e.g., individual trees dying and creating canopy gaps that may be colonized by different species), eventually an uneven-aged forest with well-developed stratification will be achieved (Hunter 1990).  In general, older stands tend to be more stratified than younger ones and forests with several vertical strata have higher species diversity than young or middle-aged stands with few strata (Willson 1974, Hunter 1990).  This is important in maintenance of the community over time given that species diversity has been found to be positively related to community stability (Bolen and Robinson 2003).

### Factors that influence the plant community

Factors that influence the development and maintenance of a characteristic plant community in most wetlands including high gradient, headwater riverine systems in West Virginia include the physical site characteristics, the hydrologic regime, weather events, anthropogenic disturbances, and various ecological processes such as competition, disease, browsing pressure, shade tolerance, and community succession.  Alterations to these factors or processes in the stream channel, adjacent riparian area, or to the surrounding watershed may directly affect the species composition and biodiversity of the site (Askins et al. 1987, Keller et al. 1993, Kilgo et al. 1997).

The moisture regime is one of the most important determinants of the structure and composition of plant communities.  In high gradient, headwater riverine ecosystems, water delivery occurs as direct precipitation, overland flow, or groundwater discharge from the surroundings uplands.  Overland flow is believed to be the most important of the three in the maintenance of hydrology in these riverine systems.

Activities that degrade the physical nature of a stream, especially its flow regime, have the potential to have deleterious effects on the plant community and, if significant enough, may alter the plant community for extended periods, and even permanently. For example, depositing fill in a stream channel fundamentally changes the substrate and hydrologic regime and, if amounts are substantial, can result in conversion of the area from riverine system to upland.

Some alterations that do not even occur in the stream channels themselves may have serious negative consequences for the plant community. For example, clearing the natural vegetation in the upland watershed and adding impervious surfaces (roads, parking lots, etc.) can result in significantly more water entering a stream and could alter community composition and structure. If mean water depths increase beyond the ability of even these species to survive, the area essentially would become an open water basin with vegetation existing only at the edges.

Except for anthropogenic impacts, high gradient, headwater riverine ecosystems in West Virginia are influenced primarily by small-scale frequent disturbances, especially individual tree mortality which leads to gap-phase regeneration. Forests that develop under such conditions generally are composed of shade-tolerant species of different age (and by inference size) classes (Hunter 1990).

**Functional capacity index**

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

- Channel Alterations (*CHANNELALT*)
- Vegetation composition and diversity (*COMP*)
- Tree Cover (*TREE*)
- Shrub Cover (*SHRUB*)
- Herbaceous Cover (*HERB*)

The assessment models for calculating the FCI for the maintenance of a characteristic plant community in high gradient, headwater riverine ecosystems are given below. The choice of models depends on the characteristics of the dominant vegetation present within the ecosystem. If the site contains a tree or shrub layer ($\geq$10% total tree or shrub cover), then equation 5 is used. If neither trees nor shrubs are common (<10% cover), then equation 6 is used.

$$\left[CHANNELALT \times \left(\frac{TREE + SHRUB + COMP}{3}\right)\right]^{1/2} \qquad (5)$$

$$\left(CHANNELALT \times HERB\right)^{1/2} \qquad (6)$$

These models represent the existing plant community in the wetland and include variables that provide insight into its serial stage, structure, species composition, diversity, and stability. The models assume that the physical environment necessary to maintain the community (e.g., hydrology) is also present. If not, any recent environmental changes that may affect the long-term persistence of the community should be reflected in reduced FCIs for Functions 1 and 2. In the context of this function, Average Percent Cover of Trees (*TREE*) and Average Percent Cover of Shrubs (*SHRUB*) are structural indicators of serial stage and of disturbance. The vegetation composition and diversity variable (*COMP*) reflects floristic quality and diversity, as well as seral stage and disturbance. In a forested system (equation 5), subindices for *TREE*, *SHRUB*, and *COMP* are averaged. In systems without trees or shrubs *HERB* is the only vegetation variable and equation 6 is used. In both equations the vegetative variables are combined with *CHANNELALT* using a geometric mean reflecting the importance of hydrology to the ecosystem. For herbaceous dominated ecosystems, the maximum FCI is 0.32.

## Function 4: Wildlife Habitat

### Definition

This function is defined as the capacity of a high gradient, headwater riverine 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 amphibians, reptiles, birds, and mammals. Birds and amphibians were selected as the focus of this function. Birds were chosen because they are of considerable public and agency interest, and they respond rapidly to changes in the quality and quantity of their habitats. In addition, birds are a diverse group and individual species have strong associations with the different strata of the multi-layered forests that characterize those sites that were considered to be functioning at the highest level (reference standard). Birds have been shown to be sensitive indicators and integrators of environmental change such as that brought about by human use and alteration of landscapes (Morrison 1986, Croonquist and Brooks 1991, O'Connell et al. 2000). Amphibians were chosen because of the importance of wetlands as breeding habitat. Various species of salamanders and frogs breed in shallow streams, temporary ponds, and moist leaf litter or duff. In the adult stages, they often disperse into suitable habitat in the adjacent uplands.

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 birds and amphibians that use high gradient, headwater ecosystems in West Virginia throughout the annual cycle. Data requirements for model validation include direct monitoring of wildlife communities using appropriate techniques for each taxon. Ralph et al. (1993) described field methods for monitoring bird populations. 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

Wetlands and the adjacent surrounding upland are recognized as valuable habitats for a diversity of animal species including both vertebrates and invertebrates. In the vicinity of headwater streams, birds and mammals are diverse and abundant. 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 wetland and adjacent upland habitats, they serve as a conduit for energy exchange between the two systems (Mitchell et al. 2004). Wharton et al. (1982), Johnson (1987), Whitlock et al. (1994), Crowley et al. (1996), Mitsch and Gosselink (2000), and Bailey et al. (2004) are all good sources of information regarding animal communities of wetlands.

Many wildlife species associated with wetlands have experienced serious population declines. Within the United States, approximately one third of the plant and animal species listed as threatened or endangered are associated with wetlands during some part of their life cycles (Dahl and Johnson 1991). In West Virginia, high gradient, riverine wetlands and the adjacent riparian areas constitute a relatively small percentage of the landscape within the state, therefore, these areas are likely are important for the maintenance of local populations of many species.

### Characteristics and processes that influence the function

Hydrologic alteration of high gradient, riverine ecosystems has the potential to impact a number of wildlife species, but the most serious impacts would be to amphibians. Animals with direct dependence on water, such as amphibians that use seasonally ponded micro-depressions within high gradient, riverine ecosystems for reproduction, are highly vulnerable to drainage or filling. Even partial draining or filling 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 a riverine ecosystem by excavating or by augmenting runoff into the wetland can potentially reduce the suitability for amphibians by allowing fish populations to become established. Bailey et al. (2004) 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 introductions.

Besides the direct effects of hydrologic change on animals, indirect effects can occur through changes in the plant community. Sites with unaltered hydrology that have not been subjected to significant disturbance for long periods support a characteristic vegetation composition and structure (i.e., tree size, density, stratification, etc.) as described in the plant community model discussion. Wildlife species have evolved with and adapted to these conditions. Thus, altering the hydroperiod has the potential to change the composition and structure of the wildlife community. Factors other than hydrology, including droughts and catastrophic storms, competition, disease, browsing pressure, shade tolerance, community succession, and natural and anthropogenic disturbances, also affect the plant community directly and wildlife community indirectly. Following is an overview of the relationships between specific characteristics of the plant community and wildlife utilization of forested ecosystems including wetlands. Wharton et al. (1982), Hunter (1990), and Morrison et al. (1992) are all good sources of information on this subject.

Habitat structure is probably the most important determinant of wildlife species composition and diversity (Wiens 1969, Anderson and Shugart 1974). Undisturbed high gradient, riverine ecosystems in West Virginia normally 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). This is especially well documented with birds, which tend to show affinities for habitats based on physical characteristics, such as the size and density of overstory trees, density of shrub and ground cover, number of snags, and other factors. For example, some bird species utilize the forest canopy, whereas others are associated with the understory (Cody 1985, Wakeley and Roberts 1996).

While the structure of the forest in the immediate vicinity of a headwater stream is an important determinant of animal habitat availability, the characteristics of adjacent uplands 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. (2004) concurred, stating that “a seasonal wetland without appropriate surrounding upland 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 around wetlands to protect various wetland 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 over-wintering. 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. Coffey (1998) reported that minimal woody debris was found in bottomland hardwood stands younger than 6 years of age. 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 wetlands also are important to the integrity of the wetland 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 (Rhode 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 directly or indirectly affect amphibians through improved water quality and provide benefits to the entire wildlife community. Semlitsch and Bodie (2003) recommended a 30-60 m (100-200 ft) wide “buffer” around the wetland for this purpose alone.

**Functional Capacity Index**

The following variables are used in the assessment model for the function Provide Characteristic Wildlife Habitat:

- Channel Alterations (*CHANNELALT*)
- Channel Geomorphology (*CHANNELGEO*)
- Large Woody Debris (*LWDEBRIS*)
- Land Cover (*COVER*)
- Stream Sediment Size (*SED*)
- Soil Detritus (*DETRITUS*)
- Tree Cover (*TREE*)
- Herbaceous Cover (*HERB*)

The model used for deriving the functional capacity index for the wildlife habitat function in high gradient, riverine ecosystems depend on the characteristics of the uppermost stratum of vegetation within the wetland. If the site supports a tree layer ($\geq$10% total tree or shrub cover), then equation 7 is used. If neither trees nor shrubs are common (<10% cover), then equation 8 is used.

$$\left[ CHANNELALT \times \left( \frac{COVER + CHANNGEO + SED + TREE + DETRITUS + LWDEBRIS}{6} \right) \right]^{1/2} \quad (7)$$

$$\left[ CHANNELALT \times \left( \frac{COVER + HERB + SED + CHANNGEO + LWDEBRIS}{5} \right) \right]^{1/2} \quad (8)$$

This model is assumed to reflect the ability of high gradient, riverine ecosystems to provide critical life requisites for wildlife, with an emphasis on amphibians and birds. 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 birds characteristic of high gradient, riverine ecosystems within the reference domain will be present.

The first part of each equation is an expression of the hydrologic integrity of the stream channel and only involves the variable *CHANNELALT*. In the context of this function, a characteristic hydrologic regime is essential as a source of water for breeding amphibians and to support the plant community upon which the animal community depends. The second part of each equation contains variables that reflect seral stage, cover potential, food production potential, nest site potential, availability of dispersal habitat, and other factors that depend on stand structure, maturity, and connectivity. *TREE* is used when the ecosystem is dominated by trees and *HERB* is used in wetlands lacking sufficient trees. Other features of forested wetlands such as snags, are also are important habitat requirements for various members of the wildlife community, but are not explicitly included in the model. It was assumed that if the structure of the tree layer is appropriate, then these additional features will be present in the appropriate numbers or amounts. Channel integrity is assumed to be critical to the maintenance of wetland wildlife habitat; therefore, the hydrology component is used as a multiplier in each equation. The other terms in the model, which reflect onsite and offsite habitat conditions, 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 high gradient, headwater riverine ecosystems dominated by trees, the maximum possible FCI is 1.0. In ecosystems containing few trees, the maximum FCI is 0.82.

## Models

### Hydrology Functions

$$\left[\left(CHANNELALT \times \left\{\frac{CHANNELGEO + LWDEBRIS}{2}\right\}\right)^{1/2} \times \left(\frac{COVER + SLOPE + \left\{\frac{TREE + SHRUB}{2}\right\}}{3}\right)\right]^{1/2} \quad (1)$$

$$\left[\left(CHANNELALT \times \left\{\frac{CHANNELGEO + LWDEBRIS}{2}\right\}\right)^{1/2} \times \left(\frac{COVER + SLOPE + HERB}{3}\right)\right]^{1/2} \quad (2)$$

### Biogeochemical Functions

$$\left[(CHANNELALT \times CHANNELGEO)^{1/2} \times \frac{\left(\frac{COVER + SLOPE}{2}\right) + \left(\frac{TREE + SHRUB}{2}\right) + \left(\frac{DETRITUS + LWDEBRIS}{2}\right)}{3}\right]^{1/2} \quad (3)$$

$$\left[(CHANNELALT \times CHANNELGEO)^{1/2} \times \left\{\frac{HERB + LWDEBRIS + \left(\frac{COVER + SLOPE}{2}\right)}{3}\right\}\right]^{1/2} \quad (4)$$

### Plant Community Functions

$$\left[CHANNELALT \times \left(\frac{TREE + SHRUB + COMP}{3}\right)\right]^{1/2} \quad (5)$$

$$(CHANNELALT \times HERB)^{1/2} \quad (6)$$

### Habitat Functions

$$\left[CHANNELALT \times \left(\frac{COVER + CHANNGEO + SED + TREE + DETRITUS + LWDEBRIS}{6}\right)\right]^{1/2} \quad (7)$$

$$\left[CHANNELALT \times \left(\frac{COVER + HERB + SED + CHANNGEO + LWDEBRIS}{5}\right)\right]^{1/2} \quad (8)$$

## References


Anderson, S. H., and Shugart, H. H. Jr. (1974). "Habitat selection of breeding birds in an east Tennessee deciduous forest," *Ecology* 55, 828-837.

Askins, R. A., Philbrick, M. J., and Sugeno, D. S. (1987). "Relationship between the regional abundance of forest and the composition of forest bird communities," *Biological Conservation* 39, 129-52.

Bailey, M. A., Holmes, J. N., and Buhlmann, K. A. (2004). "Habitat management guidelines for amphibians and reptiles of the southeastern United States." Partners in Amphibian and Reptile Conservation Technical Publication HMG-2.

Beaulac, N. M., and Reckhow, K. H. (1982). "An examination of land use nutrient export relationships," *Water Resources Bulletin* 18(6), 1013-24.

Bolen, E. G., and Robinson, W. L. (2003). *Wildlife ecology and management, 5th ed*. Prentice Hall, Upper Saddle River, NJ. 634 pp.

Bormann, F. H., and Likens, G. E. (1970). "The nutrient cycles of an ecosystem," *Scientific American* 223, 92-101.

Boyd, L. (2001). "Buffer zones and beyond: wildlife use of wetland buffer zones and their protection under the Massachusetts Wetland Protection Act." Wetland Conservation Professional Program, Department of Natural Resources Conservation, University of Massachusetts, Amherst, MA.

Burton, T. M., and Likens, G. E. (1975). "Salamander populations and biomass in the Hubbard Brook Experimental Forest, New Hampshire," *Copeia* 1975, 541-546.

Carpenter, S. R. (1988). *Complex interactions in lake communities*. Springer Verlag, New York, 283 pp.

Cody, M. L. (1985). *Habitat selection in birds*. Academic Press, Inc., Orlando, Florida

Coffey, P. L. (1998). "Evaluation of early successional bottomland hardwood forests." M. S. Thesis, Tennessee Technological University, Cookeville, TN.

Croonquist, M.J., and Brooks, R. P. (1991). "Use of avian and mammalian guilds as indicators of cumulative impacts in riparian wetland areas," *Environmental Management* 15(5), 701-714.

Crow, J. H., and MacDonald, K. B. (1978). "Wetland values: Secondary productivity," *Wetland functions and values: The state of our understanding*. P. E. Greeson, J. R. Clark, and J. E. Clark, ed., American Water Resources Association, Minneapolis, MN.

Dahl, T. E., and Johnson, C. E. (1991). ""Status and trends of wetlands in the coterminous United States, mid-1970s to mid-1980s," U. S. Fish and Wildlife Service, Washington, DC.

Daniels, R. B., and Gilliam J. W. 1996. "Sediment and chemical load reduction by grass and riparian filters." *Soil Science Society of America Journal* 60, 246-251.

Dickinson, C. H., and Pugh, G. (1974). *Biology of plant litter decomposition, Vol. 1*. Academic Press, London, England.

Dodd, C. K., Jr. (2003). "Monitoring amphibians in Great Smoky Mountains National Park.," Circular No. 1258, U.S. Geological Survey, Washington, DC, 117 pp.

Duellman, W. E., and Trueb, L. (1986). *Biology of amphibians.* McGraw-Hill, New York.

Federico, A. D. (1977). "Investigations of the relationship between land use, rainfall, and runoff quality in the Taylor Creek watershed," Technical Publication 77-3, South Florida Water Management District, West Palm Beach, FL.

Fredrickson, L. H. (1978). "Lowland hardwood wetlands : Current status and habitat values for wildlife," *Wetland functions and values: The state of our understanding*. P. E. Greeson, J. R. Clark, and J. E. Clark, eds., American Water Resources Association, Minneapolis MN.

Gemborys, S. R., and Hodgkins, E. J. (1971). "Forests of small stream bottoms in the coastal plain of southwestern Alabama," *Ecology* 52, 70-84.

Gibbons, J. W., and R. D. Semlitsch. (1981). "Terrestrial drift fences and pitfall traps: An effective technique for quantitative sampling of animal populations," *Brimleyana* 7, 1-16.

Grubb, H. F., and Ryder, P. D. (1972). "Effects of coal mining on the water resources of the Tradewater River Basin, Kentucky," Geological Survey Water-Supply Paper 1940, U.S. Government Printing Office, Washington, DC.

Harmon, M. E., Franklin, J. F., and Swanson, F. J. (1986). "Ecology of coarse woody debris in temperate ecosystems," *Advances in Ecological Research* 15, 133-302.

Harris, L. D., and Gosselink, J. G. (1990). "Cumulative impacts of bottomland hardwood forest conversion on hydrology, water quality, and terrestrial wildlife." *Ecological processes and cumulative impacts illustrated by bottomland hardwood wetland ecosystems.* J. G. Gosselink, L. C. Lee, and T. A. Muir, ed., Lewis Publishers, Chelsea, MI, 259-322.

Hayes, A. J. (1979). "The microbiology of plant litter decomposition," *Scientific Progress* 66, 25-42.

Heyer, W. R., M. A. Donnelly, R. W. McDiarmid, L. C. Hayek, and M. S. Foster. (1994). *Measuring and monitoring biological diversity: Standard methods for amphibians.* Smithsonian Institution Press, Washington, DC.

Hunter, M. L. (1990). *Wildlife, forests, and forestry: Principles of managing forests for biological diversity.* Prentice Hall, Englewood Cliffs, NJ.

Hupp, C. R., Woodside, M. D., Yanosky, T. M. (1993). "Sediment and trace element trapping in a forested wetland, Chichahominy River, Va," *Wetlands* 13, 95-104.

Johnson, T. R. (1987). "The amphibians and reptiles of Missouri," Missouri Department of Conservation, Jefferson City, Missouri.

Keller, C. M. E., Robbins, C. S., and Hatfield, J. S. (1993). "Avian communities in riparian forests of different widths in Maryland and Delaware," *Wetlands* 13, 137-44.

Kilgo, J. C., Sargent, R. A., Miller, K. V., and Chapman, B. R. (1997). "Landscape influences on breeding bird communities in hardwood fragments in South Carolina," *Wildlife Society Bulletin* 25, 878-85.

Mausbach, M. J., and Richardson, J. L. (1994). "Biogeochemical processes in hydric soils," *Current Topics in Wetland Biogeochemistry* 1, 68-127.

Mitchell, J. C., I. N., Bailey, M. A., Holmes, J. N., and Buhlmann, K. A. (2004). "Habitat management guidelines for amphibians and reptiles of the southeastern United States." Partners in Amphibian and Reptile Conservation Technical Publication HMG-2.

Mitsch, W. J., and Gosselink, J. G. (2000). *Wetlands. 3rd ed*., John Wiley and Sons, New York.

Morrison, M. L. (1986). "Bird populations as indicators of environmental change," *Current Ornithology* 3, 429-451.

Morrison, M. L., Marcot, B. C., and Mannan, R. W. (1992). *Wildlife Habitat Relationships: Concepts and Applications*. University of Wisconsin Press, Madison, Wisconsin.

Nelson, J. B. (1986). "The Natural Communities of South Carolina: Initial Classification and Description." S.C. Wildlife and Marine Resources Dept. Division of Wildlife and Freshwater Fisheries. Columbia, SC.

O'Connell, T. J., L. E. Jackson, and R. P. Brooks. (2000). "Bird guilds as indicators of ecological condition in the central Appalachians," *Ecological Applications* 10, 1706-1721.

Ostry, R. C. (1982). "Relationship of water quality and pollutant loads to land uses in adjoining watersheds," *Water Resources Bulletin* 18 (1), 99-104.

Perry, D. A. (1994). *Forest ecosystems.* Johns Hopkins University Press, Baltimore, MD.

Pugh, G., and Dickinson, C. H. (1974). *Biology of plant litter decomposition, Vol. II.* Academic Press, London, England.

Ralph, C. J., Geupel, G. R., Pyle, P., Martin, T. E., and DeSante, D. F. (1993). "Handbook of field methods for monitoring landbirds," General Technical Report PSW-GTR-144, U.S. Dept. of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA. 41 pp.

Reiners, W. A. (1972). "Terrestrial detritus and the carbon cycle," G. M. Woodwell and E. V. Pecan, ed. *Carbon and the biosphere*. Conference proceedings, United States Atomic Energy Commission.

Rhode, W. A., Asmussen, L. E., Hauser, E. W., Wauchope, R. D., and Allison, H. D. 1980. "Trifluralin movement in runoff from a small agricultural watershed," *Journal of Environmental Quality* 9, 37-42.

Rothermel, B. B., and Semlitsch, R. D. (2002). "An experimental investigation of landscape resistance of forest versus old-field habitats to emigrating juvenile amphibians," *Conservation Biology* 16, 1324-1332.

Schlesinger, W. H. (1977). "Carbon balance in terrestrial detritus," *Annual review of ecology and systematics* 8, 51-81.

Schoener, T. W. (1986). "Resource partitioning." *Community ecology: Patterns and processes*. J. Kikkawa and D. J. Anderson, eds., Blackwell, Melbourne, 91-126.

Rosgen, D. and Silvey, L. (1998). Field Guide for Stream Classification. Wildland Hydrology, Colorado.

Semlitsch, R. D., and Bodie, J. R. (2003). "Biological criteria for buffer zones around wetlands and riparian habitats for amphibians and reptiles," *Conservation Biology* 17, 1219-1227.

Semlitsch, R. D., and Jensen, J. B. (2001). "Core habitat, not buffer zone," *National Wetlands Newsletter* 23, 5-6.

Shahan, A. N. (1982). "Estimation of pre- and post-development nonpoint water quality loadings," *Water Resources Bulletin* 18, 231-237.

Singh, J. S., and Gupta, S. R. (1977). "Plant decomposition and soil respiration in terrestrial ecosystems," *Botanical Review* 43, 449-528.

Snyder, N. J, Mostaghimi, S., Berry, D. F., Reneau, R. B., and Smith, E. P. (1995). "Evaluation of a riparian wetland as a naturally occurring decontamination zone." *Clean water, clean environment – 21st century. Volume III: Practices, systems, and adoption.* Proceedings of a conference March 5-8, 1995, Kansas City, Mo., American Society of Agricultural Engineers, St. Joseph, Michigan, 259-262.

Spight, T. M. (1968). "The water economy of salamanders: evaporative water loss," *Physiological Zoology* 41, 195-203.

Strecker, E. W., Kernar, J. M., Driscoll, E. D., Horner, R. R., and Davenport, T. E. (1992). "The use of wetlands for controlling stormwater pollution," The Terrene Institute, Alexandria, VA.

U.S. Department of Agriculture, Soil Conservation Service. (1993). Soil Survey Manual. USDA Handbook 18. U.S. Government Printing Office, Washington, D.C.

U.S. Department of Agriculture. (2004). "Soil Survey of McDowell County, West Virginina," Natural Resources Conservation Service.

U. S. Fish and Wildlife Service. (1980). "Habitat Evaluation Procedures," Ecological Services Manual 102, Washington, DC.

Vogt, K. A., Grier, C. C., and Vogt, D. J. (1986). "Production, turnover, and nutrient dynamics of above and belowground detritus of world forests," *Advances in Ecological Research* 15, 303-77.

Wakeley, J. S., and Roberts, T. H. (1996). "Bird distribution and forest zonation in a bottomland hardwood wetland," *Wetlands* 16, 296-308.

Wakeley, J. S. and Smith, R. D. (2001). "Hydrogeomorphic Approach to Assessing Wetland Functions: Guidelines for Developing Regional Guidebooks - Chapter 7 Verifying, Field Testing, and Validating Assessment Models," ERDC/EL TR-01-31, U.S. Army Engineer Research and Development Center, Vicksburg, MS (http://el.erdc.usace.army.mil/wetlands/pdfs/trel01-31.pdf).

Wharton, C. H., Kitchens, W. M., Pendleton, E. C., and Sipe, T. W. (1982). "The ecology of bottomland hardwood swamps of the southeast: A community profile," Report FWS/OBS-81/37, U.S. Fish and Wildlife Service, Office of Biological Services, Washington, DC.

Whitlock, A. L., Jarman, N. M., and Larson, J. S. (1994). "WEThings; Wetland Habitat Indicators for Nongame Species, Wetland-Dependent Amphibians, Reptiles and Mammals of New England," Publication 94-1, The Environmental Institute, University of Massachusetts, Amherst, MA.

Whittaker, R. H. (1975). *Communities and ecosystems.* MacMillan Publishing Company, New York.

Wiens, J. A. (1969). "An approach to the study of ecological relationships among grassland birds," *Ornithological Monographs* 8, 1-93.

Willson, M. F. (1974). "Avian community organization and habitat structure," *Ecology* 55, 1017-1029.

Young, R. A., Huntrods, T. and Anderson, W. (1980). "Effectiveness of riparian buffer strips in controlling pollution from feedlot runoff," *Journal of Environmental Quality* 9, 483-487.

Zarbock, H., Janicki, A., Wade, D., Heimbuch, D., and Wilson, H. (1994). "Estimates of total nitrogen, total phosphorus, and total suspended solids loadings to Tampa Bay, Florida," Tampa Bay National Estuary Program, St. Petersburg, FL.

**Site Name -** **Assessment Date -**

**Impact Area (acres) -** **Impacted Stream Length (feet) -**

| **Stream channel alterations (*CHANNELALT*)** | |
|---|---|
| **Type of Alteration** | **%** |
| unaltered | |
| restored | |
| incised or excess sediment in channel | |
| dammed | |
| channelized/straightened | |
| dredged | |
| Channel >50% filled | |

| **Average Percent Slope of Watershed (*SLOPE*)** | |
|---|---|
| **Percent Slope** | **%** |
| 30 to 45 or unaltered | |
| (20 to 29) or (46 to 65) | |
| 10 to 19 | |
| (5 to 9) or (66 to 90) | |
| less than 5 | |

| **Average Stream Sediment Size (*SED*)** | |
|---|---|
| **USDA Texture** | **%** |
| bolders, stones, and cobbles (>3 in.) | |
| gravel (3/4 to 3 in.) | |
| sand | |
| silt | |
| clay/pavement | |

| **Land Cover Within Watershed (*COVER*)** | |
|---|---|
| **Land cover** | **%** |
| forest | |
| shrub | |
| orchards | |
| pasture or hay | |
| urban, roads | |

| **Average Percent Cover of Trees (*TREE*) (≥3 in. dbh)** | |
|---|---|
| **Percent Cover** | **%** |
| Greater than 90 | |
| 70 to 90 | |
| 50 to 69 | |
| 20 to 49 | |
| 10 to 19 | |
| less than 10 | |

| **Average Percent Cover of Shrubs (*SHRUB*) (>39 in tall and <3 in. dbh)** | |
|---|---|
| **Percent Cover** | **%** |
| Greater than 50 | |
| 20 to 50 | |
| 10 to 19 | |
| less than 10 | |

| **Average Percent Cover of Herbaceous Vegetation (*HERB*)** | |
|---|---|
| **Percent Cover** | **%** |
| 70 to 100 | |
| less than 70 | |

| **Number of Native Species (*COMP*)** | |
|---|---|
| **# of species** | |

| **Average Percent Cover of Detritus (*DETRITUS*)** | |
|---|---|
| **Percent Cover** | **%** |
| Greater than 75 | |
| 50 to 75 | |
| 25 to 49 | |
| 10 to 24 | |
| less than 10 | |

| **Large Woody Debris in Channel (*LWDEBRIS*)** | |
|---|---|
| **# of logs in channel** | |

| **Channel Geomorphology (*CHANNGEO*)** | |
|---|---|
| **Slope and Pools** | **%** |
| >4% slope with many step pools (or unaltered) | |
| 2 to 4% slope with common step pools | |
| 1 to 1.9% slope with few step | |
| Less than 1% slope with no step pools | |

| | |
|---|---|
| Investigator(s): | |
| County: | |
| Latitude: | |
| Longitude: | |
| Topo Quad: | |

Remarks:

| Photos | |
|---|---|
| Identifier | Description |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |