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*Wetlands Regulatory Assistance Program*

# A Regional Guidebook for Applying the Hydrogeomorphic Approach to Assessing Wetland Functions of Forested Riverine Wetlands in Alluvial Valleys of the Piedmont Region of the United States

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# A Regional Guidebook for Applying the Hydrogeomorphic Approach to Assessing Wetland Functions of Forested Riverine Wetlands in Alluvial Valleys of the Piedmont Region of the United States

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# Abstract

The Hydrogeomorphic (HGM) approach is used for developing and applying models for the site-specific assessment of wetland functions. It was initially designed for use in the context of the Clean Water Act Section 404 Regulatory Program permit review process 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 design of wetland restoration projects, projecting ecological outcomes, developing success criteria and performance standards, and adaptive monitoring and management of wetlands. This guidebook provides an overview of the HGM approach including classification and characterization of the principal alluvial riverine wetlands identified in the Piedmont physiography. Eight potential subclasses of Piedmont wetlands, including Headwater, Low- and Mid-gradient Riverine, Floodplain Depression, Footslope Seeps, Flats, Precipitation Depressions, and Fringe wetlands were recognized. However, the occurrence of Flats, Precipitation Depressions, and Fringe wetlands in the Piedmont, are uncommon and not generally associated with alluvial riverine systems which is the subject of this Guidebook. Detailed HGM assessment models and protocols are presented for the five most common Piedmont riverine subclasses: Headwater, Low- and Mid-gradient Riverine, Floodplain Depression, and Footslope Seep. For each wetland subclass, the guidebook presents (a) the rationale used to select the wetland functions considered in the assessment process, (b) the rationale used to select assessment models, and (c) the functional index calibration curves developed from reference wetlands used in the assessment models. The guidebook outlines an assessment protocol for using the model variables and functional indices to assess each wetland subclass. The appendices provide field data collection forms. In addition, an automated spreadsheet model is provided to make calculations.

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# Preface

This work was performed by the US Army Engineer Research and Development Center (ERDC) and funding was provided through the Wetlands Regulatory Assistance Program (WRAP, Funding Account FB08K6, AMSCO Code 088893). It was prepared in accordance with guidelines established by ERDC. Some methods and protocols used were adapted from the regional guidebook covering the southeastern Coastal Plain of the US (Wilder et al. 2013) but modified to reflect conditions unique to the Piedmont. Therefore, portions of the text and some figures are similar or identical to sections of those HGM guidebooks, particularly with respect to generic descriptions of HGM protocol. Developed models were designed for application across the entire Piedmont (northern and southern), and variables were chosen to maximize efficiency of assessment.

At the time of publication, Mr. Alan Katzenmeyer was the chief of the Aquatic Ecology and Invasive Species Branch; Mr. Mark D. Farr was chief of Ecosystem Evaluation and Engineering Division, EL; Mr. Kyle B. Gordon was program manager, WRAP; and the director of the EL was Dr. Edmond Russo.

The Project Delivery Team (PDT) members for the development of this guidebook are provided in Table A3 (Appendix A). Critical reviews were provided by Mr. Morris Flexner and Mr. Bill Ainslie (EPA, Region 4), Mr. Justin Hammonds (USACE, Savannah District), Dr. Tom Roberts (Tennessee Technological University), Mr. David Lekson (USACE, Wilmington District) and, Ms. Dee Pederson (NRCS, Athens, Georgia). Ms. Pederson also participated in *beta* testing the final draft guidebook.

This guidebook is dedicated in memory of Chris Noble, long-time soil scientist of ERDC and practitioner of HGM.

COL Christian Patterson was commander of ERDC and Dr. David W. Pittman was director.

# 1 Introduction

## 1.1 Background

The Hydrogeomorphic (HGM) approach is a method for developing functional indices to assess the capacity of a wetland to perform functions relative to a similar type of wetland in a region. The approach was initially designed to be used in the permit review process in the Clean Water Act Section 404 Regulatory Program as a method 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 HGM approach have been identified, including determining minimal effects under the Food Security Act, designing wetland restoration projects, formulating performance standards, and adaptively monitoring and managing wetlands.

## 1.2 Objective

The objective of this Regional Guidebook is to provide an approach to classify and assess the functions of wetlands that occur within alluvial valleys of the Piedmont region of the US. Although the potential for nine wetland subclasses in the Piedmont are recognized, detailed functional assessment criteria and models in this guidebook are only presented for the five most common wetland subclasses. The rationale for concentrating on these five subclasses and excluding others is given along with descriptions of the subclasses. This report is organized in the following manner. Chapter 1 provides the background, objectives, and organization of the document. Chapter 2 provides a brief overview of the major components of the HGM approach, including the procedures recommended for the development and application of regional guidebooks. Chapter 3 characterizes the regional wetland riverine subclasses in the alluvial valleys of the Piedmont. Chapter 4 discusses the wetland functions, assessment variables, functional indices, and assessment models to specific regional wetland subclasses and defines the relationship of assessment variables to reference data. Chapter 5 outlines the assessment protocol for conducting a functional assessment of regional riverine wetland subclasses in the alluvial valleys of the Piedmont. Appendix A is an overview of the HGM approach. Appendix B1 presents preliminary project documentation and field sampling guidance. Appendix B2 provides a preparation checklist for field assessments. Appendix B3 provides field data forms and Appendix C contains the glossary. An electronic calculator is available online as a companion to this Guidebook.[*]

## 1.3 Approach

In the HGM approach, the functional indices and assessment protocols used to assess a specific type of wetland in a specific geographic region are published in a document referred to as a *Regional Guidebook*. Guidelines for developing these were published in the National Action Plan developed cooperatively by the US Army Corps of Engineers (USACE), US Environmental Protection Agency (USEPA), US Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS), Federal Highway Administration (FHWA), and the US Fish and Wildlife Service (USFWS) (Federal Register 1997). The Action Plan[†] outlines a strategy for developing Regional guidebooks throughout the US, provides guidelines and a specific set of tasks required to develop a Regional guidebook under the HGM approach, and solicits the cooperation and participation of Federal, state, local agencies, academia, and the private sector. In addition, Appendix A provides a general overview of the HGM approach.

* https://wetlands.el.erdc.dren.mil/guidebooks.cfm

† http://www.epa.gov/OWOW/wetlands/science/hgm.html

# 2 Characterization of Alluvial Valley Riverine Wetlands of the Piedmont Region

## 2.1 Reference domain

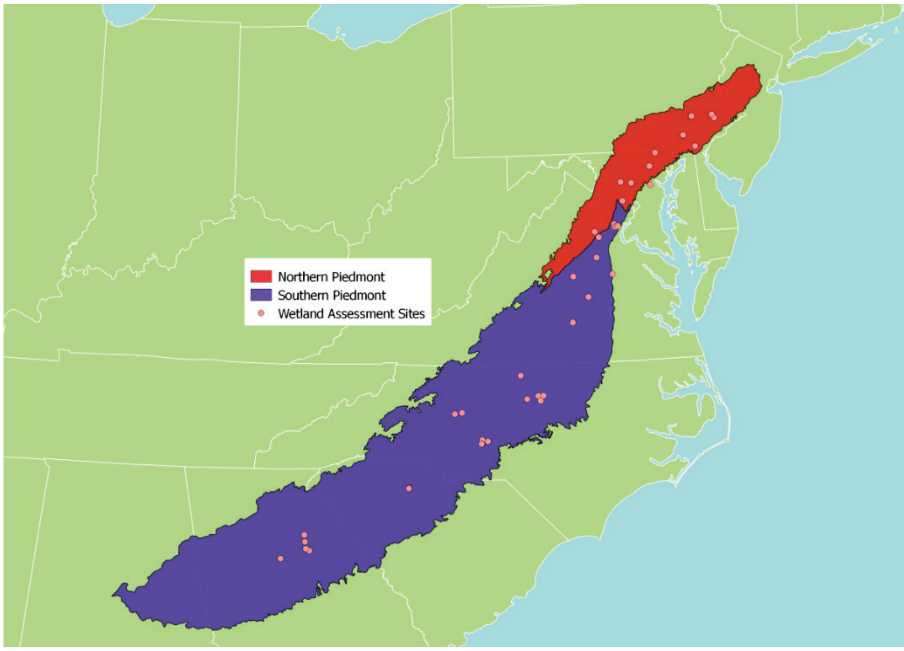
This HGM guidebook applies to selected freshwater wetland types of riverine alluvial valleys located in the Piedmont Physiographic Province, which includes northern and southern regions. The name “Piedmont” comes from the Latin “pedemontium,” which means, “foot of a mountain.” Generally lying between the Atlantic Coastal Plain and the Appalachian Mountain range, the Piedmont is bounded on the east by the Fall Line of the Atlantic Seaboard. The Ridge and Valley Province is the western border of the northern and southern sections of the Piedmont, whereas the Blue Ridge Province is the western border the central section of the Piedmont.

The reference domain extends south from a small section in New Jersey to central Alabama.* The Piedmont from northwestern Virginia northward is called the northern Piedmont (MLRA 148), whereas the southern Piedmont lies to the south (MLRA 136) (Figure 1).

The Piedmont is approximately 210,000 $km^2$ in area and varies from a very narrow band north of the Delaware River to being nearly 475 km wide in North Carolina. The surface relief of the Piedmont is characterized by relatively low rolling hills with elevations above sea level ranging from 50 m near the Coastal Plain boundary to 350 m near the Appalachian Mountains. Several major river systems flow through the Piedmont, including the Ogeechee (Georgia), Pee Dee (South Carolina), Roanoke (North Carolina), James (Virginia), Hudson (New York), Connecticut (Connecticut), and Passaic (New Jersey) to name a few. Historically, cotton was the most important crop in the southern Piedmont, whereas tobacco, fruit, and livestock predominated in the northern Piedmont. General climatic conditions for both the northern and southern Piedmont are included below.

* https://water.usgs.gov/lookup/getspatial?mlra

Figure 1. Reference domain and reference sites (*orange dots*) for alluvial valleys of the northern (MLRA 148) and southern Piedmont (MRLA 136).




During the Holocene, Piedmont streams (and their floodplain wetlands) flowed freely to the sea, reworking their floodplains *en route*. There is convincing evidence that before European colonization (pre-1720), the alluvial valley bottoms were dominated by anastomosing channels dominated by sedges (Voli et al. 2009; Merritts et al. 2011). However, it is unclear how much beaver influenced and perpetuated this condition. The Piedmont physiography was subdivided into two major areas, north and south, due to variation in climate, local topography, geology, soils, vegetation, and long-term alternations.

### 2.1.1 Northern Piedmont

The geographic area of the northern Piedmont ecoregion is approximately 30,120 km$^2$ (11,629 mi$^2$)* and includes parts of New Jersey, Pennsylvania, Delaware, Maryland, District of Columbia, and Virginia (Auch 2002). Parts of major metropolitan Philadelphia, Baltimore, and Washington are included in the northern Piedmont. The Northern Piedmont's landforms

* For a full list of the unit conversions used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office, 2016), 345–47, https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf.

include low, rounded hills, irregular plains, and open valleys (USEPA 1996).

The Piedmont climate is moderate in the winter and warm and humid in summer. The mean annual precipitation in the northern Piedmont is 101 cm (40 in.). Mean annual temperature ranges between 10.3°C and 19.1°C (50.6°F–66.3°F). The first fall frost is at the end of October, and the last spring frost is early April.

Soils vary across the ecoregion, ranging from thin, stony soils on prominent ridges and low mountains to fertile limestone-derived soils in some plains and valleys (Auch 2002). The population of the Northern Piedmont increased by nearly 2 million people between 1970 and 2000, reaching 11,434,000 by 2003, with population density typically declining from east to west across the ecoregion (US Bureau of the Census 1973 and 2003). Land use varies, ranging from urban and suburban, to intensely farmed land and livestock pastures. The dominant land cover classes form a mosaic of agricultural, forested, and developed lands, but the mixtures vary locally. Agricultural land ranges from intensely cropped cornfields and horticultural nurseries to less intensely used hayfields and pastures. Forested areas typically occur on land that has marginal utility for contemporary agricultural use, due to steep slopes and nutrient-limited soils. Forested areas are also often managed as public resources (Matlack 1997; Marsh and Lewis 1995; Morel and Gottmann 1961).

### 2.1.2 Southern Piedmont

The geographic region of the southern Piedmont covers parts of Alabama, Georgia, South Carolina, North Carolina, and Virginia (Figure 1). Omernik (1987) described the area as the Southeastern Plains Ecoregion. This Ecoregion includes the Washington, Winder, and Greenville Slope areas. Streams flowing to the southwest occupy shallow, open valleys with broad, rounded divides, whereas streams flowing to the southeast occupy narrow, deeper valleys with narrow, rounded divides. Streams flowing through the Winder and Washington Slope areas drain into the Atlantic Ocean, whereas the Gulf of Mexico receives water flowing through the Greenville Slope area (Pruitt 2001).

Much of the original Piedmont topsoil has eroded away due to poor agricultural practices that occurred at the turn of the twentieth century, leaving red clay subsoils exposed in many areas (Trimble 1969). Most soils, which are sandy clay loam to sandy loam, contain mica schist and quartz. There are numerous dome-shaped, granite surfaces in the Southern Piedmont. Prevalent geologic formations in the area are metamorphic in origin, consisting mostly of mafic gneisses, especially hornblende gneisses with intercalated amphibolites and biotite gneisses (Bennison 1975). Soils have developed from parent material dominated by acid crystalline, metamorphic rock deposits formed from granites, gneisses, and schists, all rich in iron and magnesium, but low in nitrogen and phosphorus.

Mean annual rainfall in the southern Piedmont is 112 to 142 cm (44 to 56 in.) (Robertson 1968). Mean annual temperature ranges between 15°C and 18°C (59 °F and 64 °F). Mean midsummer maximum temperatures are 31 °C–33°C (88°F–91°F), and midwinter mean minimum temperature falls between 0 °C and 2 °C (32°F-36°F). The frost-free season in the southern Piedmont is 210–240 days.

Much of the Southern Piedmont region is dominated by hardwood/mixed forests or pines, especially on steeper terrains and on less fertile soils. The less steep areas, where the topsoil has not been completely eroded away, are planted in corn, cotton, soybean, and grain sorghum. About 70% of the subregion is woodland and 20% is dedicated to cropland and pastureland (Robertson 1968). However, areas heavily affected by high urban densities (e.g., Atlanta) are growing steadily.

The following description is generally pertinent to both the northern and southern Piedmont. Wharton (1977) characterized the Piedmont physiographic province as “alluvial river and swamp systems.” Geomorphologically, the Piedmont consists of foothills and broad interstream divides (Perkins and Shaffer 1977). Cressler et al. (1983) described the Piedmont area southeast of the Chattahoochee River as a superimposed dendritic drainage pattern. Elevations range from approximately 152 to 457 m (500 to 1,500 ft) above sea level. According to the Cowardin et al. (1979) classification system, most of the wetlands within the study area are classified as a Palustrine (nontidal freshwater) dominated by forest subclasses. Utilizing the more specific, geomorphologic based (i.e., hydrogeomorphic) HGM classification system, most Piedmont wetlands are riverine ecosystems (*sensu* Brinson 1993b), characterized by frequent flood events in their unaltered state.

Although the reference domain covered in this guidebook is large (210,000 $km^2$), alluvial valleys are remarkably similar across the domain. Wetlands associated with Piedmont alluvial valleys function similarly and HGM models are designed to work effectively across the entire reference domain. The key to designing effective models is to classify wetlands, using reference data, so the natural variability inherent in these wetlands can be reduced sufficiently to differentiate conditions caused by man-made alterations.

The following sections discuss geologic, edaphic, climatic, and hydrogeomorphic factors that affect natural variability among alluvial valley wetlands across the reference domain, with emphasis on those factors that influenced the authors' classification, model development, and identification of reference standards. The classification section summarizes the criteria used to classify the wetlands discussed in this guidebook and describes differences in forest canopy composition among the identified subclasses, based on reference data collected across the reference domain and data collected by other scientists. The final section summarizes the most common human alterations to each of the Riverine wetland subclasses and how those alterations affect the physical, chemical, and biological integrity of each subclass.

## 2.2 Geology

Piedmont geology is complex with its underlying bedrock composed of igneous and metamorphic rocks. The Piedmont is the remnant of several ancient mountain chains that have eroded away due to mass wasting processes. Geologic formations, from a variety of origins, have been exposed to various geologic processes during periods of mountain building (orogenies) and erosion over time (e.g., plate tectonics, volcanism, faulting, folding, and metamorphosis). Geologists have identified at least five separate geological events leading to the formation of the Piedmont's geomorphology, including the Grenville orogeny (the collision of continents that created the supercontinent Rodinia) and the Appalachian orogeny that created the supercontinent Pangaea. Rocks at the eastern edge of Pangaea formed from subduction and volcanic processes when the future North American and African plates collided, forming the Ancestral Appalachians, which were once as high as the present-day Rockies. During this process, the rocks were strongly folded, faulted, and metamorphosed. Differential weathering of these rocks has led to the Piedmont's current rolling landscape. The last major geologic event in the history of the Piedmont was the break-up of Pangaea, when North America and Africa began to separate along what is now the mid-Atlantic Ridge (rift zone) and the mountains began to erode. As the mountains weathered, some of the sediment collected in the large rift basins formed by continental rift zones. The resulting Triassic Basins are scattered along the eastern margin of the Piedmont.

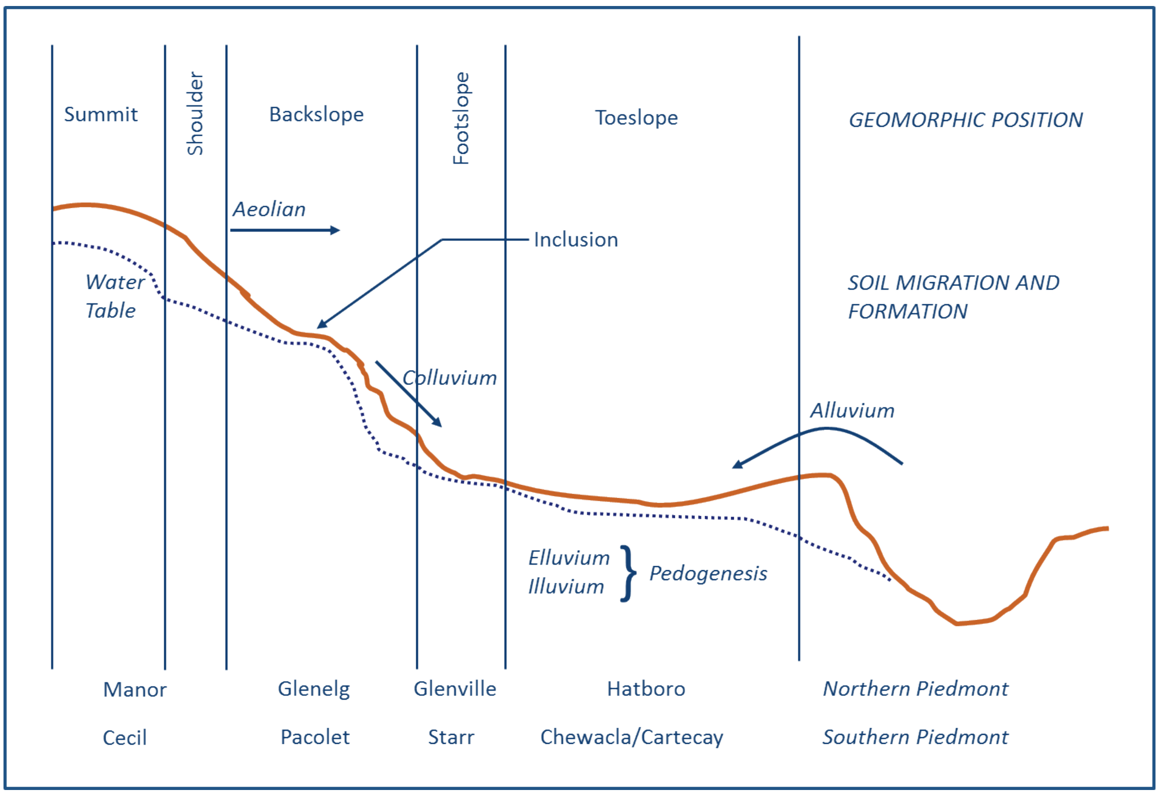
## 2.3 Soils

Piedmont soils are characteristically clay-dominated and moderately fertile. In many areas, soils have suffered from erosion from intensive farming, particularly in the southern Piedmont where cotton was historically the chief crop grown. Rural areas of the southern Piedmont now predominantly consist of small farms and managed forests. In the central Piedmont region of North Carolina and Virginia, corn is the main cash crop, whereas in agricultural areas to the north, land use is more diverse in that farms include more orchards, dairy farms, and pastures. However, much of the northern Piedmont is now dominated by suburban and urban land uses.

Soil associations typically form along a topographic gradient (catena) or geomorphic position (Figure 2). Soils form via four major transport processes: aeolian, colluvial, alluvial, and pedogeneic (within the soil profile). Aeolian (windblown) transfer of soils to floodplains is more prevalent in the northern Piedmont than the southern Piedmont but does not have a major effect on most riverine wetlands. In contrast, colluvial and alluvial transport processes affect riverine wetlands most. Colluvial transport usually proceeds slowly, unless the process is accelerated by poor land management along hillslopes, resulting in mass wasting of backslopes. Colluvium is generally more prevalent in the northern Piedmont, as evidenced by soil series mapped at the footslope geomorphic position (e.g., Glenville soil). Many historic floodplains are overlain by 1–5 m of laminated, fine-grained sediment (Walter and Merritts 2008), a consequence of poor farming practices and sediment trapping by the many historic milldams that once lined creeks in the middle reaches of stream networks. A silt loam texture is common in soils in toeslope and footslope geomorphic positions in the northern Piedmont.

In the southern Piedmont, colluvial material filled valley flats and was eventually transported downstream and deposited via vertical accretion (as alluvium) during overbank flood events. Consequently, many soil series mapped on the toeslope can be considered, in geologic time, as being recently formed (Order Entisols). Alluvial material has been reported to be over one meter thick in many southern Piedmont valley flats (Burke and Nutter 1995). Riverine wetlands have been adversely affected over the past two centuries by both colluvial and alluvial processes due to historically poor agricultural practices on hillsides (i.e., accelerated mass wasting during the cotton era).

Figure 2. Correspondence between a typical soil catena, soil series, and soil transport direction (*arrows*). Colluvium is more prevalent in the Northern Piedmont, whereas alluvium is more prevalent in the Southern Piedmont.

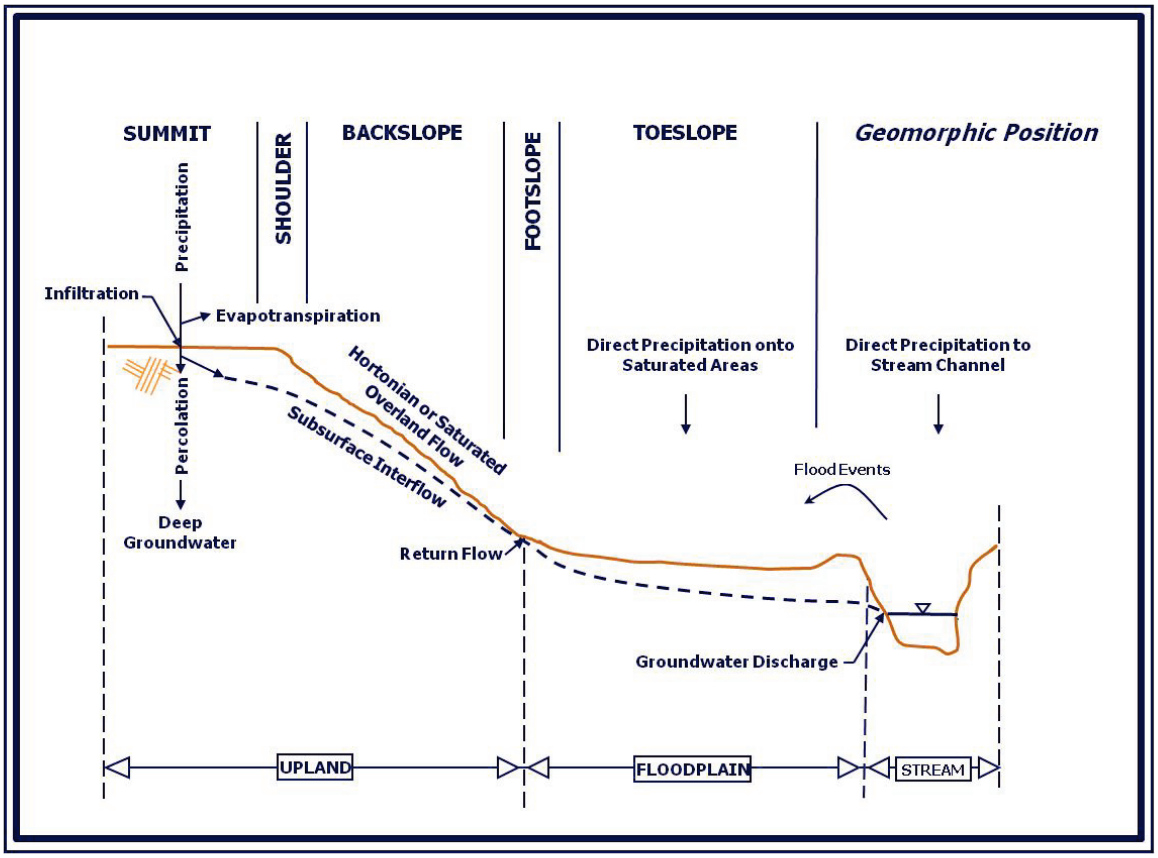



## 2.4 Predominant water sources for Piedmont wetlands

Prior to applying the HGM approach, wetlands must be classified by three hydrogeomorphic categories: geomorphic position, predominant water source(s), and hydrodynamics (Appendix A). These categories are characterized in detail in the section below entitled, “Classification of Piedmont Alluvial Valleys.” In the Piedmont, before channels became incised, active floodplains of higher order stream were located on toeslopes on Mid-gradient streams that collected, stored, and conveyed overbank floodwaters. Water entering riverine wetlands was usually from overbank flooding, which typically moved down-gradient, using the floodplain as a flood channel. The energy associated with overbank flow was sufficiently high to move sediment, woody debris, and other organic materials onto and off floodplains. Thus, overbank flooding was a significant source of water to wetlands of the riverine class before channel incision hydrologically disconnected floodplains from frequent and long-duration overbank flooding events.

Given that groundwater moves toward stream channels at the base of backslopes (footslope position), wetlands that occupy historic floodplain/riverine landscape positions now receive appreciable amounts of groundwater, which then saturate wetland soils. Thus, the predominant water source for many floodplains is now return flow at footslope seeps, where many alluvial wetlands now occur (Figure 3). Hydrodynamics (i.e., magnitude and flow direction) in most alluvial wetlands are now an expression of groundwater discharge, which is characterized by relatively low energy and unidirectional flow onto toeslopes. Return flow at the footslope is now a critical flow path in most Piedmont systems due to a major reduction in the frequency of overbank flood events (now rare) in response to channel incision and enlargement.

Figure 3. Conceptual hillslope catena cross-section with depiction of geomorphic position and hydrologic flow vectors (*arrows*) of current-day wetland that are incised due to poor land use practices from the early 1800s to the 1930s.




## 2.5 Hydrogeomorphic variation within drainage networks

The alluvial valley subclasses covered in this guidebook are physically interconnected ecosystems in that they are all part of a larger stream network system in their drainage basins. The headwater portion of a stream network (herein called Headwater subclass), usually located at the head of a valley, is primarily fed by surficial groundwater, or directly by precipitation, which infiltrates into the ground before moving down-gradient. Soils in these headwater reaches become saturated at or near the surface and the extent of saturated soils continues down the valley to a location where channels begin to form intermittent streams and eventually, perennial streams.

First order streams continue down-gradient until they eventually coalesce with other first order streams to form second order streams, then two second order streams eventually combine to form third order streams, and so on (Strahler 1952). As the drainage basin above each successive point down gradient expands, the flow patterns to the outlet of the basin also expand (i.e., water will move downslope via groundwater, surface flow, and/or overbank flow).

Headwaters constitute 70%-90% of stream length in a typical stream network (Leopold et al. 1964). The remaining 10%–30% of stream length in a drainage network consists of mid-gradient (third to fourth order) and low-gradient (greater than fourth order) streams. The low-gradient, higher order streams are usually deeper and wider than most mid-gradient streams, due to increased surface flows. Thus, most low-gradient stream reaches in the Piedmont were too deep and too wide to adequately collect channel-related data without use of a boat or they were located upstream of a reservoir. In contrast, reaches in mid-gradient watershed positions were wadeable during normal flow periods, and thus were accessible for field sampling.

Down gradient of groundwater-driven headwater systems, many mid-gradient streams of the Piedmont are deeply incised due to destructive land use practices that occurred during the late 1700s to the 1930s. Thus, overbank flooding events now occur infrequently along most mid-gradient reaches. Where overbank flooding is still relatively frequent, flooding is of such short duration that wetlands no longer exist on the floodplains, except at footslopes at the upland edge of valley flats. However, footslope wetlands are generally absent where channel incision is particularly deep and/or where channels are near footslopes.

As previously mentioned, floodplains of mid-gradient channels of the Piedmont aggraded with legacy sediments during the early 1800s to the 1930's. Some scientists refer to mid-gradient channels with legacy sediment on their valley flats as Anthropocene streams because they are a consequence of human-caused degradation. Legacy sediment refers to historic sediment delivery and deposition during a period when agricultural practices did not include land management to prevent erosion or the transport and delivery of soil to the stream channel (e.g., the accelerated sedimentation that occurred during the cotton era).

Although wetlands occur at some footslope locations, the only other location they occur in Mid-gradient systems is in depressions on valley flats. Some of these depressions pond water after rainfall and retain water for various durations. Larger depressions, mostly associated with abandoned channels, hold water for long periods, sometimes year-round.

Legacy colluvial material in headwater reaches has been mostly eroded and transported downstream onto the Mid-gradient valleys. Thus, most sediment of a stream network is stored in Mid-gradient reaches. Thus, Mid-gradient valley flats are a net source of sediment to a drainage basin. When the Low-gradient portion of a stream network receives sediment-laden water, the sediment either is deposited on floodplains or is transported further downstream, eventually reaching coastal estuaries.

## 2.6 Major land resource areas (MLRA)

Major Land Resource Areas (MLRA) encompassed by the reference domain (Figure 1, Table 1) represent geologic and climatic differences among the two Piedmont Regions (northern and southern), which were initially considered in classifying wetland types. The source of sediment on floodplains (or historic floodplains) differs between the northern and southern Piedmont. In the northern Piedmont (especially in Pennsylvania), the source of legacy sediment on floodplains is lacustrine and fluvial, whereas sediment in the southern Piedmont is more colluvial in origin (Walter and Merritts 2008). The difference between Piedmont regions is that reservoirs of mill dams covered a substantial portion of stream reaches in the industrialized north and fine sediments collected behind those dams, eventually filling the reservoirs. Sediments of the Southern Piedmont originated from land-clearing activities during the same period. Mass wasting (severe land erosion and gullying) in Georgia and South Carolina during the cotton era introduced tremendous amounts of sediment from adjacent farmland, which was then carried to valleys via overland flow during rain events. These colluvial deposits were eventually eroded from floodplains and carried downstream during high stream flow events, which converted the deposits to fluvial sediments. In the north, the historic location of mill dams is important in determining the intensity of channel incision at any given point along a reach. The closer one is to the historic location of a downstream dam, the greater is the channel incision from head cutting. In the southern Piedmont, the degree of channel incision is generally uniform along a reach, apart from reaches immediately upstream of historic dams.

Table 1. Major Land Resource Areas (MLRA) and Land Resource Regions (LRR) of the reference domain.

| MLRA Name | MLRA Code | LRR Name | LRR Code |
|---|---|---|---|
| Northern Piedmont | 148 | Northeastern Forage and Forest Region | R |
| Southern Piedmont | 136 | South Atlantic and Gulf Slope Cash Crops, Forest, and Livestock Region | P |

### 2.6.1 Classification of Piedmont alluvial valleys

Almost all traditional hydrogeomorphic classes are represented in the Piedmont (Figure 4, Table 2), though some are rare, such as wet flats dominated by precipitation.

Figure 4. Typical form and landscape position of Piedmont riverine wetland subclasses. Landscape positions depicted: backslope in *light green*, toeslope/floodplain in *light blue*, footslope at backslope/toeslope interface. Footslope wetlands may not necessarily be located on an active floodplain.

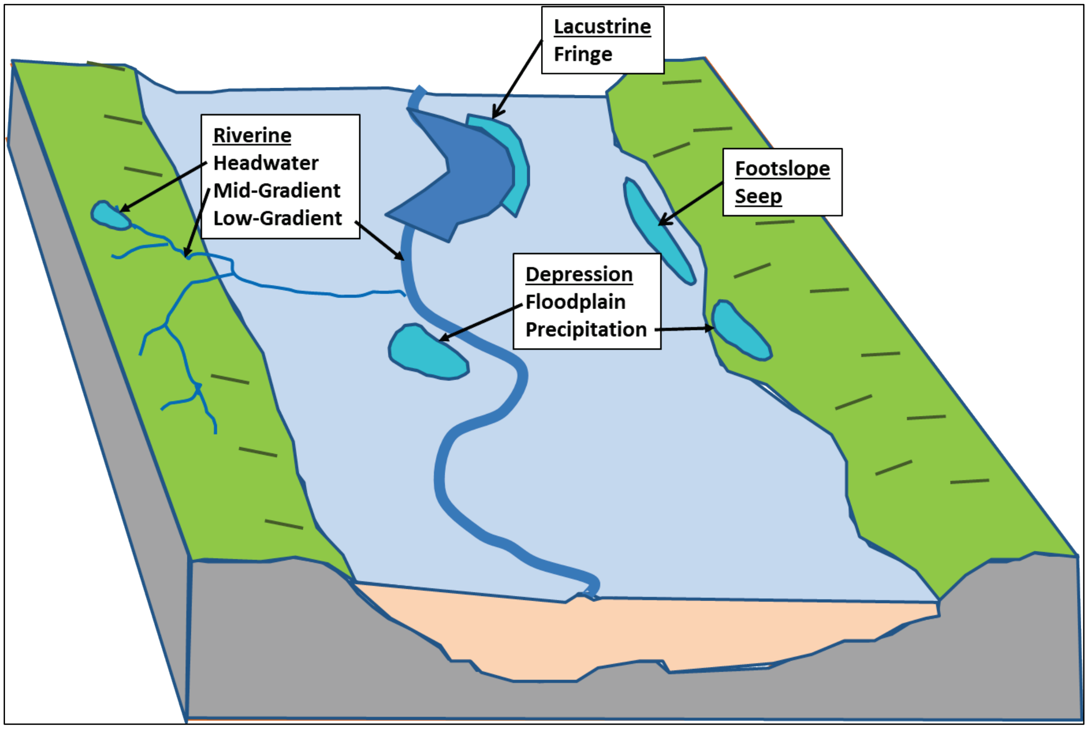


Table 2. HGM classification of Piedmont riverine alluvial valleys.

| Wetland Class | Subclass | Typical Hydrogeomorphic Setting (see Geomorphic Position on Figure 4) |
|---|---|---|
| Riverine | Headwater | Groundwater-driven seepage areas at the headward extent of valleys generally above bed-and-bank channel geometry. First and second order streams are included in this subclass. Flow periodicity is predominantly intermittent with frequent periods of no flow during drought. Dominant hydrodynamics are unidirectional, horizontal. Some Headwaters are deeply incised by head-cutting. |
| | Mid-gradient | Third and fourth order perennial streams with gravel or coarse sand point bars. Overbank flow is infrequent or very short duration when flood events occur. Can be deeply incised. |
| | Low-gradient | Fifth and higher order streams (rivers), with point bars and natural levee deposits. Back swamp communities are uncommon unless the valley flat is broad. Many Low-gradient systems have been dammed in the Piedmont. |
| | Floodplain Depression | Dominant water source is groundwater (return flow and interflow). Infrequent surface water flow from overbank events is possible. However, may be isolated from riverine processes and subject to long durations of saturation from ground-water sources. Dominant hydrodynamics are vertical. |
| | Footslope Seep | The dominant water source is groundwater discharge (return flow) at the base of the backslope, usually at a contact between clay layers and more permeable overlying strata. The hydrodynamics are unidirectional and horizontal. |
| Flat | Mineral Soil Flat (Not addressed in this guidebook) | Broad, flat expanses not on active floodplains, but on large floodplain terraces. Predominant water source is precipitation. They receive no groundwater discharge, which distinguishes them from Floodplain Depressions and Footslope Seeps. Uncommon in Piedmont. |
| Depression | Precipitation Depression (Not addressed in this guidebook) | Depressions generally occurring on floodplain terraces or hillslopes, not associated with riverine systems, and fed predominantly by precipitation. The dominant hydrodyamics are vertical. Usually underlain by an aquiclude or aquitard (impervious or semi-impervious soil). Uncommon in Piedmont. |
| Fringe | Lacustrine Fringe (Not addressed in this guidebook) | Margins of man-made lakes[1] not within a stream floodplain. Dominant water source is overbank flow from the lake, and the dominant hydrodynamics are bidirectional, horizontal. |

[1] There are no naturally-occurring lakes in the Piedmont. Oxbow lakes are classified as Floodplain Depression in this guidebook.

### 2.6.2 Class: Riverine

**General Description.** Riverine class includes streams and their associated valley flats (floodplains and historic, colluvial-filled terraces). Five Riverine subclasses occur in the Piedmont: (a) Headwater, (b) Mid-gradient, (c) Low-gradient, (d) Floodplain Depression, and (e) Footslope Seep (described separately below).

Mid- and Low-gradient streams are frequently degraded by deep channel incision. Incision is the result of historic, abusive land use practices, particularly within cotton-growing regions of the Southern Piedmont. In addition, many reaches were dammed to supply power for gristmills. Dams were particularly dense in the northern Piedmont, mostly in northern Virginia and Pennsylvania (Walter and Merritts 2008). After dam reservoirs filled with sediment, they were abandoned and either deteriorated or were dismantled, allowing streams to headcut though the lacustrine sediments of the former dam reservoir. Thus, the incision depth of channels, along many reaches in the northern Piedmont may reflect proximity to historic dam locations and the height of those dams (Merritts et al. 2011).

At the Fall Line, rivers form rapids as they flow from the eastern-most, weathered rocks of the Piedmont into the Coastal Plain. The Fall Line is a geologically distinct boundary, generally less than twenty miles wide, where river reaches are interspersed with low waterfalls and rapids. Major cities arose along the Fall Line (e.g., Macon and Augusta in Georgia) because the change in gradient could be harnessed to provide industrial power and the location is the most inland extent of navigation for ocean-going vessels (e.g., barge traffic).

1. *Subclass: Headwater*. Headwater subclasses occur at the headward (upstream) extent of stream networks and may or may not have a defined channel. Since most first and second order streams are considered high gradient, they were included in this subclass. The predominant water source is groundwater, and the dominant hydrodynamics are unidirectional and horizontal. Surface water is usually seasonal, and frequent periods of no flow are common especially during periods of drought. This subclass provides an important extension of riparian corridors for wildlife and vegetation and high-water quality.

Flow at the upper reaches of headwaters is sluggish and channels may be absent, or if present, consist of multiple channels that form and disappear as water flows through hyporheic zones. At these mostly headwater locations, wetlands are characterized by water tables at or near the surface.

Channels of headwater streams are generally poorly developed in the upper reaches, becoming more distinct with progression down-gradient. Channels generally range in width from 0.5 to 2.0 m and vary widely in depth because some are deeply incised due to head-cutting. Valley widths of headwater reaches are usually narrow (<30 m) and natural levees are generally absent because hydraulic energy is too low.

Channels that form further down-gradient, the first and second order streams at the lower end of the subclass, often stop flowing after leaf-out in response to evapotranspiration (ET), especially during drought periods. In contrast, in winter, when the water table is high and ET is low, heavy rains can lead to a rapid rise in the water table, eventually shallowly inundating the entire valley flat, if the stream channel is not too deeply incised.[*] Water rarely ponds in headwater reaches, except in shallow depressions, at Footslope Seeps, and in divots produced by tree tip-ups. Because the water table is close to the surface, especially in early spring, such microtopographic depressions often support breeding habitat for amphibians.

The valley of many headwater reaches filled with sediment during massive land-clearing episodes in the late 1700s and intensive agriculture that followed.[†] In such degraded systems, channels head-cut upstream. Further lateral and upstream head-cutting occurs now during heavy rains, but little additional sediment has been supplied to downstream reaches since reforestation. Headwater reaches that received minimal colluvial inputs are still in relatively good condition and provide data for reference standards.

Headwater reaches attenuate surface flow to stream channels down-gradient, dampening the hydrograph during high precipitation events

* An incised channel acts like a drainage ditch, draining the valley flat more rapidly than the water table rises.

† Mill dams were even constructed in headwater reaches, especially in the Northern Piedmont.

and extending base flow downstream as the water is released slowly and continuously over time (Miwa et al. 2003). Because of their proximity to a groundwater source, soils in the Headwater riverine subclass tend to remain saturated for much of the year during normal rainfall years, although ET can cause a lowering of the water table in early spring.

In headwaters, green ash shares dominance with red maple and tulip poplar, whereas sweetgum, swamp blackgum (*Nyssa biflora*), and boxelder (*Acer negundo*) are locally abundant. The most important woody understory species are spicebush, highbush blueberry (*Vaccinium corymbosum*), possumhaw (*Viburnum nudum*), blackhaw (*Viburnum prunifolium*), and the invasive Japanese barberry (*Berberis thunbergii*) and multiflora rose (*Rosa multiflora*). The most frequently occurring mid-canopy trees are ironwood, American holly (*Ilex opaca*), and southern sugar maple (*Acer floridanum*), whereas the most frequently occurring canopy saplings are sweetgum, red maple, sycamore (*Platanus occidentalis*), and pignut hickory (*Carya glabra*).

The herbaceous stratum of headwater systems contains numerous species, but the invasive *Microstegium vimineum* (Nepalese browntop) is by far the most abundant. Other species frequently encountered include *Rubus hispidus, Impatiens capensis, Lonicera japonica* (invasive), *Athyrium felix-femina, Carex communis, Smilax* spp., and *Chasmanthium latifolia*. *Sphagnum* spp. is also encountered frequently.

2. *Subclass: Mid-gradient*. The Mid-Gradient Riverine subclass occupies the floodplains of third to fourth order streams, which typically constitute about 10%–20% of total stream length in a drainage basin. Mid-gradient streams are characterized with single or multi-threaded channels and side and/or point bars. Because of channel entrenchment, overbank flood events only occur on higher recurrence intervals (e.g., > 5 yr flood frequency). The dominant hydrodynamics of associated wetlands of mid-gradient streams are unidirectional and horizontal. Mid-gradient reaches are the major source of sediments to Low-gradient systems, and it would probably take centuries to remove legacy sediment.

Today, the elevated Mid-gradient floodplains flood infrequently and for short duration when flooding does occur. However, in urban landscapes, Mid-gradient reaches flood more frequently due to concentrated runoff storm water from impervious surfaces and valley confinement, but flood for very short durations (creating flashy hydrographs). Thus, wetlands are rare on urban Mid-gradient floodplains (except at some footslopes due to return flow, Figure 3). Except for active floodplains, where frequent flood events result in overbank flooding, groundwater is the predominant water source of nearly all Mid-gradient systems (Pruitt 2017). However, Mid-gradient floodplains function to briefly store water during storm events and delay water discharge to downstream reaches, thus ameliorating flood damage to infrastructure downstream.

The floodplains of the least altered Mid-gradient systems are dominated by red maple, tulip poplar, river birch (*Betula nigra*), and sweetgum in the canopy, whereas green ash and swamp blackgum are locally abundant. The woody midstory is dominated by spicebush and pawpaw (*Asimina triloba*) in the shrub stratum, by southern sugar maple and ironwood in the mid canopy, and by saplings of slippery elm (*Ulmus rubra*) and red maple.

We encountered 46 herbaceous species on Mid-gradient floodplains. The most frequently occurring species were *Microstegium vimineum, Carex communis, Dichanthelium dichotomum, Rubus* spp., *Boehmeria cylindrica*, and *Smilax rotundifolia*, whereas *Chasmanthium latifolia* was locally abundant.

3. *Subclass: Low-gradient*. The Low-gradient Riverine subclass occurs on streams greater than fourth order. Streams associated with this subclass are usually named rivers and/or major tributaries to rivers, are perennial, and are usually not wadeable. On most Low-gradient streams, natural levees occur along their banks where coarse sediment (sand) is deposited when water velocity slows during overbank flooding events. Their floodplains also contain depressions of various sizes (see Floodplain Depression), which are usually underlain by tight, clayey soils that slow infiltration and may perch water at or near the surface. The flood return interval of Low-gradient floodplains is 1–5 yr, during which time sediment from upstream erosion of Mid-gradient streams is added to the floodplain (i.e., alluvium). Thus, Low-gradient streams

functions as sediment sinks, which mediates sediment supply to coastal plain streams. The major ecological benefit of Low-gradient streams is to store floodwater and provide substrate for nutrient cycling. Vegetation in Low-gradient wetlands cycles and/or stores nutrients. Soil microbes recycle nutrients and enhance denitrification in microtopographic depressions where soils are wettest.

Low-gradient floodplains differ in canopy composition from the other subclasses. In Low-gradient stands, sycamore and boxelder share dominance, whereas green ash, black walnut, eastern cottonwood (*Populus deltoides*), and American elm (*Ulmus americana*) are locally abundant. The understory is dominated by pawpaw and Chinese privet (*Ligustrum sinense*) in the shrub stratum, boxelder in the midstory, and saplings of green ash. The herb stratum is composed mostly by *Microstegium vimineum, Lonicera japonica, Carex communis, Toxicodendron radicans, Dichanthelium dichotomum, Symphyotrichum dumosum, Polygonum hydropiperoides*, and *Carex leptalea*.

4. *Subclass: Floodplain Depression*. Floodplain Depressions, as the name implies, are depressions located on floodplains (Figure 4). The dominant water source is groundwater (return flow and interflow), and the dominant hydrodynamics are vertical. In addition, infrequent surface water flow from overbank flood events is possible. Piedmont Floodplain Depressions vary widely in flooding duration, due to wide variations in their size, the permeability of their confining layer, reliability of hydrologic inputs (e.g., precipitation, groundwater and/or overbank flow), and the presence and relative elevation of sills at drainage outlet(s). The Floodplain Depression subclass recognized in this guidebook is distinguished from ephemeral (vernal) pools by being deeper, larger, and holding surface water for much or all the growing season in normal years. The Floodplain Depression subclass occurs throughout the Piedmont, but it is relatively rare. Depressions are particularly rare on relic floodplains, due to the deep incision of most Piedmont streams, which prevent frequent overbank floods (< 5 yr flood frequency) from reaching low areas on valley flats. Underlying soils slow infiltration, usually due to their high clay contents.

   In headwater bottoms, water input into Floodplain Depressions is mostly derived from groundwater or precipitation. Most seem to be intimately connected to footslope seeps either by direct surface connections (from seep outflow) or from groundwater upwelling. For depressions relying on surface inflow and precipitation, duration of flooding depends on the permeability of underlying soils.

Large floodplain depressions probably do not occur in headwater riverine settings. They are rare in Mid-gradient riverine settings because floodplains there are so disconnected from their channels (i.e., overbank flood events occur too infrequently). In fact, in Mid-gradient settings, only depressions characterized with clayey soils (aquitard) can perch water long enough to retain surface water long enough to support wetlands. The predominant water source of Riverine depressions is commonly direct precipitation because overbank flood events are infrequent. Such depressions tend to support mesic species, but rarely support hydrophytic species. Thus, most wetland depressions that still occur on Mid-gradient floodplains are small and should be treated as a special case.

Floodplain Depressions most frequently occur on floodplains of Low-gradient streams, due to several factors such as: (1) overbank flooding is relatively frequent, (2) substrates are composed of fine sediment (clays) that impede drainage, and (3) floodplains tend to be wide enough to support large depressions. All three factors contribute to increased ponding duration. Floodplain Depressions function to detain (slow) water, recycle nutrients, provide sites for denitrification, and provide a variety of wet and open-water habitats for wildlife.

Vegetation in floodplain depressions is very variable, due to wide variations in hydroperiod and water depth. Plant cover tends to be sparse, at least in the deepest parts of a depression, and usually, the shrub and herbaceous strata are absent or patchily distributed on higher mounds or hummocks. Usually, obligate wetland species dominate all strata, where vegetation is present.

Forest stands of deep Floodplain Depressions are dominated by flood-tolerant canopy species, usually by only one or two species. Most sites flooded for long durations are dominated by tupelo (*Nyssa aquatica*), swamp blackgum, and green ash with few or no shrubs or herbaceous plants. Sites flooded for shorter periods support red maple, sycamore, river birch, and sweetgum. Common woody understory dominants include buttonbush (*Cephalanthus occidentalis*) and sweetspire (*Itea virginica*) in the shrub stratum, boxelder in the midstory, and saplings of red maple and blackgum. The most commonly occurring herbaceous species are *Mitchella repens, Symphyotrichum dumosum, Toxicodendron radicans, Polygonum hydropiperoides*, and *Boehmeria cylindrica*.

5. *Subclass: Footslope Seep*. This subclass occurs within the Headwater, Mid-gradient, and Low-gradient subclasses, and can also be conceptualized as a subclass. The dominant water source is groundwater discharge, and the hydrodynamics are unidirectional and horizontal. Footslope Seep wetlands occur, if the channel is not too deeply incised, at the footslope of valley flats where subsurface interflow is expressed as return flow (Figure 3) (Dobbs 2013). Water may also reach near the surface further into the valley flat, depending on spatial variations in hydraulic conductivity and the lithology of the sediment of the fill terrace, depth of channel incision, distance to channel, and seasonal and annual variation in precipitation regimes. Footslope Seeps can occur adjacent to Mid-gradient streams, but predominantly occur on the floodplain associated with headwater and Low-gradient riverine subclasses because channel incision is usually less pronounced in those subclasses. Mid-gradient reaches are often so deeply incised that most seeps are, in essence, drained by the channel due to hydraulic head differential (i.e., the incised channel causes the water table to slope so steeply toward the channel at the toeslope that its potentiometric surface occurs well below the terrace). In this case, seeps may occur within the stream channel.

   In much of the Piedmont, channels are so deeply incised that most wetlands occurring on valley flats only occur at footslope seeps. These seepage areas, though often small in extent, are biogeochemical hotspots amenable for denitrification (mediated by soil microbes). At seeps where water is ponded, one is likely to see iron precipitation in the water, mediated by iron bacteria, which oxidize ferrous iron to ferric iron ($Fe^{2+}$ to $Fe^{3+}$). A rusty-colored, filamentous growth in the water and an oil-slick-looking sheen on the surface are indicators that reduced iron ($Fe^{2+}$) and dissolved organic matter are expressed with return flow. Footslope seeps are also biological hotspots because they provide standing water for long-enough duration that amphibians can mate, and their young can complete metamorphosis.

It is difficult to quantify canopy vegetation of footslope seeps due to their inherently small size and propensity to remain wet for long periods. In the small areas of seeps sampled, there were often few or no trees or shrubs. Consequently, the vegetation sampling included terrain adjacent to the seeps, including uplands.

Stands in footslope seep positions are co-dominated by red maple (*Acer rubrum*), but various other species co-dominated as well, including green ash (*Fraxinus pennsylvanica*), red oak (*Quercus rubra*), southern red oak (*Quercus falcata*), blackgum (*Nyssa sylvatica*), yellow birch (*Betula lutea*) (in northern latitudes), sweetgum (*Liquidambar styraciflua*), tulip poplar (*Liriodendron tulipifera*), and beech (*Fagus grandifolia*). This wide variety in potential canopy species is partially since footslopes occur within all the other geomorphic classes (headwaters to large river floodplains) and near the upland slope at the edge of floodplains. Some upland species, beech for example, occur on the valley slopes, particularly as large trees.

The main shrub and vine species inhabiting seeps are spicebush (*Lindera benzoin*) in the shrub stratum, ironwood (*Carpinus caroliniana*) in the midstory, and beech in the sapling stratum. A wide variety of herbaceous species frequent footslope seeps as well, including *Symplocarpus foetidus, Athyrium felix-femina, Polygonum hydropiperoides, Boehmeria cylindrica, Parthenocissus quinquefolia, Smilax* spp., and *Microstegium vimineum*. These species are tolerant of more hydric conditions than most of the dominant herbaceous species listed for the other HGM subclasses.

## 2.7 Modern alterations of Piedmont alluvial valleys

### 2.7.1 Historic alteration of Piedmont systems

Upland Piedmont soils, which occur on rolling, semi-steep terrain, are generally highly erodible. Forest clearing followed by intensive agriculture (primarily cotton in the southern Piedmont) during the colonial era left soils exposed, which in turn led to massive filling of valleys flats with sediment from upland erosion. Erosion and colluvial deposition were so acute in the south that deep gullying of the upland landscape led to rapid filling of the bottoms with sediment (Figure 5).* After farms were abandoned and forests regenerated, sedimentation in bottoms diminished.

In the northern Piedmont, many reaches were dammed to power gristmills and industry (Figure 6). In fact, historic records show that, by 1875, dam reservoirs inundated 70% of stream networks in Headwater and Mid-gradient stream reaches (Walter and Merritts 2008). The milldam reservoirs filled with sediment and were then abandoned. Forests regenerated in the bottoms on the filled reservoirs as land tillage practices (contour tilling) lessened sediment input to bottoms.

Channel incision of the filled valleys began in earnest after forests stabilized the bottoms. This era of forest-clearing, unsustainable agriculture and mass wasting, dam building, dam abandonment, and channel incision explain the present condition of Piedmont streams. Some authors now refer to the time period (ca. post 1700,) as the "Anthropocene Epoch," to reflect the magnitude of human impacts globally (Isendahl 2010).

Table 3 summarizes the major types of human alterations to the Anthropocene bottoms of the Piedmont, differentiated by HGM wetland subclass. Most alterations are common to several, but not all subclasses. The most significant alterations to riverine wetlands are due to the loss of the historic hydraulic connection between floodplains and their channels. Other alterations may be more typical to a subset of subclasses. For example, today, large impoundments are usually only built across streams and rivers with perennial flow and where sufficient topography provides conditions for the creation of large reservoirs for generating power and for supplying municipal water, although the effects of smaller, historic, breached milldams still exert influence on the degree of channel incision upstream.

In general, alterations to Piedmont stream and valley corridors also affect nutrient dynamics and food chain support at all trophic levels (Figure 7). Hydrologic impacts up-gradient of the wetland can result in lowing base flow and even desiccation, which affects processes at all trophic levels.

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* One area in Stewart County Georgia became so deeply gullied that it has become a tourist attraction called Providence Canyon, touted as one of the seven "natural" wonders of Georgia: https://en.wikipedia.org/wiki/Providence_Canyon_State_Park (last accessed 6/12/16).

Depending on the dominant water source and land use conditions, water quality impairment from anthropogenic sources can affect the function Maintain Characteristic Biogeochemical Cycling. Introduction of invasive plant and animal species adversely affects functions, Maintain Characteristic Plant and Animal Communities. The most significant Anthropocene alterations are tabulated in Table 3 and described in detail below.

Figure 5. Extreme example of mass wasting in the Southern Piedmont: (a) Providence Canyon, Georgia (photo by Robbie Honerkamp), (b) Erosion in South Carolina.

Figure 6. Density of mill dams in the Piedmont, circa 1840 (from Walter and Merritts 2008). Approximate boundary of Southern Piedmont outlined in *white*, Northern Piedmont in *yellow*.

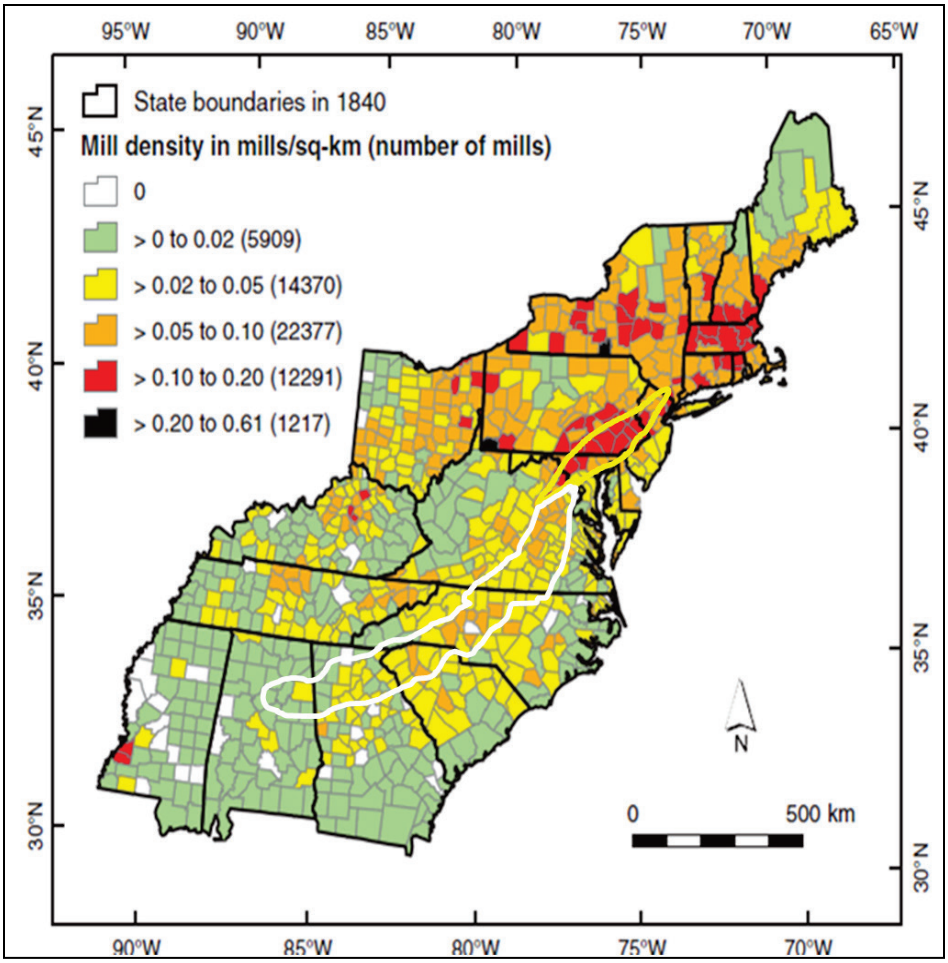


Figure 7. Stream and valley alterations expressed as physical and human factors depicted at trophic levels.

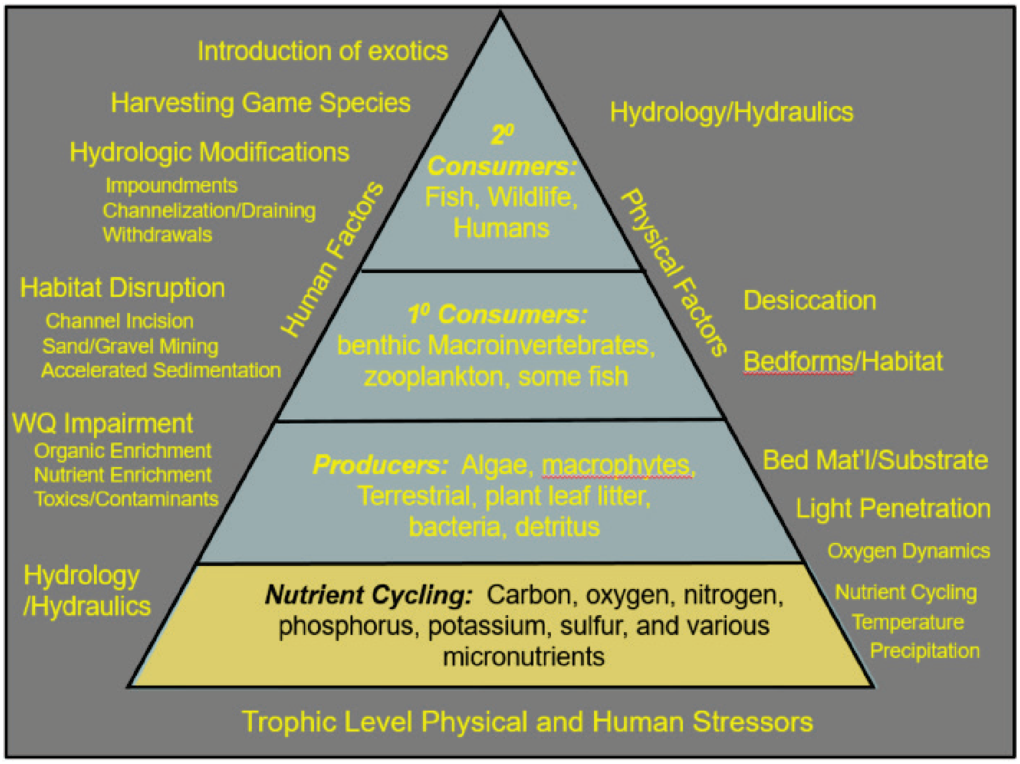


Table 3. Impacts to alluvial valleys in Piedmont riverine subclasses by type of alteration and the affected model variables.

| Alteration | Head-water | Mid-gradient | Low-gradient | Depression | Footslope seep | Affected Variables | Effects |
|---|---|---|---|---|---|---|---|
| Fill or excavation | ✓ | ✓ | ✓ | ✓ | ✓ | All Variables | Reduces wetland and floodplain area, changes hydrodynamics. |
| Stormwater discharge | ✓ | ✓ | ✓ | ✓ | ✓ | $V_{HYDROALT}$, $V_{LULC}$, $V_{INCISION}$, $V_{STORAGE}$, $V_{SOILQUAL}$ | Makes hydrograph flashier, deposits sediment and pollutants onto the floodplain, and increases the potential for incision/head-cutting, and subsequently causes shear stress, instability, and lateral migration of stream banks. |
| Channel incision | ✓ | ✓ | | ✓ | ✓[1] | $V_{HYDROALT}$, $V_{STORAGE}$, $V_{SOILQUAL}$, $V_{INVASIVE}$ | Reduces or completely eliminates hydrologic connection between channel and floodplain, lowers water table, reduces denitrification potential, eliminates sediment accumulation, and eventually changes species composition in channel and on floodplain. |

| Alteration | Head-water | Mid-gradient | Low-gradient | Depression | Footslope seep | Affected Variables | Effects |
|---|---|---|---|---|---|---|---|
| Farm ponds | ✓ | | | | | $V_{HYDROALT}$, $V_{STORAGE}$, $V_{SOILQUAL}$, $V_{FLOW}$, $V_{INVASIVE}$ | Eliminates wetland and wetland habitats, reduces down-gradient transport of water via evaporation. |
| Ditches | ✓ | | | ✓ | ✓ | All Variables | Eliminates wetland and wetland habitats, shunts pollution, sediment directly into stream. |
| Head-cutting | ✓ | ✓ | | | | $V_{HYDROALT}$, $V_{STORAGE}$, $V_{SOILQUAL}$, $V_{INVASIVE}$ | Causes channel incision (see above). |
| Invasive species | ✓ | ✓ | ✓ | ✓ | ✓ | $V_{HYDROALT}$, $V_{STORAGE}$, $V_{SOILQUAL}$, $V_{INVASIVE}$ | Reduces biodiversity by reducing habitat heterogeneity for animals, reduces native plant species populations, and may alter nutrient cycling. |
| Livestock | ✓ | ✓ | ✓ | ✓ | ✓ | $V_{HYDROALT}$, $V_{SOILQUAL}$, $V_{INVASIVE}$ | Causes bank erosion, water quality problems, soil compaction, change plant composition. |
| Silvicultural conversion | ✓ | | ✓ | | | $V_{BIG3}$, $V_{BIG3COMP}$, $V_{REGEN}$, $V_{CORE}$ | Changes species composition, reduces biodiversity, reduces detrital carbon pool. |

| Alteration | Head-water | Mid-gradient | Low-gradient | Depression | Footslope seep | Affected Variables | Effects |
|---|---|---|---|---|---|---|---|
| Dam (historic and extant) | ✓ | ✓ | ✓ | ✓ | | $V_{HYDROALT}$, $V_{LULC}$, $V_{INCISION}$, $V_{STORAGE}$, $V_{SOILQUAL}$ | Reduces sediment aggradation downstream, changes frequency, timing, and duration of overbank flow events, changes species composition on floodplain. |
| Surface mining | | | ✓ | | | $V_{HYDROALT}$, $V_{LULC}$, $V_{INCISION}$, $V_{STORAGE}$, $V_{SOILQUAL}$ | Creates knick point for incipient head-cutting, alters fish spawning habitat, raises stream temperature. |

### 2.7.2 Fill or excavation of floodplains and riparian zones

Fill is often associated with road construction across streams, conversion of headwater riparian zones to row-crop agriculture, and farm ponds. Excavations are usually associated with mining (see Surface mining, below). Fill and excavation reduce wetland area directly, converting wetlands to upland or open water, respectively. Fill associated with roads crossing floodplains also often restricts the flow of water down floodplains during flood events. Culverts under roads are often undersized, or their inverts are higher than wetland surfaces, causing ponding up-gradient (also see alterations by dams, below). Roadside ditches also shunt stormwater directly to floodplains and streams (see Stormwater discharge and ditches, below). Such road impacts are common in the Piedmont.

### 2.7.3 Stormwater discharge

Stormwater infrastructure is usually designed to route storm flows directly to the nearest streams. In many urban areas, this causes flashier hydrographs and incised stream channels (Hardison et al. 2009). Flashier hydrographs are due to water more quickly receding after flood events and to a reduction in baseflow, which limits the access of aquatic biota to floodplains and stream-channel habitats. Stormwater also deposits sediment and pollutants onto floodplains. In rural areas, most stormwater infrastructure is associated with road networks. The total length of roadside ditches in rural areas is often similar to the total length of natural headwater streams in a drainage network. However, there is a notable lack of published studies on the effects of road runoff on headwater streams and their wetlands, particularly for Piedmont drainages.

### 2.7.4 Channel incision

This is by far the most common alteration in Piedmont alluvial valleys. Incision radically changes the functioning of stream networks and their floodplains because it severs the hydrologic connection between the two (Table 4). As previously discussed, mass wasting in the southern Piedmont and sediment accumulation behind mill dams and subsequent dam breaching in the northern Piedmont, have left Piedmont stream channels (e.g., Mid-gradient) severely incised after the channels down-cut back to bedrock. Currently, many head-cuts have extended into the upper stream networks, even into headwater reaches at the top of watersheds (see Headcut section below). Subsequent deposition (aggradation) generally occurs in downstream reaches.

Valley bottoms that now occur on top of sediments deposited behind former reservoirs that were inundated during the Anthropocene. These valley bottoms are referred to as "fill terraces" by Walter and Merritts (2008) because they were never relic floodplains. The colluvial material is finer than the material that once occurred on relic floodplains and is frequently stratified in the soil profile, a result of episodic sedimentation. Fill terraces of former mill dams occur throughout the Piedmont but are much more common in the Northern Piedmont.

Incised channels behave like channelized streams in that channels are hydrologically disconnected from their floodplains (O'Driscoll et al. 2009 et al. 2010). This hydrologic de-coupling affects floodplain wetland functions, such as nutrient cycling, carbon export, and transformation of elements. However, the nitrogen cycle is one of the most altered functions; the reduction of floodwaters results in reduced denitrification potential in floodplains (Harnsberger and O'Driscoll 2010).

Although Mid-gradient reaches are now much more disconnected from their relic floodplains and fill terraces than they were before incision began, they still flood during infrequent, high flow events. Thus, even in their current, hydrologic altered state, some reaches provide a flood storage function, although at a much-reduced magnitude than they did historically (because the duration of storage is much reduced) (Table 4).

Table 4. Differences in hydrologic functioning of streams and associated floodplains, (i.e., fill terraces) under various flow regimes between incised and natural channels.

| Conditions | Incised | Natural |
|---|---|---|
| A. Baseflow | 1. Water table deep in floodplain.<br>2. Often no or few toeslope seeps.<br>3. Secondary channel, if present, dry near surface. | 1. Shallow water table in floodplain.<br>2. Toeslope seeps prevalent.<br>3. Secondary (overflow channel) saturated to surface. |
| B. High flow | 1. Water contained in main channel.<br>2. Water table in floodplain is shallow, but soil not saturated to surface. | 1. Water flows in overflow channels.<br>2. Floodplain saturated to surface and inundated in lowest spots. |
| C. Very high flow | 1. Floodplain inundated.<br>2. Flood duration short, water returns to channel quickly as stage quickly drops.<br>3. Very high flow may be a frequent event (3-4/year)[1], but low duration (flashy). | 1. Floodplain inundated.<br>2. Flood duration long, water returns to channel slowly as stage slowly drops.<br>3. Very high flows are an infrequent event (1-year return interval), but long-lived. |
| D. Historic flood event | 1. Floodplain inundated.<br>2. Flood duration moderately long, floodplain storage help ameliorate flooding of infrastructure. | 1. Floodplain deeply inundated.<br>2. Flood duration long, floodplain storage help ameliorate flooding of infrastructure. |

[1] Particularly in urban settings where high frequency is due to high imperviousness within the watershed.

Mid-gradient channels now erode at their channel edges, sending sediment downstream during storm-driven pulses (Hupp et al. 2013; Noe and Hupp 2009). Low-gradient streams have too little stream power to erode channel sides (except during major storm events), but Mid-gradient streams do possess adequate energy. Consequently, Mid-gradient streams are in the slow geologic process of eroding sediment from channel walls and sending the sediment downstream. The erosive process is particularly slow in forested relic floodplains because trees stabilize channel banks and increase roughness.

Bankfull height (BFH) of pre-colonization era channels was probably very similar to channel-full height (CFH), [that is, a ratio of BFH/CFH close to 1:1, whereas Anthropocene channels have a ratio much lower, BFH/CFH ratio < 1.0]. BFH is the discharge and associated stage that has a recurrence interval of 1 to 2 years, which over time, shapes the channel the most (Dunne and Leopold 1978). CFH is the discharge and stage where incipient flooding of the valley occurs regardless of whether the valley is an active floodplain or not. BFH occurs within the channel of incised streams, consequently, below CFH. However, when BFH equals CFH, incipient flooding occurs on the valley flat, in which case, the valley is considered an active floodplain. See illustration associated with $V_{INCISION}$ on the field forms.

### 2.7.5 Farm ponds

Many wetlands in the most-headwater extent of stream networks have been dammed or excavated to construct farm ponds, primarily to provide water for cattle, but also for recreational fishing. Headwater locations were ideal for small ponds because they tapped a reliable source of groundwater usually at springheads. Thus, many headwater wetlands, which occur at this geomorphic position on the landscape, may be rare on private land in the Piedmont.

### 2.7.6 Ditches

During the Colonial period, ditches were commonly dug along the footslope (toe ditch), primarily to intercept groundwater expressed at seeps and redirect surface water down gradient. This was done to expand arable land in the floodplain bottoms. Some historic ditches are still visible. The old ditches sometimes hold groundwater if they are blocked or filled down gradient.

Today, recently created ditches are not particularly common in Piedmont bottoms but do occur in all subclasses. Low- to Mid-gradient floodplains are usually too well drained for floodplain ditches to be effective in removing surface and ground water. Consequently, ditches mostly drain headwater reaches. In contrast, in all riverine subclasses, road ditches intercept subsurface interflow, short-circuit delayed flow, and route flow and associated sediment and pollutants rapidly down valley to the nearest stream crossing. Although road ditches generally do not cross wetlands, they are a common alteration to riverine alluvial valleys.

### 2.7.7 Head-cutting

A head-cut is the process of a stream bed degrading up-gradient from a knickpoint in response to base level control. The knickpoint migrates upstream during periods of high flow, causing channel incision. They occur at the most up-gradient point of an incised channel, both within main channels and within side channels. At the knickpoint, where active head-cutting is occurring, there is a steep elevation drop-off in the channel. Head-cuts are most common in the Headwater subclass and rare in Mid-gradient reaches, except where tributaries cross floodplains. Head-cutting has already occurred in almost all Mid-gradient reaches, resulting in the subsequent incision of channels seen today.

### 2.7.8 Invasive species

All wetlands may potentially harbor invasive species (Miller 2003). The presence of these often indicate past alterations or stress (e.g., past vegetation clearing, changes in nutrient availability) (Alpert et al. 2000). Non-native, invasive plant species, when prevalent, reduce space for native plant species and reduce heterogeneity of habitats for animal species. The fruits of some invasive species are eaten by birds (e.g., berries of privet). However, some invasive plant species are allelopathic (i.e., they produce chemicals that prevent other plants from growing near them). There is also evidence that invasive species alter nutrient cycles (Zedler and Kercher 2004), but more research is needed in this area.

There are few persistent invasive canopy tree species in Piedmont riverine reaches. However, shrubs, vines, and grasses are more commonly problematic (Table 5). Of particular concern are Russian olive (*Elaeagnus angustifolia*), privet, multiflora rose, barberry, Japanese honeysuckle, Oriental bittersweet (*Celastrus orbiculatus*), and Nepalese browntop (*Microstegium vimineum*) (Table 5). *Microstegium* is especially abundant in Piedmont valley flats and is suspected to be allelopathic.

Table 5. The most common non-native, invasive plant species inhabiting Piedmont alluvial valleys or riverine wetlands identified during fieldwork (for additional invasive species, see https://www.invasivespeciesinfo.gov/).

| Species[1] | Southern Piedmont | Northern Piedmont | Common name | Form |
|---|---|---|---|---|
| *Ajuga repens* | ✓ | | Blue bugle | Herb |
| *Euonymus fortunei* | ✓ | | Spindle vine | Vine |
| *Polygonum convolvulus* | ✓ | | Wild buckwheat | Herb |
| *Poncirus trifoliata* | ✓ | | Hardy orange | Shrub |
| *Elaeagnus angustifolia* | ✓ | ✓ | Russian olive | Shrub |
| *Ligustrum sinense* | ✓ | ✓ | Chinese Privet | Shrub |
| *Lonicera japonica* | ✓ | ✓ | Japanese honeysuckle | Vine/Herb |
| *Lonicera morrowii* | ✓ | ✓ | Bush honeysuckle | Shrub |
| *Rosa multiflora* | ✓ | ✓ | Multiflora rose | Shrub |
| *Microstegium vimineum* | ✓ | ✓ | Nepalese browntop | Herb |
| *Ambrosia artemisiifolia* | | ✓ | Common ragweed | Herb |
| *Berberis thunbergii* | | ✓ | Japanese barberry | Shrub |
| *Celastrus orbiculatus* | | ✓ | Oriental bittersweet | Vine |

[1]All species can occur in Piedmont Riverine classes.

#### 2.7.9 Livestock

Livestock potentially access all Piedmont subclasses. They can erode banks, alter the composition of vegetation through differential grazing pressure, compact soils, and cause a variety of water quality problems (DeSteven and Lowrance 2011; Morris and Reich 2013). However, at least one study suggests that the removal of grazing pressure detrimentally affects bog turtle populations by allowing shrubs to reestablish (Tesauro and Ehrenfeld 2007).

#### 2.7.10 Silvicultural conversion

Industrial silviculture is not especially common in Piedmont bottoms. However, all Piedmont subclasses are potentially affected where it does occur. Slash pine (*Pinus elliottii*) and loblolly pine (*P. taeda*) are the most managed species. Obviously, pine monoculture changes canopy composition, but understory composition is detrimentally affected as well, due to soil preparation before planting, reduced light in the understory, active mechanical and chemical understory management, and production of acidic litterfall by pines. Active management also prevents large down wood from accumulating, which in turn affects long-term nutrient cycling and carbon sequestration in soils.

### 2.7.11 Dams (historic and extant)

Smaller, headwater streams are often impounded to create small ponds for agricultural, recreational, and residential uses. In addition to small ponds, there has also been a proliferation of large to medium-sized reservoirs in the Piedmont, constructed to store drinking water and generate power. Dams not only inundate floodplains and stream channels; they also generally cause a shift in plant community composition and probably alter amphibian animal communities as well. In addition, they create habitat conditions for fringe wetlands at their edges and in the deltaic benches where creeks enter reservoirs. Because most reservoir levels are actively managed, fringe wetlands shift laterally over time, sometimes over great distances, depending on shoreline gradients and how rapidly water is released. This guidebook does not address fringing wetlands of reservoirs because they are so variable, ephemeral, and regulated by various state and federal agencies, but it does address the effects of dams on downstream flow and altered rates of sedimentation downstream. The effects of historic, breached dams on current channel incision in Piedmont streams was addressed above.

### 2.7.12 Surface mining

Sand and gravel are mined from Piedmont floodplains primarily for road and building construction (Meador and Layher 1998). Surface mines primarily occur in channels and floodplains of the Low-gradient subclass. Gravel mining increases sediment loads and turbidity in streams, destabilizes channels by creating knickpoints that then migrate upstream and into tributaries (head-cutting), altering pebble size distributions required for fish spawning, eliminating riparian habitat, increasing stream temperature, and traps organic material (Kondolf 1993, 1997; Brown et al. 1998). Head-cutting may result in reducing flood frequency onto adjacent alluvial wetlands.

Impacts from mining activities extend both up and downstream from the actual area of extraction. Even mining in floodplains can eventually impact adjacent streams if the mined area is captured by the lateral migration of the channel.

# 3 Wetland Variables, Subindex Curves, Functions, and Assessment Models

## 3.1 Reference data

In this chapter, reference data collected for each model variable is summarized by subclass. Likewise, for each discussed variable, functional capacity sub-index curves are provided by wetland subclass. When a variable's reference data for two or more subclasses did not vary, they were combined and summarized to produce a single subindex curve for all subclasses. The subindex curves were based primarily on field data; however, some variables relied on physical traits (e.g., proportion of catchment size) or were derived from the scientific literature (e.g., available core habitat).

## 3.2 Variables

The following 12 model variables are used to estimate the functional capacity of alluvial valley wetlands assessed in the Piedmont of the southeastern US.

- Site Hydrologic Alterations ($V_{HYDROALT}$)
- Change in Catchment Area ($V_{CATCH}$)
- Catchment Land use/Landcover ($V_{LULC}$)
- Channel Incision ($V_{INCISION}$)
- Dam Effect ($V_{FLOW}$)
- Surface Water Storage ($V_{STORAGE}$)
- Soil Quality ($V_{SOILQUAL}$)
- Basal Area of Largest Trees ($V_{BIG3}$)
- Canopy Tree Composition ($V_{BIG3COMP}$)
- Invasive Plant Species ($V_{INVASIVE}$)
- Regeneration Potential ($V_{REGEN}$)
- Available Core Habitat ($V_{CORE}$)

Each variable is defined and then the rationale for its selection is discussed in the subsequent paragraphs. The relationship of each variable to functional capacity is also provided, based on reference data collected in the reference domain. The scaling of each variable can be found in this Chapter and procedures for measuring each variable in the field can be found in Chapter 4. Certain variables are applicable to all five subclasses; others are only applicable to a subset of the subclasses (Table 6).

Table 6. Applicability of assessment variables, by Riverine subclass, of Piedmont alluvial valleys. Variables used in an assessment model of a subclass are indicated by "✓." Biogeochemistry (BGC).

| Variable | Headwater Riverine | | | | Mid-gradient Riverine | | | | Low-gradient Riverine | | | | Riverine Depression | | | | Footslope Seep | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hydro | BGC | Plant | Animal | Hydro | BGC | Plant | Animal | Hydro | BGC | Plant | Animal | Hydro | BGC | Plant | Animal | Hydro | BGC | Plant | Animal |
| $V_{HYDROALT}$ | ✓ | | | | ✓ | | | | ✓ | | | | ✓ | | | | ✓ | | | |
| $V_{CATCH}$ | ✓ | | | | | | | | | | | | | | | | ✓[4] | | | |
| $V_{LULC}$ | ✓ | | | | | | | | | | | | | | | | ✓[4] | | | |
| $V_{INCISION}$ | | | | | ✓ | | | | ✓ | | | | ✓ | | | | ✓[3] | | | |
| $V_{FLOW}$ | ✓ | | | | ✓ | | | | ✓ | | | | ✓ | | | | | | | |
| $V_{STORAGE}$ | | | | | | | | | | | | | ✓ | | | | | | | |
| FCI Hydro[1] | | ✓ | ✓ | | | ✓ | ✓ | | | ✓ | ✓ | | | ✓ | ✓ | | | ✓ | ✓ | |
| FCI Plant[2] | | | | ✓ | | | | ✓ | | | | ✓ | | | | ✓ | | | | ✓ |
| $V_{SOILQUAL}$ | | ✓ | | | | ✓ | | | | ✓ | | | | ✓ | | | | ✓ | | |
| $V_{BIG3}$ | ✓ | ✓ | ✓ | | | ✓ | ✓ | | | ✓ | ✓ | | | ✓ | ✓ | | ✓ | ✓ | ✓ | |
| $V_{BIG3COMP}$ | ✓ | | ✓ | | | | ✓ | | | | ✓ | | | | ✓ | | | | ✓ | |
| $V_{INVASIVE}$ | ✓ | | ✓ | | | | ✓ | | | | ✓ | | | | ✓ | | | | ✓ | |
| $V_{REGEN}$ | | | ✓ | | | | ✓ | | | | ✓ | | | | ✓ | | | | ✓ | |
| $V_{CORE}$ | | | | ✓ | | | | ✓ | | | | ✓ | | | | ✓ | | | | ✓ |

[1]Use the Hydrology FCI for the subclass, which includes all the variables listed under Hydrology.

[2]Use the Plant Habitat FCI for the subclass, which includes all the variables listed under Plant Community.

[3]$V_{INCISION}$ only used for Footslope seeps on Mid-gradient floodplains.

[4]$V_{CATCH}$ and $V_{LULC}$ are used only for Footslope seep subclasses that occur in Headwaters.

### 3.2.1 Site Hydrologic Alterations ($V_{HYDROALT}$)

This variable is defined as anthropogenic alterations to the natural hydrology of a wetland due to activities *within* the wetland assessment area. These on-site alterations include ditches, road crossings and placement of other fill material, excavations, mining, water diversion, and constructed levees. The intent of this variable is to capture impacts that prevent, retard, or accelerate the natural movement of water in and out of an alluvial valley. This variable differs from $V_{CATCH}$ and $V_{LULC}$ in that the impacts occur *within* a WAA, rather than in an up-gradient catchment or watershed. The $V_{HYDROALT}$ variable is only applied to the hydrologic function.

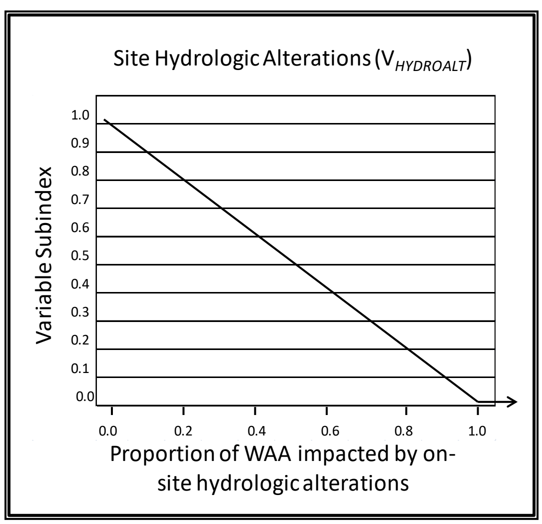
The hydrologic regime of unaltered headwater floodplains and footslope seeps are dominated by groundwater. In hydrologic unaltered sites, the entire floodplain is sometimes inundated across the valley flat from footslope to footslope, but only during major storm events and only briefly. Inundation persists for longer periods in small depressions in late winter and early spring, and after summer storm events.

Within the Riverine subclasses, on-site alterations ranged from complete isolation of the WAA from the adjacent stream channel to ineffective floodplain ditching or partial obstruction of floodwaters. Wetlands associated with unaltered Mid-gradient and Low-gradient riverine streams are flooded by surface flow from adjacent streams during overbank flood events. The duration of flooding generally increases with watershed size, with the longest events occurring mainly in late winter and early spring. The frequency and duration of inundation also depends on a site's position within its floodplain. The highest elevation features, such as natural levees are flooded least frequently, and for only short periods during the most extreme hydrologic events. The lowest features, such as back swamps, sloughs, swales, and abandoned channel segments are often flooded multiple times per year. Inundation of these features typically persist long after floodwaters recede in adjacent channels, partly because their soils tend to be fine silts and clays, but also because drainage back to the stream channel is often impeded by higher elevations that are superimposed across them, thus blocking surface flow as the flood waters recedes. In addition, the contemporary predominant water source can be return flow at the footslope from hillslope hydrologic processes.

Draining, filling, excavating, and diverting water (i.e., alterations associated with $V_{HYDROALT}$) changes the natural hydrologic regime of all subclasses. However, only "alterations that capture surface water or intercept shallow groundwater and drain water off a site are considered active or "functional ditches" that alter natural hydrologic regimes. At sites exhibiting reference standard conditions (subindex = 1.0), there are no alterations to the natural hydrologic regime within a floodplain.

The proportion of the WAA affected by fill or excavation determines the subindex score, and so is a straightforward, 1:1 linear relationship with area affected by a change in water storage capacity (Figure 8). Determining the areal influence of drainage features or constructed levees is more problematic. First, one must be reasonably sure that the drainage feature or obstruction interferes with flow. Does the ditch lead to a down-gradient location (e.g., creek) or does the obstruction completely prevent drainage? If the feature interferes with flow, then the area drained or the area affected by blockage of flow should be determined and the proportion of that area relative to the WAA calculated. Likewise, the same determinations should be used for predicting the effects that a project will have on a WAA (i.e., determine the area over which the effect is expected relative to the total area of the WAA).

Figure 8. Relationship between on-site hydrologic area of impact and subindex score.




In the headwater subclass, major channel incision is not pervasive, but sometimes a head-cut originating downstream incises a channel, causing it to lower the water table on the floodplain, creating an effect like that of an incision. This is especially prevalent in urban and suburban headwater stream bottoms. Thus, for the Headwater subclass only, the effect of channel incision should be evaluated as part of the $V_{HYDROALT}$ variable and treated like a ditch. In contrast, channel incision is so pervasive in the Mid-gradient subclass, that degree of channel incision is an independent variable and not evaluated as part of $V_{HYDROALT}$.

### 3.2.2 Change in catchment area ($V_{CATCH}$)

This variable is defined as the proportional change around a WAA catchment, watershed, or basin that results from diversions of water into or away from the catchment (i.e., interbasin transfer). Ditches, berms, etc. can either bring more water to a site or divert water away from a site. Roadside and footslope diversion ditches are the most-common alterations described by this variable.

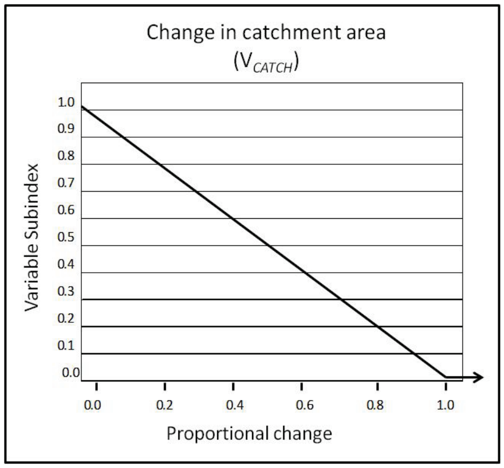
The purpose of this variable is to express the change affecting the amount of water delivered to a wetland due to alterations to a watershed that either reduce or augment subsurface (groundwater) or surface input. $V_{CATCH}$ applies to the hydrology function only in the subclasses headwater riverine and footslope seep (in headwaters only), both of which have relatively small catchments.

The $V_{CATCH}$ variable is calculated by determining the proportional change in catchment area resulting from diversions of groundwater and surface water to or from the wetland being assessed. This is obtained by identifying diversions to and from the catchment area and subtracting the absolute value of the existing catchment area from the natural catchment area, dividing the value by natural catchment area, and subtracting that value from 1.0:

$$\text{Catchment Change} = 1 - \left( \frac{|Natural\ catchment\ area - existing\ catchment\ area\ |}{Natural\ catchment\ area} \right), \quad (1)$$

where natural catchment area is the size of the catchment before it was diverted, and the existing catchment area is its present area or predicted area after project completion (either altered or restored). By using the absolute value of the difference between natural and present/future area, both augmentation and reduction of the delivery of water are modeled as being equally detrimental to hydrologic alteration (Figure 9).

Figure 9. Relationship between the effective area of a WAA's catchment and the variable subindex score.




For example, if the natural catchment area is 100 hectares and an area equal to 10 hectares is diverted into the effective catchment area from an adjacent catchment area, the proportional change would be 1-( |100-110 |/100 = 1-(10/100) = 0.9). If the effective area of the catchment is unchanged (i.e., no water diversions), then the subindex score is by convention, 1.0. For reference standard sites, it is assumed that the area of their catchments is natural (i.e., both natural and present area are the same). The relationship between functional capacity and the percent change in catchment area is assumed to decline linearly to 0.0 9that is, when water to the entire basin is diverted [catchment area equals zero] or the catchment area is doubled). This relationship assumes that, as the effective size of the catchment decreases or increases, the amount of water leaving or entering the wetland is proportionately changed and is either not available to the wetland or is available to the wetland in too large a volume.

### 3.2.3 Catchment land use/land cover ($V_{LULC}$)

This variable is defined as the potential surface water runoff of a catchment of a WAA resulting from the conversion of forest cover to other land use/land cover categories. Forests have the highest interception potential (lowest runoff potential) of any land cover category, due to their ability to: (1) intercept and absorb the energy of falling rain, (2) capture and store rainfall in the canopy, (3) release water into the atmosphere through evapotranspiration (ET), and (4) provide conditions in leaf litter and soils that encourage rainwater absorption and infiltration. Under optimal conditions during the growing season and in full leaf-out, approximately 78% of total rainfall within a catchment is returned to the atmosphere via ET (Leopold et al. 1964).

Other land uses have lower interception potential and encourage a rapid release of surface water down gradient, causing intercepting streams to become flashier. Thus, the volume and rate of surface water delivery and infiltration in the WAA's catchment will vary, depending on the infiltration and ET potential of the various land uses in the catchment and the area covered by each land use. For example, impervious surfaces (urban land covers) provide very flashy surface water flow down gradient during storm events and immediately following rain events; consequently, the variable is assigned a runoff potential of 0.1.* Pastures, lawns, and golf courses allow for infiltration, but also are areas of reduced ET and more rapid surface runoff than forests during storms. Likewise, agricultural lands have lower ET than forests and provide a flashier delivery of water downslope because most farm management activities are designed to drain water rapidly, usually to the nearest stream.

The $V_{LULC}$ variable is used to indicate the relative infiltration/ET potential of a catchment, based on the relative ability of various land uses to intercept rainwater. The $V_{LULC}$ variable differs from the $V_{CATCH}$ variable (above) in that $V_{LULC}$ is an indicator of *indirect* consequences of water delivery caused by land use changes rather than direct effects caused by water diversion or augmentation, (i.e., it indicates the change in water input due to changes in the amount of ET and infiltration potential, based on the effects of land cover). The area evaluated for $V_{LULC}$ is the same area as that evaluated for $V_{CATCH}$ (i.e., the WAA's catchment). Like $V_{CATCH}$, $V_{LULC}$ only applies to the hydrology function of Headwater Riverine and Footslope Seep subclasses, which both tend to have relatively small watersheds.

The $V_{LULC}$ variable metric uses weighted land use categories based on Anderson coverage categories (Anderson et al. 1976) times the proportion of catchment area covered by each coverage category. Five infiltration/ET potential categories are used in this guidebook (weighting in parentheses): (1) Forest, water, wetlands (1.0), (2) grasslands and shrub lands, including golf courses, ball fields, and pastures (0.8), (3) agricultural lands and nurseries (0.3), (4) bare, (i.e., non-vegetated) lands (0.2),

* Although, stormwater basins are now the BMPs for new construction, most cities still manage older infrastructure by attempting to route stormwater into streams as quickly as possible via outfalls.

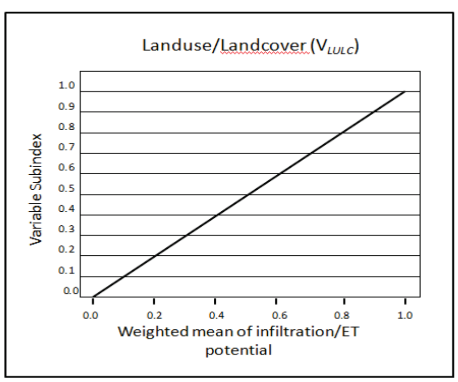
Urban/suburban, buildings, parking lots (0.1) (Table 7). Urban land use was not assigned a zero weight because some stormwater BMPs are likely applied, especially in newer developments. Because catchments of those subclasses are so small in extent, in many cases, especially for seeps, one can estimate the proportion of coverage in the field or from high resolution aerial photos.

Table 7. Infiltration potential for various $V_{LULC}$ categories in a hypothetical catchment.

| Landuse/Landcover cover category | Infiltration Potential | Area (example) | Score |
|---|---|---|---|
| Forest | 1.00 | 0.50 | 0.50 |
| Grassland/shrubland | 0.80 | 0.05 | 0.04 |
| Agriculture, nurseries | 0.30 | 0.40 | 0.12 |
| Bare ground | 0.20 | 0.00 | 0.00 |
| Impervious, urban | 0.10 | 0.05 | 0.01 |
| Subindex score ($V_{LULC}$) | | | 0.665 |

It is assumed that reference standard sites have completely forested catchments; thus, their weighted infiltration/ET potential, and by extension, their subindex scores would be 1.0, by convention (Figure 10). If land use is not fully forested in a catchment, then the proportion of each cover category is multiplied by its infiltration/ET potential and summed (Table 7). For example, if a catchment has 50% forest, 5% suburban, 40% agriculture, and 5% roads and parking lots (impervious), then $V_{LULC}$= [(1.0 * 0.5) + (0.8 * 0.05) + (0.3 * 0.4) + (0.1* 0.05)] = 0.66.

Figure 10. Relationship between a change in the surface water infiltration/ET potential and the variable subindex score.



## 3.3 Channel Incision ($V_{INCISION}$)

Degree of incision is defined as the ratio of bankfull height (BFH) divided by the channel-full height (CFH), (BFH/CFH)*. Degree of incision provides a ratio that can be converted to a subindex score. Under normal, unaltered conditions, floodplains are flooded (i.e., reach CFH height) once every 1.5 years on average, where BFH/CFH equals 1.0 (Leopold et al. 1964). In contrast, BFH/CFH is less than 1.0 in incised channels, where channel-full capacity is not exceeded, and surface water remains in the channel. Consequently, when BFH/CFH is less than 1.0, a storm event of higher magnitude (generally > 1.5 years recurrence interval) is required to flood the adjacent valley flat.

As discussed at length in earlier sections, channel incision is one of the most pervasive, persistent, and serious alterations to Piedmont floodplains and their associated wetlands. In this regard, Piedmont streams and associated floodplain ecosystems differ from most other regional wetland subclasses, which is why addressing channel incision is important in the Piedmont.

Channel incision and enlargement generally reduces overbank flooding, so even when flooding occurs, flood duration can be reduced. Incision also lowers the water table on the floodplain, reducing hillslope processes, such as return flow which is normally expressed in footslope seeps. Thus, both frequency and duration of flooding/soil saturation are affected by channel incision. See incision channel picture to the right on the guidebook title page.

Channel incision is an especially pervasive alteration in the Mid-gradient subclass, where the channel bed may occur several meters below the floodplain surface. In some cases, headwater reaches have been adversely affected by head-cutting, but to a lesser degree than downstream reaches. In addition, flooding via overbank flow does not normally occur in headwater systems because they are dominated by groundwater flows expressed in narrow valleys and steeper stream slopes. Bankfull indicators are more difficult to discern in headwater systems and channel incision is not measured there. Bankfull indicators are also difficult to discern in Low-gradient reaches, and such reaches are usually too deep to wade

* Channel-full height is the lowest elevation of the bank, where incipient flooding begins. See illustration associated with $V_{INCISION}$ in the field forms and spreadsheet calculator.

across safely to measure height above thalweg. For these reasons, only the Mid-gradient subclass incorporates the $V_{INCISION}$ variable (incision ratio) in its hydrologic models.

Indicators of bankfull can be observed during when stream stage is below bankfull stage and discharge. Bankfull stage is indicated by easily discernible indicators caused by erosive water flow. Indicators of bankfull include (but are not limited to) the following:

1. The top (highest elevation) of point bars
2. The elevation of the most prominent bench (Kilpatrick and Barnes 1964)
3. Surface elevation of benches along channel sides where there is an abrupt leveling in geomorphology in contrast to the steep channel side
4. Changes in soil or sediment structure or texture generally associated with a bench)
5. The presence of litter and debris, which may occur just above bankfull stage
6. Locations at elevations along channel banks below which plants do not grow or growth of terrestrial vegetation has been precluded or greatly reduced. In general, this indicator corresponds to the flat bench surface described in Number 3 above
7. The occurrence of "wrested vegetation," which is the clear line of demarcation between water flow and vegetation growth caused by the erosive movement of water that removes soil and debris, thus preventing growth of vegetation, especially herbaceous vegetation (GDNR 2017).

Bankfull elevations can be cross-referenced against one another because several indicators usually exist at every site. The practitioner is encouraged to identify several indicators at various longitudinal locations along the stream channel. If a local hydrologic gage is available, bankfull indicators can be used in combination with the gage data. Bankfull indicators can also be compared against regional hydraulic geometric curves. (Pruitt 2001).[*]

Most Mid-gradient streams are deeply incised. Even those in best condition have an incision ratio of 0.4–0.6. In this case, the best attainable condition is altered, but *in situ* recovery requires major erosion of

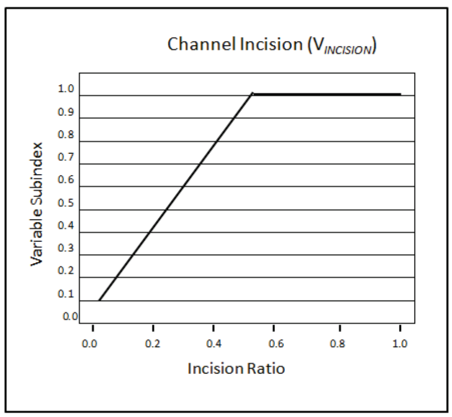
[*] https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/water/?cid=nrcs143_015052

floodplains over geologic time. A long natural recovery period is involved because many channels are now stabilized by forests.

Considering the current condition of Mid-gradient channels, standards for $V_{INCISION}$ are based on the best conditions occurring among our reference sites.

To determine $V_{INCISION}$, use the graph in Figure 11 or divide the calculated Incision ratio (IR) by 0.5. This conversion is performed because there are no Mid-gradient stream channels that have an IR of 1.0 (i.e., the best remaining reaches in the Piedmont are all deeply incised [IR = 0.5]). An example for calculating $V_{INCISION}$ is as follows: if BFH = 0.35 m, CFH = 1.4 m, the IR = 0.25, $V_{INCISION}$= IR/0.5 = 0.5. Note that IR cannot equal zero, and by extension, neither can $V_{INCISION}$.

Figure 11. Relationship between Channel Incision Ratio and the subindex score.




### 3.3.1 Dam Effect ($V_{FLOW}$)

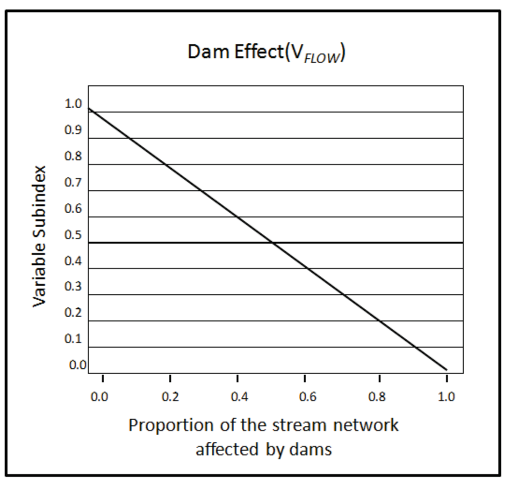
All subclasses except Footslope Seep use $V_{FLOW}$ in their models.

Dams are common in Piedmont streams, ranging from small farm ponds in headwaters, to low mill dams on Mid-gradient streams, to large structures constructed for water supply and/or recreation. The dams also provide power generation and flood control. Except for oxbows and beaver ponds, the Piedmont has no natural-occurring lakes, yet now has tens of thousands of artificial impoundments, and almost every major river has at least one large dam.

Dams can adversely affect hydrology and sediment input to floodplains downstream. Hydrologically, they reduce peak flows and maintain a base flow at a higher stage than is natural (the "damping" effect). Dams intercept and store sediment in their reservoirs and thus prevent sediment from reaching floodplains downstream. Commonly, the reaches downstream from dams are sediment starved, bedforms and aquatic habitat are not maintained, and channel incision occurs.

This variable assumes that dams in the sub-basins up-gradient from a WAA alter the WAA's natural hydrologic regime and sediment contributions from upstream. The value for $V_{FLOW}$ can be determined from the graph in Figure 12 or by determining the proportion of the WAA's stream network (or area of drainage basin) that occurs above the furthest downstream dams (no dams mean 100% undammed, index score = 1.0). Dams that adversely affect a WAA can occur in several sub-watersheds within the drainage network upstream of the WAA. In such cases, the sub watershed impacts are additive.

Figure 12. Relationship between effect of flow on upstream dams and variable subindex.




The WAA located on Cornish Creek at the Georgia Wildlife Federation, Covington, Georgia, is used as an example for how $V_{FLOW}$ can be calculated from proportion of stream network altered by dams (Figure 13, watersheds A, B, C). Using StreamStats, the watershed area influenced by a dam or several dams upstream of the WAA can be estimated as follows:

1. Go to

   https://water.usgs.gov/osw/streamstats/

2. Select *StreamStats Application*.

3. Enter location in Search Window by one of the following categories:
    a. Street Address, City, State
    b. County, State
    c. Zip Code
    d. Coordinates (Latitude 33.62287, Longitude: -83.80328 used in this example).
4. Determine if dam(s) occur in the watershed above the WAA. If not, $V_{FLOW}$ is not affected and equals 1.0 and do not continue this stepwise process. In this example, two impoundments were identified upstream, Cornish Creek Reservoir and Wallace Lake (Figure 11a).
    a. The presence of dams in a specific watershed can be identified in the National Inventory of Dams (NID database), from the State dam safety office, by inspecting aerial photographs or the Southeast Aquatic Resources Partnership (SARP) website at: https://www.southeastaquatics.net/news/new-sarp-southeast-aquatic-barrier-prioritization-tool-released-1
5. If dams are identified in the stream network upstream of the WAA, select *State*––in blue box (Georgia in this example).
6. Enable the *Delineation Tool* by zooming in to level 15 or greater.
7. Select *Delineate* in blue box.
8. Select streamline at the WAA (Figure 11a).
9. Once watershed is delineated in yellow, select *Continue*.
10. Select *Basin Characteristics*.
11. Under Select All Basin Characteristics, select DRNAREA (drainage area).
12. Pan down and select *Continue*.
13. Select *Basin Characteristics Report,* followed by *Continue*.
14. Record DRNAREA (27.7 square miles at the WAA in this example).
15. Report can either be printed out or saved as a pdf file.
16. Close report window and select *Identify a Study Area* followed by *"Clear Basin Area"* to delineate the sub watershed at the dam upstream of the WAA (repeat steps 5 through 14). In this example, the watershed above the Cornish Creek Reservoir dam was selected and equaled 24.7 sq mi (Figure 11*b*).
17. If additional dams occur in other sub-watersheds, repeat steps 5 through 14 above (see caveat in Step 18 below). In this example, the watershed above the Wallace Lake dam was selected and equaled 0.83 sq mi (Figure 11*c*).
18. If one or more dams are located up-gradient in any watershed already delineated, do not delineate the up-gradient sub-watershed (its dam

effect has been over-ridden by the most downstream dam in the sub-watershed).

19. Delineate the watershed area of the WAA.

*Error Message*: If you select a point to delineate the watershed and the error message, "No points were found at this location" is returned, clear the basin, select *Delineate* again, and adjust your curser location on the map.

$V_{FLOW}$ is calculated by:

$$V_{FLOW} = 1.0 - \frac{\sum A_1 \ldots A_n}{A_{WAA}}$$

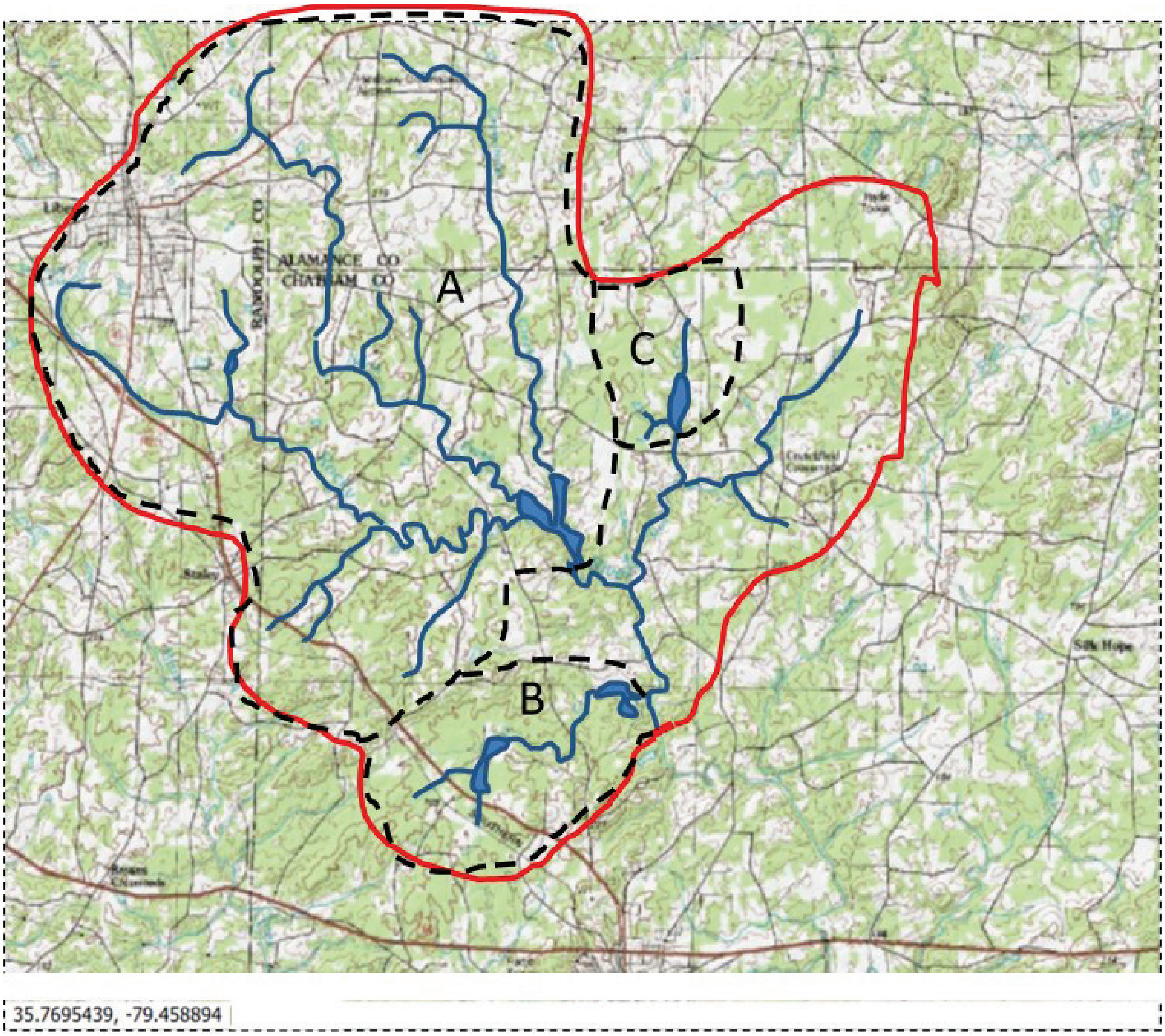
where

$A_1$ = Watershed area above dam 1 (e.g., 24.7 sq. mi.)
$A_n$ = Watershed area above additional dams (n) (e.g., 0.83 sq. mi.)
$A_{WAA}$ = Watershed area above the Wetland Assessment Area (e.g., 27.7 sq. mi.)

In the above example, $V_{FLOW}$ = 1.0–(24.7 + 0.83) / 27.7 = 0.08

Consequently, 92% of a WAA's stream network is above dams. We assume that 92% of its potential sediment load is prevented from reaching the WAA, and 92% of the watershed's hydrologic regime is controlled by the dam. Thus, the undammed reaches of the WAA's stream network are assumed to be the only reaches that influence flow regime and supply sediment to the WAA. Infrequent out-of-bank flood events in Cornish Creek adjacent to the WAA were confirmed based on continuous stage records over a 3-year period (Pruitt 2017). Note that the $V_{FLOW}$ variable can be zero, if the WAA is at the base of a dam, meaning that natural water flow and sediment input have been completely altered.

Figure 13. Comparison of a WAA stream network (enclosed by *red line*) and proportion affected by a dam (enclosed by *black dashed lines*). Dark blue lines show network with locations of reservoirs/dams (small tributaries are not shown for illustrative purposes). In this example, the watershed is affected by dams in three sub-basins: A (55% of the network), B (10% of network), and C (5% of network). There are two dams in sub-basins A and B, but only the most-downstream dams define the extent of impact in the sub-basin. In this example, $V_{FLOW}$=0.30 [100%−−(55% + 10% + 5%]. Location of hypothetical WAA: 35.7867, -79.4636.




### 3.3.2 Surface Water Storage ($V_{STORAGE}$)

Surface water inflow and outflow are important in maintaining the hydrologic regime of depressions. Most floodplain depressions are hydrologically connected to their streams' channels, except where stream stormflow discharge never or very seldom exceeds its banks. Hydrologically isolated floodplain depressions receive water solely from groundwater[*] and precipitation with loss occurring due to ET. However, most floodplain depressions also receive water from inlets connected with the stream during periods of high river levels. During periods of high stage, water flows from a mainstream channel through a smaller channel on its floodplain that connects to a depression. This channel functions to deliver water to a depression on its floodplain during high flows and drains it during low flows. The amount and rate of drainage depends on the height of the sill separating the inflow/outflow channel from the depression, and to a lesser extent, the rate of evaporation and rate of transpiration by vegetation growing in the depression.

Floodplain Depressions can be hydrologically altered in four ways by: (1) constructing a drainage ditch from the depression to the main channel if it does not already have an inlet/outlet, (2) lowering the sill between the depression and a natural channel if it does have a natural inlet/outlet, (3) connecting the depression with a stormwater channel from uplands (i.e., input from drained uplands) or otherwise diverting water to the depression, or (4) using pumps to mechanically remove water from the depression. All these alterations would affect the variable index score for $V_{STORAGE}$. The objective here is to use field measurements to approximate relative changes in storage capacity due to alterations to surface inflow and outflow, and by extrapolation, duration of water retention in Floodplain Depressions.

Surface Water Storage ($V_{STORAGE}$) addresses alterations to both surface inflow and surface outflow from a Floodplain Depression. The variable only measures human-caused changes to a depression's storage capacity by assessing changes to inflow and outflow parameters. A natural headcut is not addressed by this variable, even though human impacts downstream may have precipitated the headcut.

The variable score is determined several ways, depending on the type of alteration in surface water storage that has occurred, as listed above. For a depression that is drained by a ditch or an outlet that is lowered, an estimate is needed to estimate the proportional change in storage capacity of the depression due to draining. Usually, ditches are designed to completely drain a depression, by making the bottom of the ditch the same elevation as the bottom of the depression. Two elevations should be

[*] Groundwater probably provides little contribution to depressions on river floodplains where most input is via surface water and precipitation.

measured or estimated, based on work by Hyashi and van der Kamp (2000) and applied to vernal pools by Brooks and Hyashi (2002): (1) an estimate of the surface area of the depression at full capacity ($A_{max}$) and the maximum depth of the depression at full capacity ($D_{max}$), and (2) the altered depth ($D_{alt}$), after ditching or lowering of the outlet. Then volume (V) of the depression at any depth can be calculated using the following equation:

$$V = \frac{\mathrm{Amax} * \mathrm{Dmax}}{1+(\frac{2}{p})} x \left(\frac{\mathrm{Dalt}}{\mathrm{Dmax}}\right)^{(1+\frac{2}{p})} \qquad (2)$$

where $p$ is a constant based on the average basin profile.* Brooks and Hyashi determined that vernal pools in southern New England had a profile ($p$) ranging between 0.6 to 2.4, with a median of 1.02. Based on those results, it is reasonable to assume a profile ($p$) of 1.0 for floodplain depressions, unless $p$ is determined empirically.

Substituting 1 for $p$ in equation 2, gives the following equation for volume at any depth:

$$V = \frac{Amax * Dmax}{3} x \left(\frac{Dalt}{Dmax}\right)^{3} \qquad (3)$$

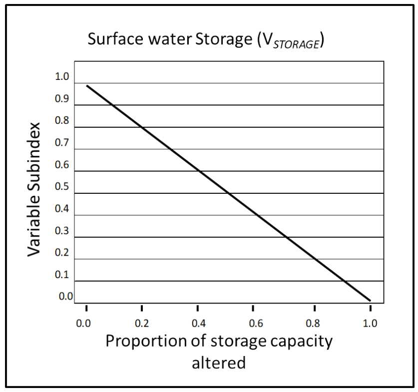
Maximum storage volume ($Vmax$) and altered storage volume ($Valt$) can then be calculated to determine the proportion of storage lost by lowering an outlet. For the unaltered condition, $Dalt = Dmax$. Otherwise, $Dalt <$ $Dmax$ and altered storage volume ($Vmax$) is less than the unaltered storage volume ($Vmax$).

Knowing the surface area and depth of the depression at full capacity and depth after alteration, one can determine the percent change in volume due to alteration, that is, altered volume/original (unaltered) volume. For example, a depression at full capacity that covers with 500 $m^2$ and a maximum depth of 1 m, has a volume of 167 $m^3$ ($Vmax$ = (500 × 1 .0)/3) × 1.0^3. If the outlet is lowered 0.5 m, the new maximum volume would be 21 $m^3$ ($Valt$ = (500 × 1.0)/3) × ((0.5/1) ^3). The change in storage capacity ($V_{STORAGE}$) would be 0.126 (i.e., $Valt/Vmax$ = 21/167). The relationship

* p=1 is an inverted cone, p<1 is convex, p>1 is a concave profile.

between altered storage capacity ($V_{STORAGE}$) and the subindex score is illustrated in Figure 14.

Figure 14. Relationship between the proportion of a depression's altered storage capacity and its subindex score.




Diverting water to a depression would not affect its maximum storage capacity, but it would affect the time over which the depression remains at full capacity and could affect its water quality. Increasing the duration of flooding could affect tree survival and rate of recruitment, since recruitment usually occurs during periods of drawdown. One could determine the percent increase in flooding duration caused by the input, but that could require long-term data collection and is not practical for a rapid assessment protocol. Therefore, depressions that receive an artificial input of water (a rare alteration) should receive a $V_{STORAGE}$ score of 0.5. The rationale is that water-dependent organisms can still use the depression and the supplemental water might partially compensate for a reduced frequency of flooding if the stream channel is incised.

For depressions where water is mechanically removed, one should estimate the altered average depth and apply the formula provided above. Otherwise, a $V_{STORAGE}$ of zero should be assigned.

### 3.3.3 Soil Quality ($V_{SOILQUAL}$)

The quality of soils is not only important in maintaining the earth's biosphere for production of food and fiber, but also in maintaining environmental quality at multiple spatial scales and ecosystem types. Soil quality in riverine wetlands is influenced by several physical, chemical, and biological attributes. The ability of wetland soils in riverine ecosystems to cycle nutrients and sequester metals and other elements and compounds imported to riverine wetlands from upland sources (and via overbank flooding) depends on the physiochemical and biological properties of soils, such as presence and amount of organic matter, moisture, living organisms (including microbes), and proportions of inorganic mineral matter (sand, silt, and clay) (Van der Valk et al. 1979; Lee et al. 1995; Klopatek 1978). In general, nutrients include macronutrients (e.g., nitrogen, phosphorus, potassium, sulfur) essential for plant growth and development. Excess nutrients (eutrophication) pollute waters and lead to algal blooms and anoxic (low oxygen) conditions that stress biota.

Riverine wetlands occur in geomorphic landscape positions that enable them to intercept elements and compounds originating from adjacent uplands before the elements reach streams, thus improving water quality of imported water (Brinson 1993a). Compounds such as synthetic organics (e.g., pesticides) that reach wetlands can be temporarily stored, sequestered, or in some cases, transformed to non-toxic forms in wetland ecosystems. Floodplains of headwater and low order streams are particularly well situated to remove such elements before they reach waterways. Floodplain wetlands of higher order streams also remove elements during overbank flood events (Mitsch et al. 1979). Most of this capacity to remove pollutants (and improve water quality) occurs in soils, and so soil quality is important to fully functioning riverine wetlands. Functioning hydric soils in wetland ecosystems enhance water quality in a number of ways: (1) by supporting soil microbes that conduct denitrify-cation, (2) by providing organic material that supplies energy needed by microbes to recycle nutrients and conduct denitrification, (3) by converting nutrients to forms that wetland plants can use to grow, (4) by removing and transforming synthetic organic compounds (e.g., pesticides), (5) by sequestering heavy metals and other pollutants, and (6) by temporarily storing groundwater and releasing it slowly to adjacent streams (i.e., delayed flow).

Footslope Seep wetlands that receive constant groundwater seepage during periods of normal rainfall are called “perennial seeps” and generally accumulate organic matter in the upper strata of their soils, in the “O” horizon, “A” horizon, or both. Seepage wetlands fed mostly by seasonal groundwater inputs are sometimes called “wet-weather seeps” because groundwater inputs are reduced during the dry portions of the year. Evapotranspiration removes groundwater at a rate that allows seeps to dry out, thus reducing discharge of water from seeps to streams.

Soil color, as a component of hydric soil identification, is a requirement of wetland determination at national and regional scales (Environmental Laboratory 1987, USACE 2012). This guidebook evaluates wetland soil quality by applying some of the factors used to identify hydric soils, such as soil color, organic content, and various redoximorphic features. This guidebook uses two categories of indicators to assess the $V_{SOILQUAL}$ variable: percent organic matter (OM) and redoximorphic features (Redox). We use Version 8.1 of the hydric soil's manual, entitled *Field Indicators of Hydric Soils of the United* States (US Department of Agriculture 2016), to identify hydric soil indicators (listed below). However, the listed hydric soil indicators are limited to indicators recognized for the Piedmont land resource region, depicted as "P" in Figure 6 of the hydric soil's manual. Indicators of organic matter accumulation are provided in the "All Soils" section of the hydric soil's manual, as follows:

| | |
|---|---|
| A1--Histosol | A6--Organic Bodies |
| A2--Histic Epipedon | A7--Mucky Mineral |
| A3--Black Histic | A9--1 cm Muck |
| A5--Stratified Layers | A12--Thick Dark Surface |

Even though sandy soils are uncommon in the Piedmont Physiographic Province, sandy soil indicators that result in an accumulation of organic carbon can be identified as follows (for Piedmont land resource region only): S1–Sandy Mucky Mineral and S7–Dark Surface.

Redoximorphic features (redox) form by oxidation-reduction reactions mediated by soil microbes in association with saturated and anaerobic (non-oxygenated) conditions (Vepraskas 1994; O'Donnell et al. 2010). Indicators of oxidation-reduction reactions are expressed in the form of redox features, including accumulations and depletions of iron and/or manganese (in the form of masses) on pore linings and ped faces. Formation and occurrence of redox features is evidence of soil saturation and anaerobiosis, nutrient cycling, macronutrient availability and uptake by wetland plants, metal sequestration and removal, and sometimes, the transformation of synthetic organics and denitrification.

Presence of redox features are provided in the "All Soils," "Sandy Soils," and "Loamy and Clayey Soils" section, as follows (for Piedmont land resource region only):

- A5––Hydrogen Sulfide
- S4––Sandy Gleyed Matrix
- S5––Sandy Redox
- S6––Stripped Matrix
- F1––Loamy Mucky Mineral
- F2––Loamy Gleyed Matrix
- F3––Depleted Matrix
- F6––Redox Dark Surface
- F7––Depleted Dark Surface
- F8––Redox Depressions
- F12––Iron-Manganese Masses
- F13––Umbric Surface

Hydrologic modifications result in changes in saturation and/or inundation (ponding or flooding) which may change the hydric status of a soil. Ditching may or may not be “functional” in removing surface and/or ground water from the WAA. Overestimating the effect of ditches and other drainage attempts is possible (Technical Note 13, Altered Hydric Soils, Deliberations of the National Technical Committee for Hydric Soils). It is at the discretion of the end user of this guidebook to determine if the WAA has been artificially drained by “functioning” ditches, levees, dams, or pumps, and whether relict soil features are present. Indicators of relict hydric soils are discussed by Vepraskas (1994).

For the purposes of this guidebook, the $V_{SOILQUAL}$ variable incorporates the proportion of sampled soils containing organic matter and redoximorphic features. To determine proportion, an adequate number of soil observation pits should be advanced to a depth as recommended in the hydric soils manual, usually 16 in. An adequately number of unlined holes should be advanced that are representative of the WAA’s heterogeneity of soil conditions. The presence of redox features in a soil sample is scored as present (1.0) or absent (0.1) for each soil sample (pit). Then the sum of the scores is divided by the number of pits sampled proportion) to provide a “Redox” subindex score that is inserted into the equation below. For organic indicators, each soil sample is identified as either having organic indicators (1.0) or not (0.0). Then the sum of its scores is divided by the number of pits sampled. The organic matter variable is then rescaled (indexed) based on data from Piedmont reference sites. For the Soil Quality variable ($V_{SOILQUAL}$), a subindex of 1.0 is assigned when the presence of organic matter and redox features spatially covers 60% or more of the WAA (Table 8). Below 60% coverage, a linearly decreasing subindex (to 0%) is assigned. If a soil sample cannot be obtained from a site in a Floodplain Depression subclass, due to water depth during periods with normal or below normal rainfall, then the subindex score for soil quality is assumed to be 1.0.

Table 8. Determination of organic matter (OM) and Redox subindices, based on proportion of soil samples in WAA that have these conditions.

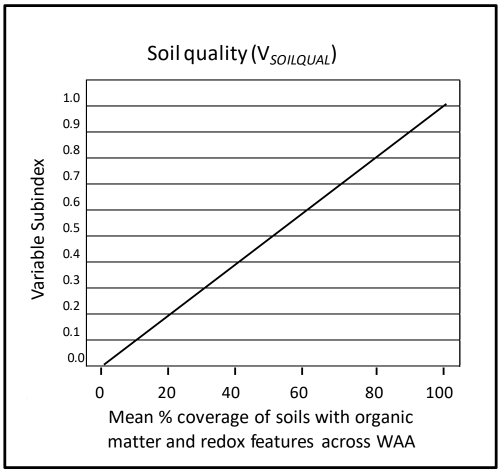
| Organic matter (OM) & redoximorphic features (Redox) | |
|---|---|
| Proportion (%) of Samples | Subindex |
| 0-10 | 0.0 |
| 11-15 | 0.1 |
| 16-20 | 0.2 |
| 21-25 | 0.3 |
| 26-30 | 0.4 |
| 31-35 | 0.5 |
| 36-40 | 0.6 |
| 41-45 | 0.7 |
| 46-50 | 0.8 |
| 51-60 | 0.9 |
| 61-100 | 1.0 |

The proportions of organic matter (OM) and redoximorphic features (Redox) of soil samples are added in the equation below and then averaged to calculate $V_{SOILQUAL}$, as follows:

$$V_{SOILQUAL} = (OM + Redox)/2$$

This $V_{SOILQUAL}$ score (mean of OM and Redox) for soil quality is a positive linear relationship between zero and 1.0 (Figure 15).

Figure 15. Relationship between soil quality and the subindex score.




### 3.3.4 Basal Area of Largest Trees ($V_{BIG3}$)

This variable is defined as the mean basal area ($m^2/ha$) of the three largest trees measured in 10 m radius circular plots. Basal area is defined as cross-sectional area, based on tree diameter at breast height (DBH), where breast height is 1.4 meters above ground. In forest ecology, basal area is a common surrogate for canopy cover. Tree size is an indicator of forest maturity (Brower and Zar 1984; DeGraaf et al. 1993) and in most cases, structural complexity (Hunter 1990). Therefore, basal area of the largest trees can be used as a surrogate for age and maturity of a forest stand (Bonham 1989; Spurr and Barnes 1981; Tritton and Hornbeck 1982; Whittaker 1975; Whittaker et al. 1974).

Structural complexity has been shown to be a predictor of tree diversity (Hakkenberg et al. 2016) in the North Carolina Piedmont. Older forests dominated by large trees typically support several distinct strata, including tree canopy, midstory, woody understory (composed of saplings and shrubs), and herbaceous or ground stratum. Young forests composed of sapling to pole-sized trees tend to be less stratified. Forested wetlands dominated by large trees provide more available habitat than forests dominated by smaller trees. For example, large trees are more likely to develop natural cavities or have cavities hollowed out by cavity excavators. Cavities provide shelter and nesting sites for gray squirrels, red-bellied woodpeckers, wood ducks, snakes, bear (very large trees), and many other species. In forests populated by oaks, age is an important factor in acorn production. Although there is considerable variation among oak species, most oaks do not begin producing acorns until they are at least 25 cm (10 in.) DBH (US Forest Service 1980).

In eastern deciduous forests, mature canopy trees are typically >15 cm DBH, but most mature forests are populated by trees >30 cm DBH. Therefore, in collecting reference data, mature trees are defined as trees at least 15 cm DBH. Forests dominated by trees at this threshold size represent the youngest, least mature end of the mature forest spectrum. Therefore, by definition, forests dominated by trees smaller than 15-cm DBH represent immature/successional forests.

The $V_{BIG3}$ variable is a mega variable that represents stand age/maturity, stand biomass, three-dimensional forest structure, volume of large down wood (LDW), snag biomass, and organic matter present in soil and on the forest floor (all of which take time to develop). The rationale for using large trees as a mega variable is that stand age/maturity, which represents a forest's development along a successional trajectory toward climax, representing the extent of ecological functioning along a successional continuum. That is, higher values for $V_{BIG3}$ represents more mature forests with higher biodiversity (and thus higher functioning), whereas lower values represent younger, successional forest (and thus lower functioning). Lack of forest (no trees) represents a very low level of ecological functioning. Data from reference sites showed significantly positive correlations between mean basal area of Big3 trees and stand basal area for all mature canopy trees (defined as stems >15-cm-dia DBH), litter cover, frequency of LDW, and snag density, thus supporting the assumption that the $V_{BIG3}$ variable represents degree of forest maturity and structural complexity, all of which are related to biodiversity.*

In reference wetlands in the Piedmont alluvial valley, mean basal area of the three largest canopy trees ranged from ranged from 13 $m^2$/ha in the Headwater subclass to 21 $m^2$/ha in the Mid-gradient riverine subclass. Therefore, in reference standard sites, a different variable subindex for 1.0 should be assigned to each subclass.

To calculate $V_{BIG3}$, measure the DBH of the largest three trees in a 10 m radius plot (regardless of size) and calculate mean basal area (see steps below). If you are in a forest with *very* large trees, trees that are so large that fewer than three large trees occur in a 10 m radius plot, then increase the number of plots and average data for each plot based on fewer than

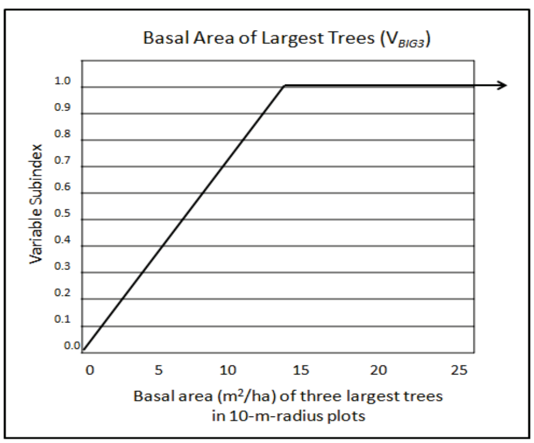
* A stand of small trees, or no trees, indicate low ecological functioning.

three trees (e.g., measure the largest two trees) so that you have at least 9 trees on which to base the $V_{BIG3}$ metric.

To calculate $V_{BIG3}$, follow the steps below.

1. Measure the DBH (cm) *and identify to species* the three largest trees in each sampled 10 m-radius plot (or larger plot if three large trees do not fit into a 10 m radius plot). A DBH tape, Biltmore stick, or tree calipers can be used to measure DBH.
2. Determine the basal area (in $m^2$/ha)* of each tree using the formula: BA = ∏*$r^2$/ (plot size in $m^2$), where r= ½ DBH (diameter in cm). (The plot size of a 10 m radius plot is 314.16 $m^2$.) This calculation provides $m^2$ (tree cross-sectional area)/ha.
3. Sum the total basal area for all trees from Step 2 and divide by the number of plots sampled. The relationship between canopy tree basal area and its subindex score is-assumed to be linear; thus, the subindex increases linearly from zero to 1.0 (Figure 16). If the resulting value is greater than 1.0, reduce the value to 1.0). $V_{BIG3}$ Reference Standards vary by subclass: Headwater (13 $m^2$/ha), Mid-gradient (21 $m^2$/ha), Low-gradient (16 $m^2$/ha), Floodplain Depression (17 $m^2$/ha), and Footslope Seep (17 $m^2$/ha).

**Figure 16. Relationship between basal area ($m^2$/ha) of mean basal area of three largest trees/plot.**




* This indexes all values to same unit area basis (per ha). If you calculate sizes in English units ($ft^2$/acre), convert the value to $m^2$/ha before determining the score.

### 3.3.5 Canopy Tree Composition ($V_{BIG3COMP}$)

This variable reflects the floristic quality of the forest using information on their wetland status and composition of the largest canopy trees. The underlying assumption for focusing on canopy trees, and on the largest trees, is that the largest trees embody most of the aboveground biomass of a forest and influence the composition of all underlying forest strata (Hunter et al. 1990). In sites that have undergone recent and severe natural or anthropogenic alteration, the largest trees are smaller than they are in unaltered stands, or the trees may be absent entirely and dominated by herbaceous species or shrubs. Indicators of shrub and herbaceous species composition are not used in this HGM model because shrub and herbaceous composition vary widely among stands and are affected primarily by competition with invasive species, grazing pressure, and changes in hydrology. Invasive competition is addressed by the variable ($V_{INVASIVE}$), grazing is addressed by the variable $V_{REGEN}$, and hydrologic changes are modeled separately.

The approach used to determine floristic quality relies on three sets of data: basal area of the three largest trees in 10 m-radius plots, their wetland status, and whether those species are appropriate in the reference standard sites of the subclass being assessed (Table 9).* Species that are not appropriate for the subclass are assigned an Indicator score of 0.1 (Step 3 below), which ensures that the encountered (sampled) species are affiliated with the subclass being assessed and that the site is neither too wet nor too dry relative to the subclass to which it belongs. For example, if the subclass in the WAA being assessed is a Floodplain Depression, but sweetgum and loblolly pine are some of the Big3 species (trees not on the checklist for Floodplain Depressions, then assigning their Indicator scores as 0.1 will trivialize its contribution to the $V_{BIG3COMP}$ score. A five-step process is required for determining the $V_{BIG3COMP}$ subindex score, which includes Steps 1 and 2 above for calculating tree basal area):

1. Measure the DBH (cm) *and identify to species* the three largest trees in each 10 m-radius plot (or larger plot if 3 large trees do not fit into a 10 m radius plot). A DBH tape, Biltmore stick, or tree calipers can be used to measure DBH.

* These tree species in the Table 9 list were identified as having a relative basal area ≥10% in a stand of its subclass or occur as a Big3 species in at least one reference standard site in the subclass.

2. Determine the basal area (in $m^2$/ha) of each identified Big3 tree measured using the formula: BA = $\prod * r^2$/plot size ($m^2$), where r= ½ DBH (diameter in cm). (The plot size of a 10 m radius plot is 314.16 $m^2$.) This calculation provides tree cross-sectional area ($m^2$/ha).
3. Multiply each species BA by its Wetland Indicator Status (Table 9), obtained from the National Wetland Plant List:

   https://wetland-plants.usace.army.mil/nwpl_static/v34/home/home.html

   The indicator values listed in Table 9 are: Obligate = 5, Facultative wetland = 4, Facultative = 3, Facultative upland = 2, and Upland species = 1. For any species not identified in Table 9 as an appropriate species, assign 0.1 as an Indicator Value for the species.

4. Sum results of all values derived in Step 3 and divide by the number of plots sampled to get a $V_{BIG3COMP}$ subindex score (score is then based on average of three trees).
5. Divide by the $V_{BIG3COMP}$ subindex score in Step 4 by the $V_{BIG3COMP}$ standard under the subclass heading for $V_{BIG3COMP}$ in Table 9 for the evaluated subclass. The relationship between canopy tree basal area and its subindex score is assumed to be linear; thus, the subindex increases linearly from zero to 1.0 (Figure 17). If the resulting value is greater than 1.0, reduce the value to 1.0.
6. An example calculation is shown in Table 10.

Table 9. Wetland indicator value of tree and shrub species. If the species is not listed, score the species as 0.1. $V_{BIG3}$ and $V_{BIG3COMP}$ standards are defined for each subclass.

| Wetland species and associated status and values | | | | Subclass and Reference Standards for $V_{BIG3}$ & $V_{BIG3COMP}$ | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Head-water | Mid-gradient | Low-gradient | Floodplain Depression | Footslope Seep |
| $V_{BIG3}$ standard score ( $m^2$/ha) | | | | 13 | 21 | 16 | 17 | 17 |
| $V_{BIG3COMP}$ standard score ($m^2$/ha) | | | | 40 | 69 | 61 | 71 | 59 |
| Species | Common Name | Wetland Status | Value | | | | | |
| *Acer negundo* | Ash-leaf Maple | FAC | 3 | ✓ | | ✓ | | |
| *Acer rubrum* | Red Maple | FAC | 3 | ✓ | ✓ | ✓ | ✓ | ✓ |
| *Acer saccharinum* | Silver Maple | FAC | 3 | | | ✓ | | |
| *Betula lutea* | Yellow Birch | FACU | 2 | | | | | ✓ |
| *Betula nigra* | River Birch | FACW | 4 | | | ✓ | ✓ | |
| *Celtis laevigata* | Sugarberry | FACW | 4 | | | ✓ | | |
| *Diospyros virginiana* | Persimmon | FAC | 3 | | | ✓ | | |
| *Fagus grandifolia* | American Beech | FACU | 2 | | | | | ✓ |
| *Fraxinus pennsylvanica* | Green Ash | FACW | 4 | ✓ | ✓ | ✓ | ✓ | ✓ |
| *Juglans nigra* | Black Walnut | UPL | 1 | | | ✓ | | |
| *Liquidambar styraciflua* | Sweetgum | FAC | 3 | ✓ | ✓ | ✓ | | ✓ |
| *Liriodendron tulipifera* | Yellow poplar | FACU | 2 | ✓ | ✓ | ✓ | | ✓ |
| *Nyssa aquatica* | Water Tupelo | OBL | 5 | | | | ✓ | |
| *Nyssa biflora* | Swamp Tupelo | OBL | 5 | ✓ | ✓ | ✓ | ✓ | |

Table 9 (con.). Wetland indicator value of tree and shrub species. If the species is not listed, score the species as 0.1. $V_{BIG3}$ and $V_{BIG3COMP}$ standards are defined for each subclass.

| Wetland species and associated status and values | | | | Subclass and Reference Standards for $V_{BIG3}$ & $V_{BIG3COMP}$ | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Head-water | Mid-gradient | Low-gradient | Floodplain Depression | Footslope Seep |
| $V_{BIG3}$ standard score ( m²/ha) | | | | 13 | 21 | 16 | 17 | 17 |
| $V_{BIG3COMP}$ standard score (m²/ha) | | | | 40 | 69 | 61 | 71 | 59 |
| **Species** | **Common Name** | **Wetland Status** | **Value** | | | | | |
| *Nyssa sylvatica* | Black Tupelo | FAC | 3 | | | | | ✓ |
| *Platanus occidentalis* | American Sycamore | FACW | 4 | ✓ | ✓ | ✓ | | |
| *Populus deltoides* | Eastern cottonwood | FAC | 3 | | | ✓ | | |
| *Prunus serotina* | Black Cherry | FACU | 2 | ✓ | | | | |
| *Quercus alba* | White Oak | FACU | 2 | ✓ | | | | |
| *Quercus laurifolia* | Laurel oak | FACW | 4 | | ✓ | | ✓ | |
| *Quercus lyrata* | Overcup Oak | OBL | 5 | | ✓ | | ✓ | ✓ |
| *Quercus michauxii* | Swamp chestnut oak | FACW | 4 | ✓ | ✓ | | ✓ | ✓ |
| *Quercus nigra* | Water Oak | FAC | 3 | | ✓ | ✓ | | |
| *Quercus palustris* | Pin Oak | FACW | 4 | | | ✓ | | |
| *Quercus phellos* | Willow Oak | FACW | 4 | ✓ | ✓ | | | |
| *Quercus rubra* | Northern Red Oak | FACU | 2 | | ✓ | | | |
| *Salix nigra* | Black Willow | OBL | 5 | | | | ✓ | |
| *Ulmus americana* | American Elm | FAC | 3 | ✓ | | ✓ | | ✓ |
| *Ulmus rubra* | Slippery Elm | FAC | 3 | ✓ | ✓ | ✓ | ✓ | ✓ |

Figure 17. Relationship between $V_{BIG3COMP}$ score and the subindex for each subclass: (A) Dashed = Footslope seep (59), solid = Headwater (40), (B) dashed = Mid-gradient (69), dotted = Low-gradient (61), and solid = Floodplain Depression (71).

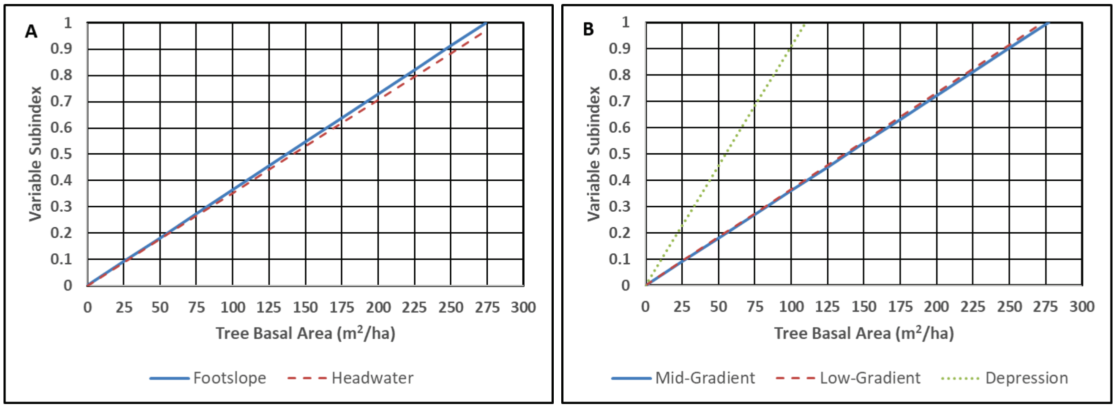



Table 10. Example calculations for determining $V_{BIG3}$ and $V_{BIG3COMP}$ variables in Headwater subclass.

| Species | Common name | DBH (cm) | BA area ($m^2$/ha) | Indicator Value | Subscore | On checklist |
|---|---|---|---|---|---|---|
| *Platanus occidentalis* | Sycamore | 45 | 5.1 | 4 | 20.2 | ✓ |
| *Platanus occidentalis* | Sycamore | 25 | 1.6 | 4 | 6.2 | ✓ |
| *Ilex opaca* | American holly | 30 | 2.2 | | 0.0 | ☐ |
| *Populus deltoides* | Cottonwood | 18 | 0.8 | 3 | 2.4 | ✓ |
| *Populus deltoides* | Cottonwood | 40 | 4.0 | 3 | 12.0 | ✓ |
| *Prunus serotina* | Black cherry | 35 | 3.1 | | | ☐ |
| *Lirodendron tulipifera* | Yellow poplar | 15 | 0.6 | 3 | 1.7 | ✓ |
| *Diospyros virgniana* | Persimmon | 20 | 1.0 | 3 | 3.0 | ✓ |
| *Juglans nigra* | Black walnut | 20 | 1.0 | 1 | 1.0 | ✓ |
| Sum of 9 largest trees | | | 19.3 | | 46.6 | |
| Mean of 3 largest trees | | | 6.4 | | 15.5 | |
| Score | | $V_{BIG3}$= | 0.40 | $V_{BIG3COMP}$= | 0.25 | |

### 3.3.6 Invasive Plant Species ($V_{INVASIVE}$)

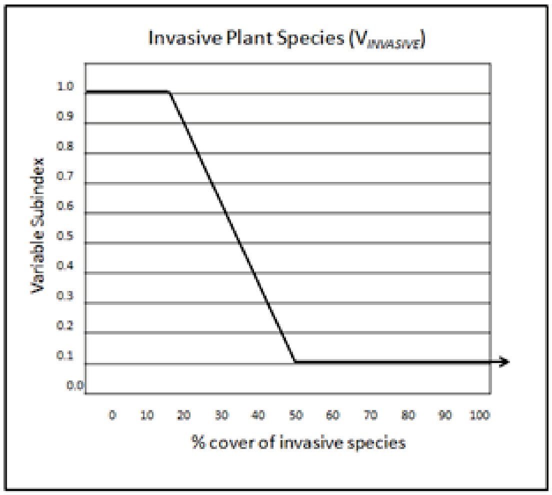
Nonnative, invasive plants commonly invade natural communities when they become stressed or altered. These invasive species are usually generalists (i.e., they do not require special habitat conditions), they reproduce rapidly at a young age, and have high dispersal rates. As a result, invasive species can co-occupy space after disturbances. Many, perhaps all, nonnative, invasive species produce chemicals that repel or kill native competitors (allelopathy). Within a relatively short time after invasion, they tend to outcompete and displace indigenous species, thus lowering ecosystem biological diversity, altering three-dimensional habitat structure, and impairing wildlife habitat quality.

Because invasive species are such generalists, they tend to invade all Piedmont wetland subclasses. Table 6 lists invasive species identified during the collection of reference data. The most-commonly occurring species were Chinese privet (*Ligustrum sinense*), multiflora rose (*Rosa multiflora*), Nepalese browntop (*Microstegium vimineum*), Japanese honeysuckle (*Lonicera japonica*), and Japanese barberry (*Berberis thunbergii*). All these invasive species occupy the understory; currently, no canopy tree invasive species have been able to displace native trees. However, if the canopy is removed (e.g., clearcutting), often privet can become so robustly established, that it prevents native tree seedlings from re-establishing, except as stump sprouts.

Most Piedmont wetland subclasses have invasive species in them, but the subclasses vary relative to the number of invasive species, their life-forms, and total coverage. Some subclasses seem to have a higher coverage of specific species, on average. For example, Nepalese browntop seems to be most prolific in Mid-gradient and Low-gradient riverine sites, whereas privet is most abundant in Mid-gradient sites. Low-gradient sites tend to have a more open canopy, which encourages the spread of Nepalese browntop. In contrast, Floodplain Depressions have relatively few invasive species and lower herbaceous cover overall, probably because flooding duration is generally longer.

The approach used to determine the degree of invasive species' impact on a WAA is to estimate the total coverage of all invasive species. The reference standard coverage of invasive species is 15%, since even high-quality stands often have a low coverage (0.0%-15%) of invasive species. This standard is used for all subclasses. The subindex declines linearly until the 50% coverage threshold is reached, at which point, the subindex becomes 0.1 (Figure 18). The rationale for not defining 0.0 as the lowest subindex is that (a) there are usually still some native species present when invasive cover is high and (b) when invasive cover is high, the major contributor is Nepalese browntop, which is pervasive throughout floodplains in the Piedmont and native trees and shrubs (not herbaceous plants) can outcompete it. To estimate coverage, use the midpoint of cover classes*, then average the cover across plots. Use a plot size that is manageable for estimating cover but use the cover classes indicated in the footnote because this assures repeatability (precision) among users and has been found to be more accurate. Of course, the average of plots will be some value between zero and 100%, although >100% is possible if invasive species occur in more than one stratum.

Figure 18. Relationship between the proportion of canopy species in the sapling stratum and the subindex score.




### 3.3.7 Regeneration Potential ($V_{REGEN}$)

Maintenance of plant community composition depends on its regenerative capacity, that is, the capacity of its plant populations to replace themselves before senescence. Several factors can inhibit a forest's ability to successfully regenerate: disease (including fungi, insect, and aphid pathogens), unsustainable grazing by wildlife and domestic animals, repeated harvesting of trees, and excessive change in flooding or moisture regimes (i.e., a stand becoming too dry or too wet for particular species to thrive or compete successfully). This $V_{REGEN}$ variable assumes that the regenerative capacity of the canopy can be used to infer regeneration capacity of all strata of the plant community.

* Coverage categories (mid-points in parentheses): 0% (0%), 0%-5% (2.5%), 5%-25% (15%), 25% (25%), 25%-50% (37.5%), 50% (50%), 50%-75% (62.5%), 75% (75%), 75%-95% (85%), 95%-100% (97.5%), 100% (100%) and >100% (100%).

Saplings of canopy species were chosen as the indicator of plant community maintenance because saplings indicate whether a riverine forest is maintaining its canopy composition over the long-term. Saplings also integrate hydrologic alterations that affect or will eventually affect canopy composition.

Seedlings of canopy trees tend to be denser in forests than saplings, but seedlings vary widely in abundance (some trees are more prolific seed producers than others) and mortality is high. For these reasons, saplings (as opposed to seedlings) of canopy trees are used to indicate the regeneration potential of the canopy. Canopy tree species identified in reference sites are listed in Table 9*, by subclass.

Although herbaceous species may be more indicative of short-term hydrologic changes, they are more difficult to identify without sufficient botanical training, many are only present seasonally, and their tendency to respond to short-period changes due to drought and wet years makes them less reliable as indicators of long-term maintenance of a forest ecosystem.

The regenerative potential variable ($V_{REGEN}$) is defined as the proportion of sapling species (stems >1 m tall, <5 cm DBH) that also occur as canopy trees (stems > 15 cm DBH) in both the WAA and listed in Table 9 for the subclass). Canopy species lists are for the entire WAA and not just in plots of the WAA. That is, a list of tree species in the canopy of the WAA stand and in Table 9 is compared with a list of sapling species in the understory of the WAA stand. The proportion of species in both lists is divided by the number of species listed for the canopy. For example, if a Mid-gradient WAA has six canopy trees species in it (all listed in Table 9 as canopy species in reference standard sites for the subclass) and five of those species are represented in the sapling stratum, then $V_{REGEN}$ = 5/6= 0.83.

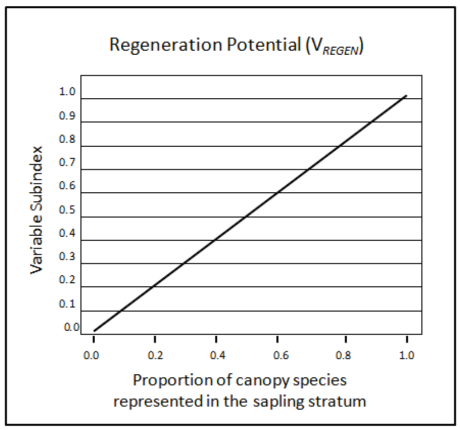
In recently clearcut or selectively cut forests, or in WAAs without a forest canopy, the canopy may be absent or degraded. In such cases, determine how many sapling species from the Table 9 list that occur in the WAA subclass. Then multiply this number by four (for all subclasses, except the Floodplain Depression subclass, see below) and divide by the number of species listed in Table 9 for the subclass (Headwater =13, Mid-gradient

* A running tally of both canopy species and saplings species in a WAA must be kept while assessing a site.

=11, Low-gradient =17, and Footslope Seep =11). For the Floodplain Depression subclass, only one species on the canopy list (Table 9) needs to be in the sapling stratum because some Floodplain Depression canopies are monotypic.

This means that to obtain an index score of 1.0, a Headwater stand should have at least four species, a Mid-gradient stand should have at least three species, a Low-gradient stand should have at least five species, a Footslope Seep stand should have at least three species, and a Floodplain Depression stand should have at least one species (Figure 19).

Figure 19. Relationship between the proportion of canopy species in the sapling stratum and the subindex score.




The rationale for assessing regeneration potential is that composition and structure of a forest canopy cannot be maintained without regenerating its canopy species (indicated as the presence of saplings of canopy species on site in the understory). Thus, $V_{REGEN}$ determines whether regeneration (canopy replacement) is maintaining the forest over a long-time frame.

### 3.3.8 Available Core Habitat ($V_{CORE}$)

This variable expresses the availability of core habitat to animals that are normally expected to use the habitat of the subclass. The focus is on wetland and riparian-dependent amphibian and reptile populations that require suitable supplemental habitat for summer foraging, winter hibernation, and migratory corridors. Forested areas of native trees of any age class and wetlands of any type are assumed to be suitable habitat. Managed forests and pine plantations are considered suitable only if soils, litter, and ground-layer vegetation have not been altered extensively such that cover has been eliminated and animal movement impeded. Areas devoted to row crops, closely mowed areas, grazed pastures, and urban areas are not suitable habitat. $V_{CORE}$ applies only to the animal habitat function.

The $V_{CORE}$ variable for the Riverine subclasses (Headwater, Low-gradient Riverine, Mid-gradient Riverine) is expressed as the proportion of an area that is in suitable habitat (De Jager and Rohweder 2011; Gustafson 1998; Riitters et al. 2002; Wickham et al. 2007) scaled to the dimensions of the subclass being assessed. When the proportion of suitable habitat is low, then generally the patches of suitable habitat are small and isolated (Gustafson 1998).

In addition to the direct loss of foraging and nesting sites, loss of access to suitable habitat decreases the likelihood that there will be sufficient gene flow among populations (De Jager and Rohweder 2011). Individuals from adjacent populations may be excluded from breeding sites when their access is cut impeded by intervening areas of altered land use.

The quality and availability of habitats for fish and wildlife species in wetlands of the alluvial valleys of the Piedmont are dependent on a variety of factors operating at various spatial scales. For example, though landscape considerations are important for birds as well as amphibians, there is a substantial difference in required patch size, with patch size requirements for some individual bird species exceeding 5,000 ha (12,355 ac). Given the current land use within the reference domain, focusing the landscape-level variables in the model entirely on bird patch-size requirements is impractical.

Core habitat requirements for herpetofauna is a more reasonable scale to incorporate into an assessment model. The width of suitable contiguous habitat needed by herpetofauna for any given wetland area depends on a number of variables, including wetland size, topography, climate, surrounding land use, and the species being considered (Semlitsch and Jensen 2001). When Semlitsch and Bodie (2003) synthesized the literature on terrestrial habitats used by amphibians and reptiles associated with wetlands they concluded that core terrestrial habitat extends 159–290 m (522–950 ft) from a wetland edge for most amphibians and 127–289 m (417–948 ft) for most reptiles, although some species may move much farther afield. For example, certain frog species sometimes move up to 1,600 m (5,250 ft) from an aquatic edge. The mean maximum distances moved (calculated from numerous studies of various herpetofauna) included 218 m (715 ft) for salamanders, 368 m (1,207 ft) for frogs, 304 m (997 ft) for snakes, and 287 m (942 ft) for turtles. Surrounding, terrestrial areas that are protected also reduce the amounts of silt, contaminants, and pathogens that enter wetlands, and moderate physical parameters, such as temperature (Daniels and Gilliam 1996; Hupp et al. 1993; Semlitsch and Bodie 2003; Semlitsch and Jensen 2001; Snyder et al. 1995; Young et al. 1980).

Semlitsch and Jensen (2001) noted that suitable terrestrial habitat surrounding breeding sites is critical for feeding, growth, maturation, and maintenance of 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 terrestrial habitat be referred to as part of "core habitat" used by animals. This is different from the traditional concept of the "buffer zone" commonly recommended for wetlands to protect various wetland functions (Boyd 2001). Thus, having sufficient core habitat for amphibians may not eliminate adverse effects of fragmentation for other species, but from an avifaunal perspective, it should be useful in protecting birds from nest parasitism and predation by animals. For example, most impacts on birds are thought to occur relatively close to an edge of disturbance (within 100–300 m [328–984 ft]) (Brittingham and Temple 1983, Strelke and Dickson 1980, Wilcove 1985).

Synthesis of amphibian and reptile requirements for core habitat (above), and the data that suggests the minimal area needed to minimize impacts to birds, the variable $V_{CORE}$ is herein defined as the average proportion of forested habitat areas in three defined core zones: 50 m (164 ft), 122 m (400 ft), and 366 m (1,201 ft) (Semlitsch and Bodie 2003). The two outer bands correspond to the study's minimum and maximum core habitat distances, respectively, while the inner band is a habitat buffer zone surrounding the wetland core needed to access the WAA.

To calculate $V_{CORE}$, one averages the proportion of forest in each zone that is directly connected to the WAA. That is, any forested area that does not have contiguous, suitable forest directly connecting the core habitat to the WAA (i.e., there is non-forest in between), is not considered in the calculation of forest habitat area (Figure 20). $V_{CORE}$ is scored by averaging the proportion of areas covered by core habitat in each zone. Then, the subindex score is a 1:1 relationship with mean proportion covered by the three zones, except that the variable subindex cannot fall below 0.1 for any zone, by convention (Figure 20). The 0.1 threshold was chosen as the lower limit because it is assumed that some species can still use the core area even if it is no longer forested or there is not contiguous, connecting forest. Using the example in Figure 21, the mean core area is calculated as follows: if the Inner zone= 100% forest, Middle zone= 100% forest, and Outer zone= 60% forest (all directly connecting the core habitat to the WAA), then $V_{CORE}$ = (1.0 + 1.0 + 0.60)/3= 0.87. Note that, relative to the proportion of total core area, zones closer to the WAA are weighted more heavily per unit area than outer zones. All subclasses use this variable.

Figure 20. Relationship between area of core habitat and the subindex score.

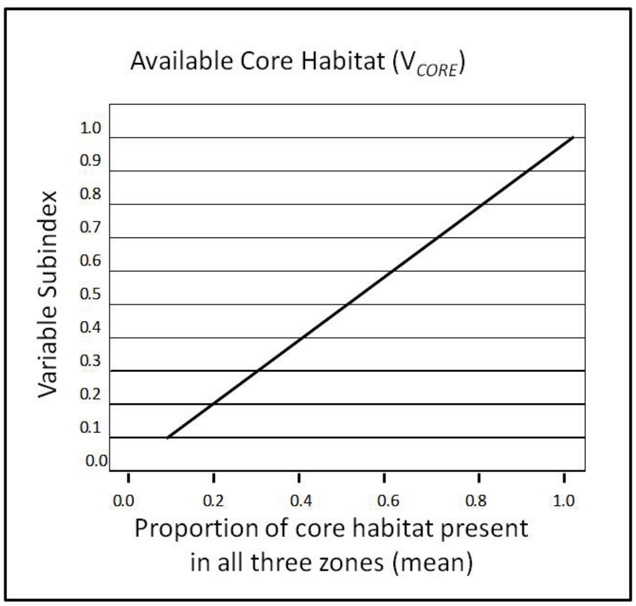
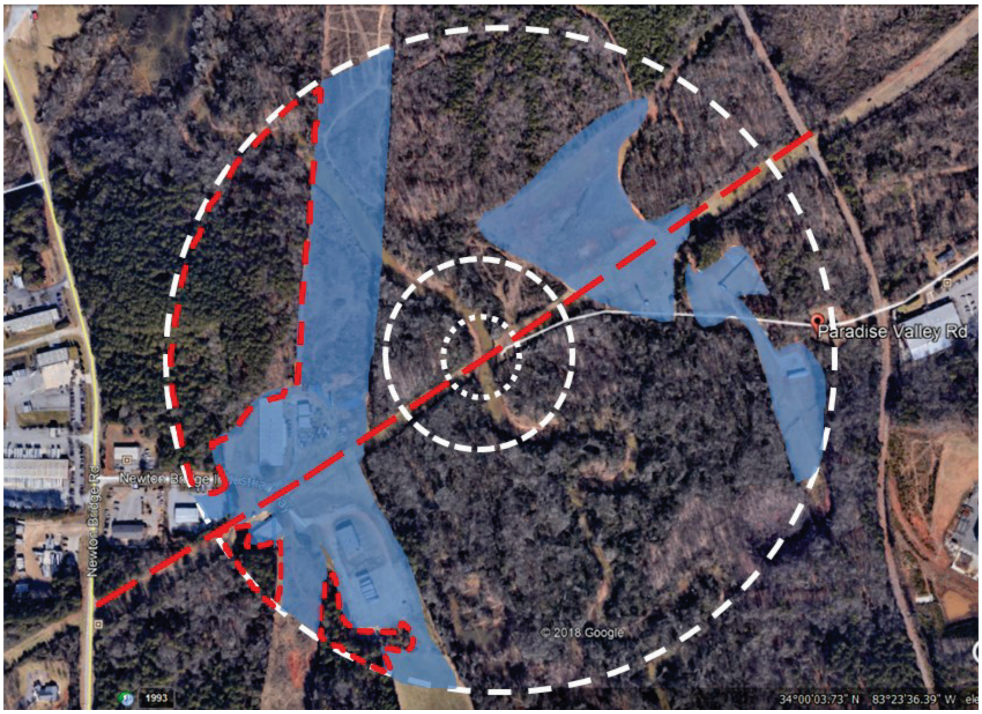


Figure 21. Illustration of how to calculate $V_{CORE}$ for a Mid-gradient Riverine subclass, where a road crossing (*red dashed line*) is proposed (34.002, -83.395). In this example, core habitat occurs in 100% of Zone 1 (the 150 ft inner core), 100% of Zone 2 (the 400 ft middle core), and 60% of Zone 3 (the 1,200 ft outer core). In this example, the areas overtopped with *blue* are not considered to be suitable habitat, and forested areas surrounded by the *red dots* are inaccessible due to intervening unsuitable habitat.




## 3.4 Functions and assessment models

The wetland subclasses, the functions that are modeled in this guidebook, and the model structure and model variables used to conduct assessments, were approved by the consensus of the Project Delivery Team (PDT) after collection of most reference data were completed. Reference data were collected in Piedmont reference sites from Pennsylvania to Georgia using many of the same methods used in developing the Coastal Plain guidebook (Wilder et al. 2013). Because most reference sites were located on public land, they may not represent the suite of conditions exhibited on privately held lands. In fact, the public lands may have been the most erodible and the most degraded lands because federal and state agencies were able to acquire such lands cheaply or seize them after they were abandoned, and property taxes were in arrears.

Based on PDT recommendations, this regional guidebook provides assessment models and methods for conducting assessments to determine the capacity of common forested wetlands of alluvial valleys of the Piedmont to perform the following functions:*

- Maintain Characteristic Hydrology
- Maintain Biogeochemical Transformations and Cycling
- Maintain Characteristic Plant Community
- Maintain Characteristic Animal Habitat

The assumption underpinning this guidebook is that reference standard sites, which represent the least altered sites in the landscape, function in a manner characteristic of the subclass and so can provide standards, using indicators, against which effects of human alterations can be compared. That is, natural variation among indicators can be differentiated from variation caused by human alterations.† To determine natural variation, particularly for biological indicators, enough reference standard sites must be sampled. This can be challenging because reference standard sites usually represent a small fraction of sites on the landscape, and the ecologist must have enough field experience and scientific expertise‡ to differentiate natural variation from human-caused variation.

Functional scores or indices represent a measure of ecosystem integrity, wherein the indices represent the degree to which conditions in a wetland deviate from the range of conditions exhibited by reference standard sites.

In this section, each function is discussed generally in terms of the following topics:

1. *Definition*: Defines the function.
2. *Rationale for selecting the function*: Discusses the reasons the function was selected for assessment, and the on-site and off-site effects that may occur because of lost functional capacity.
3. *Characteristics and processes that influence the function:* Describes the characteristics and processes of the wetland and the surrounding

* The form of the assessment models used to assess functions varies among subclasses.

† If an ecosystem's structure and function is within the range of natural variation after human modifications, then the ecosystem has not been altered enough to be identified as altered.

‡ Expertise requires solid knowledge of hydrogeology, geomorphology, plant and animal ecology, biogeochemistry, how human alterations affect ecosystem functioning, and how to recognize alterations in functioning in the field.

landscape that influences the function and lays the groundwork for the description of assessment variables.

4. *Form of the assessment model*: Presents the structure of the assessment models, describes the constituent variables, and the rationale for using the variable in the function model.

The specific forms of the assessment models used to assess functions for each regional wetland subclass are presented here. Chapter 4 presents the methods used to measure or estimate the values of the individual variables.

## 3.5 Function 1: Maintain characteristic hydrology

### 3.5.1 Definition

This function reflects the ability a particular subclass, relative to what is characteristic of unaltered wetlands of the subclass, to store, convey, and reduce the velocity and volume of water as it moves through a wetland and the time in which water resides there. The potential effects of hydrologic modification include the dampening of flood hydrographs, changes in post flood base flow, and the changes in the deposition of suspended material from the water column to wetland surfaces. Potential independent, quantitative measures for validating the functional index are direct measurements of wetland water budgets, variations in the rates of flow over multiple years, and sedimentation rate studies.

### 3.5.2 Rationale for selecting the function

The capacity of wetlands to store precipitation, intercept groundwater, and convey floodwater has been extensively documented (Campbell and Johnson 1975; Demissie and Kahn 1993; Novitski 1978; Ogawa and Male 1983; Thomas and Hanson 1981). Generally, water interacting with wetlands influences downstream water quality and dampens and reduces peak discharge downstream. Riverine wetlands can reduce the velocity of water from runoff and flooding events, and as a result, remove particulates from the water column and reduce bank erosion (Ritter et al. 1995). A significant portion of the water volume detained within wetlands is likely to be evaporated or transpired (Miwa et al. 2003), reducing the overall volume of water moving downstream. The portion of the detained flow that infiltrates into the alluvial aquifer or returns to the channel very slowly via Low-gradient surface routes may be sufficiently delayed so that the reduced flow rate contributes significantly to the maintenance of base flow in some streams long after flooding has ceased (Saucier 1994; Terry et al. 1979). Water detained in the wetland has a significant effect on elemental cycling. Prolonged saturation leads to anaerobic soil conditions and initiates chemical reactions that are highly dependent on the redox capacity of floodplain soils (Mausbach and Richardson 1994). The hydrologic function also has important implications for invertebrate and vertebrate populations. For example, some invertebrates, such as midges, have very rapid life cycles and are highly adapted to ephemeral water sources. Certain amphibian species depend on the presence of predator-free ephemeral depressions at particular times of the year to successfully complete reproduction.

This hydrologic model deals specifically with the physical influences on flow and sediment dynamics and duration of soil saturation and surface water storage. Groundwater and floodwater interaction with Riverine wetlands influences all other wetland functions, including nutrient mobility and storage, and the quality of habitat for plants and animals. Considering the overriding importance of hydrology to other wetland functions, the hydrologic model is an integral part of the other three functions modeled in this guidebook. The role of hydrology in maintaining those functions is considered separately in other sections of this chapter.

### 3.5.3 Characteristics and processes that influence the function

The manner of a wetland's interaction with surface and subsurface flows has both natural and anthropogenic origins. Climate, landscape-scale geomorphic characteristics, characteristics of the soil within and around a wetland, the configurations and slopes of the floodplains, and natural drainage features are all parameters that are largely established by natural processes. The presence of vegetation on the floodplain of a stream or within a wetland has significant effects on the hydraulics of water flow across a floodplain (McKay and Fischenich 2011) and on the hydrology of the wetland due to effects of evapotranspiration (ET) (Miwa et al. 2003). The intensity, duration, and spatial extent of precipitation events affect the magnitude of groundwater and stream discharge response. Typically, rainfall events of higher intensity, longer duration, and greater spatial extent result in greater flood peaks and durations. Watershed characteristics such as slope, size, shape, channel morphology, drainage pattern and density, and the presence of wetlands, natural lakes and reservoirs have pronounced effects on stormflow response (Brooks et al. 1991; Dunne and Leopold 1978; Leopold 1994; Patton 1988; Ritter et al. 1995). In general, the duration of flooding within a wetland increases as roughness increases and slope decreases.

In addition to natural processes, human activities may profoundly influence how a wetland interacts with water. Modifications to uplands surrounding wetlands, to the stream network of which the wetland is a component, or to the wetland itself, may affect the reception and retention of water. Upstream impoundments or other changes that intercept water, land-use conversion to agriculture or urban infrastructure, and changes in evapotranspiration after vegetation is removed, and the intensity of channel incision, directly affect characteristic hydrology. Some modifications so significantly affect the natural delivery of water and its movement within a wetland that such wetlands may lose their natural wetland characteristics, may result in a wetland becoming a different HGM wetland subclass or class, or in it no longer meeting the definition of a wetland. Thus, incision disrupts all functions that rely on maintaining characteristic hydrology.

### 3.5.4 Form of the hydrologic assessment model

The models for assessing the Maintain Characteristic Hydrology function include six variables:

- Site Hydrologic Alterations ($V_{HYDROALT}$)
- Change in Catchment Area ($V_{CATCH}$)
- Catchment Land use/Landcover ($V_{LULC}$)
- Basal area of Largest Trees ($V_{BIG3}$)
- Dam Effect ($V_{FLOW}$)
- Channel Incision ($V_{INCISION}$)
- Water storage capacity ($V_{STORAGE}$)

The models for calculating the functional capacity index (FCI) for the Maintenance of Characteristic Hydrology subclasses depend on conditions amenable to processing water on the floodplain proper, delivery of water from the catchment, and the capacity of water to reach the floodplain. However, some variables are not used for all subclasses when modeling hydrology.

For the Headwater subclass, the model is:

$$FCI = \left\{V_{HYDROALT} \times \left[\frac{\left(\frac{V_{CATCH}+V_{LULC}}{2}\right)+(V_{BIG3})}{2}\right] \times V_{FLOW}\right\}^{1/3} \quad (4)$$

Inputs of water via surface and subsurface flow from the contributing catchment ($V_{CATCH}$ and $V_{LULC}$) are important to headwater systems, which are groundwater-driven wetlands. Water removed by canopy trees ($V_{BIG3}$) via evapotranspiration (ET) is also a major pathway of hydrologic output to the atmosphere. Additional loss can occur via alterations to a floodplain via drainage features and on-site hydrology can be altered by fill or excavation, all represented by $V_{HYDROALT}$. Flow regulated by milldams upstream can also influence flow in the stream channel and reduce or eliminate naturally occurring, but rare overbank flow events following major storms. The model is designed so that any of the three main categories of alterations (surface and groundwater inputs and ET output, on-site alterations, or flow from upstream) are equally sensitive to model outputs. The rationale for the multiplicative form of the hydrologic model is as follows. If water cannot get to the floodplain, it does not matter whether the floodplain can use it or how much arrives from upstream. If insufficient water arrives from upstream, it does not matter if it can get to the floodplain or if the floodplain can accommodate it. If the floodplain cannot accommodate floodwater (e.g., filled), it does not matter whether enough arrives from upstream. Because the terms are multiplicative (and hence, dependent on one another), the lowest scoring grouping of parameters determines the FCI score.

For the Mid-gradient Riverine subclass, the model is:

$$FCI = \{V_{HYDROALT} \times V_{FLOW} \times V_{INCISION}\}^{1/3} \quad (5)$$

This model relies on three, equally sensitive parameters: alterations to the floodplain proper ($V_{HYDROALT}$), flow from upstream ($V_{FLOW}$), and degree of channel incision ($V_{INCISION}$). The lowest value of any of the three parameters will determine the FCI. Flow from upstream determines how much water is available; conditions on the floodplain determine how long it remains on the floodplain once it is there and whether there is floodplain area to accommodate the water, and degree of incision determines if water can be exchanged between the floodplain and channel. The rationale for the multiplicative terms of hydrology in the model is as follows. For this function to be fully supportive, the frequency of flooding or inundation determines the degree of functionality. Hence, all three parameters are given equal weight, and each is dependent on the contribution of the others.

For the Low-gradient Riverine subclass, the model is

$$FCI = \{V_{HYDROALT} \times V_{FLOW}\}^{1/2} \quad (6)$$

The model relies on only two parameters, both equally important and dependent on the other. The model is similar to the Mid-gradient FCI model, except that $V_{INCISION}$ is not one of the variables. The variable was omitted for two reasons: (1) the stream/river is usually not wadeable and so determining height from bank parameters to thalweg could be dangerous at times without a boat and (2) channels are usually not severely incised because low-gradient floodplains are a sink for sediment eroded from upstream reaches, indicating that overbank flow is relatively common. However, if an incision ratio can be determined (e.g., during low flow conditions), then the Mid-gradient subclass model could be used.

The rationale for the multiplicative nature of the hydrologic model is the same rationale applied to the Mid-gradient model: the capacity of the floodplain to process water ($V_{HYDROALT}$) depends on sufficient water arriving from upstream ($V_{FLOW}$), but the amount of water to supplied from upstream) is consequential only if the floodplain can process it. Hence, the two model terms are multiplicative and thus the scores are interdependent.

For the Floodplain Depression subclass, the model is:

$$FCI = \{V_{HYDROALT} \times V_{STORAGE} \times V_{FLOW}\}^{1/3} \quad (7)$$

The model relies on the capacity of a riverine floodplain depression to process water in the depression ($V_{HYDROALT}$), its capacity to store water in the depression ($V_{STORAGE}$), and the amount of water flowing into the depression from upstream ($V_{FLOW}$). The rationale for the multiplicative form of the hydrologic model is as follows: the capacity of a depression to process water ($V_{HYDROALT}$) depends on whether there is sufficient flow into and out of depression and if there is enough water arriving from upstream

($V_{FLOW}$), but the amount of water supplied from upstream depends on whether the depression can store water for processing ($V_{STORAGE}$).

The model for Footslope Seeps that occur on Mid-gradient floodplains (i.e., seeps embedded within the Mid-gradient subclass) is:

$$FCI = (V_{HYDROALT} \times V_{BIG3} \times V_{INCISION})^{1/3} \qquad (7a)$$

The model for Footslope Seeps that occur on Low-gradient floodplains (i.e., seeps embedded in the Low-gradient subclass) is:

$$FCI = (V_{HYDROALT} \times V_{BIG3})^{1/2} \qquad (7b)$$

The model for Footslope Seeps in headwaters (i.e., seeps embedded within the Headwater subclass) is:

$$FCI = \left\{ V_{HYDROALT} \times \left( \frac{\left(\frac{V_{CATCH} + V_{LULC}}{2}\right) + (V_{BIG3})}{2} \right) \right\}^{1/2} \qquad (7c)$$

For all geomorphic locations in a drainage basin, the models rely on the capacity of the seep to process water ($V_{HYDROALT}$). However, for Footslope Seeps in Mid-gradient reaches, the effect of channel incision ($V_{INCISION}$) and ET potential ($V_{BIG3}$) are also important. The effects on groundwater are modeled in Mid-gradient floodplains by the extent to which the adjacent stream is incised ($V_{INCISION}$) because the downward slope (hydraulic gradient) of the water table to the stream channel determines if groundwater bypasses the seep (i.e., flows below the seep as interflow). Watersheds of Mid-gradient reaches are too large to practically determine the effects that landuse/landcover ($V_{LULC}$) and changes in catchment size ($V_{CATCH}$) have on groundwater, so neither variable is used to model Floodplain Seeps in Mid-gradient reaches (Equation 7a).

For Footslope seeps in Low-gradient reaches, ET potential [measured by ($V_{BIG3}$)] is important in addition to ($V_{HYDROALT}$), but channel incision ($V_{INCISION}$), catchment area ($V_{CATCH}$), and landuse/landcover ($V_{LULC}$) cannot be practically measured. Thus, only two variables are used to model hydrology in Low-gradient reaches, both of which are given equal weight (Equation 7b).

For Footslope seeps in headwaters, the model relies on the capacity of a seep to process water ($V_{HYDROALT}$), the availability and reliability of groundwater ($V_{CATCH}$ and $V_{LULC}$) to reach the seep, and ET output ($V_{BIG3}$). The rationale for the form of this sub-model (Equation 7c) is like that for the Headwater subclass because both subclasses are predominantly groundwater-driven systems.

## 3.6 Function 2: Maintain characteristic biogeochemical cycling

### 3.6.1 Definition

This function refers to the ability of the assessed wetland to cycle elements, particularly nutrients and carbon, through a variety of biogeochemical processes, such as photosynthesis, microbial decomposition, and denitrification. In the context of this assessment procedure, it also includes the capacity of a wetland to permanently remove or temporarily immobilize elements and compounds that are imported into a riverine wetland. The elemental transformation and cycling function encompass a complex web of chemical and biological activities that sustain wetland ecosystem processes and affect the exchange of elements with the biosphere. Potential independent, quantitative measures for validating the functional index may include direct measurements of net annual primary productivity, annual growth rates of trees, annual litter turnover, standing stock of living and/or dead biomass, rate of organic matter accumulation, decomposition rates, rates of denitrification, and rates of carbon sequestration.

### 3.6.2 Rationale for selecting the function

In completely functioning wetlands, elements are transferred among various components of the ecosystem at a rate and magnitude sufficient for maintaining ecosystem processes (Ovington 1965; Pomeroy 1970). For example, an adequate supply of nutrients in the soil profile supports plant growth (primary production), which it turn supports the food web (Bormann and Likens 1970; Perry 1994; Whittaker 1975). The plant community provides a pool of nutrients and energy for consumer organisms and provides the habitat structure for a wide variety of animal niches that maintain animal populations (Fredrickson 1979; Wharton et al. 1982). Plant and animal communities also serve as a source of detritus, which provides nutrients and energy necessary for maintaining decomposer populations. These decomposers, in turn, break down organic material into simpler elements and nutrients that then can be assimilated by plants and thus complete the nutrient cycle (Dickinson and Pugh 1974; Harmon et al. 1986; Hayes 1979; Pugh and Dickinson 1974; Reiners 1972; Schlesinger 1977; Singh and Gupta 1977; Vogt et al. 1986). Dissolved organic carbon is a significant source of energy for microbes that form the base of the detrital food web in aquatic ecosystems (Dahm 1981; Edwards 1987; Schlosser 1991; Wohl 2000). Thus, the high productivity of alluvial valley wetlands and their interaction with streams make them important sources of dissolved and particulate organic carbon for aquatic food webs and biogeochemical processes in downstream aquatic habitats (Elwood et al. 1983; Sedell et al. 1989; Vannote et al. 1980).

### 3.6.3 Characteristics and processes that influence the function

In wetlands, elements are stored within and cycled among five major compartments: (1) the soil, (2) primary producers, such as vascular and nonvascular plants, (3) consumers (animals), (4) nonliving organic matter, such as logs, leaf litter, or other woody debris (referred to as detritus), and (5) detritivores, such as fungi and bacteria. The transformation of nutrients within each compartment and the flow of nutrients between compartments occur in a complex variety of biogeochemical processes and pathways, which is mediated by a wetland's hydroperiod (or retention time of water), which maintains anaerobic conditions, and the importation of materials from surrounding areas (Beaulac and Reckhow 1982; Federico 1977; Grubb and Ryder 1972; Ostry 1982; Shahane 1982; Strecker et al. 1992; Zarbock et al. 1994). For example, plant roots harvest nutrients from the surrounding soil and detritus and incorporate them into plant tissues. Nutrients incorporated into herbaceous or deciduous parts of plants will turn over more rapidly than those incorporated into the woody parts of plants, but woody plants can store significant amounts of carbon in their woody tissues. Ultimately, all plant tissues are either consumed by animals or die and fall to the ground where they are decomposed by fungi and microorganisms and mineralized to again become available for uptake by plants. The processes involved in nutrient cycling within wetlands have been studied extensively (Brinson 1990; Brinson et al. 1981; Brown and Peterson 1983; Conner and Day 1976; Day 1979; Harmon et al. 1986; Mulholland 1981).

### 3.6.4 Form of the assessment model

The model for assessing the Maintenance of Biogeochemical Transformation and Cycling function include the following two variables and the Hydrology FCI pertinent to the subclass being assessed.

- Basal Area of Largest Trees ($V_{BIG3}$)
- Soil Quality ($V_{SOILQUAL}$)

The models for calculating the functional capacity index (FCI) for the Biogeochemical Transformation and Cycling (BGTC) function depend on the hydrology and biomass of a site. Site hydrologic regime was modeled previously for each subclass and so it was considered reasonable to use the hydrology FCI to represent the hydrologic condition of a site. Aboveground and belowground biomass is modeled using indicators of those compartments: the basal area of the three largest trees per plot ($V_{BIG3}$) and soil quality ($V_{SOILQUAL}$), which is an indicator of soil carbon. The BGTC form of the model for all subclasses is the same. However, if a soil sample cannot be removed from a site in the Floodplain Depression subclass, due to deep flooding, the subindex score for soil quality is assumed to be 1.0.

For all subclasses, the FCI for BGTC is determined as follows, with "FCI Hydrology" referring to the specific Hydrology FCI for the subclass being assessed:

$$FCI = \frac{\left\{FCI\ Hydrology + \left[\frac{V_{BIG3} + V_{SOILQUAL}}{2}\right]\right\}}{2} \quad (8)$$

This model contains two expressions. The first expression reflects the site's hydroperiod, which incorporates the pathway by which material arrives at the site, borne in groundwater or floodwaters. It also represents the driver of biogeochemical conditions, determining the timing, extent, and duration of aerobic and anaerobic conditions, within which elements are cycled and transformed. The second expression includes aboveground components and belowground components of the ecosystem. The largest canopy trees ($V_{BIG3}$) reflect varying levels of nutrient availability and turnover rates, as trees incorporate both short-term storage of nutrients and carbon (in leaves), as well as long-term storage (in wood). As such, the largest canopy trees indicate the biomass of the forest and its aboveground detrital components, such as large, downed wood, snags, and the layer of leaves and twigs on the forest floor.

The second expression also includes soil quality ($V_{SOILQUAL}$), which incorporates both short-term storage of largely decomposed, but nutrient-rich organics on the soil surface (humus) and a longer-term storage compartment of deeper soil horizons. In deeper soil horizons, nutrients that have been released from other compartments are held within the soil and are available for plant uptake but are generally conserved within the system and not readily subject to export by runoff or floodwater. In most natural ecosystems, the belowground organic component stores as much as 40% of the carbon of an ecosystem.

The rationale for the form of this model is that without water, the BGTC function is reduced. Although the BGTC function will still occur, it will be more similar to upland ecosystems than to the wetland the subclass being assessed. Thus, various BGTC processes are not entirely dependent on hydrology. Similarly, if biomass is removed from a site, via tree removal, and hydrology is otherwise intact, BGTC functions will still occur (e.g., denitrification by soil microbes), although at a changed rate and magnitude, hence, the rationale for the additive nature of the model terms.

## 3.7 Function 3: Maintain characteristic plant community

### 3.7.1 Definition

This function is defined as the capacity of a wetland to provide the environment necessary for native plant community development and maintenance. In assessing this function, one must consider both the extant plant community as an indication of current conditions, whether the canopy is regenerating, and the hydrologic factors that determine whether a characteristic plant community is likely to be maintained over the long-term. Potential independent, quantitative measures for validating the functional index are comprehensive floristic surveys and a long-term water budget.

### 3.7.2 Rationale for selecting the function

The ability to maintain a characteristic plant community is important due to the intrinsic value of plant communities and the food and habitat they provide to other organisms, including wildlife. Many wetland attributes and processes are influenced by a plant community as well. For example, primary productivity, nutrient cycling, and the ability to provide a variety of habitats necessary to maintain local and regional biodiversity of organisms are directly influenced by the plant communities that form habitats (Harris and Gosselink 1990). In addition, plant communities of alluvial valley wetlands influence the quality of their physical habitats, nutrient status, and biological diversity of downstream ecosystems.

### 3.7.3 Characteristics and processes that influence the function

Numerous studies describe environmental factors that influence the composition and structure of plant communities in wetlands (Hodges 1997; Klimas et al. 2009; Robertson et al. 1978; Robertson et al. 1984; Townsend 2001; Wharton et al. 1982). Hydrologic regime is usually cited as the principal factor controlling plant community attributes. Soil characteristics also are significant determinants of plant community composition. In addition to physical factors, ecosystem dynamics and disturbance history are important in determining the condition of a wetland plant community at any point in time, including past land use, timber harvest history, invasion by nonnative species, sediment deposition, and periodic events such as storms, fire, beaver activity, insect outbreaks, and disease. Clearly, some characteristics of plant communities within a particular wetland subclass may be determined by factors too subtle or variable to be assessed using rapid field estimates. Therefore, this function is assessed by considering alterations that modify a site's hydrologic conditions from a natural state, the extent that the existing plant community structure, composition, and stage of maturity are appropriate to the subclass, and whether the community is regenerating.

### 3.7.4 Form of the assessment model

The model for assessing the Maintain a Characteristic Plant Community function includes four variables and the Hydrology FCI for the subclass being assessed:

- Canopy Tree Basal Area of Largest Trees ($V_{BIG3}$)
- Invasive Plant Species ($V_{INVASIVE}$)
- Canopy Tree Composition ($V_{BIG3COMP}$)
- Regeneration Potential ($V_{REGEN}$)

In addition to hydrologic condition, the four variables are used to model the structure of the forest are determined by the size of the largest trees ($V_{BIG3}$), the composition of the canopy ($V_{BIG3COMP}$) (and by extension, the composition of the forest), the effects of invasive species ($V_{INVASIVE}$) on understory composition, and the regenerative capacity ($V_{REGEN}$) of the forest.

For all subclasses, the FCI for Plant Community function is determined as follows, with “FCI Hydrology” (i.e., the hydrology of the subclass being assessed):

$$FCI = \left\{FCI\ Hydrology \times \left[\left(\frac{V_{BIG3}+V_{BIG3COMP}+V_{INVASIVE}}{3}\right) \times V_{REGEN}\right]\right\}^{1/3} \quad (9)$$

This model contains three expressions. The first represents the existing hydrologic conditions (Hydrology FCI of the site). The second expression combines three variables expressing the structure and composition of the plant community in the wetland. The basal area of the largest trees ($V_{BIG3}$) indicates the structural complexity of the forest, the composition of the largest trees ($V_{BIG3COMP}$) reflects the species composition of the forest (especially the dominant stratum), and the cover of invasive species ($V_{INVASIVE}$) reflects the degree to which the composition of the understory is altered. The third expression ($V_{REGEN}$) indicates the regenerative capacity of the forest.

The rationale for the form of the model is that without wetland hydrology, the absence of a characteristic wetland hydrology would result in a severe degradation of the site’s ability to maintain an appropriate plant community, which would be reflected in its regenerative capacity. Further, without native wetland forest trees, recruitment is inhibited, especially by heavy mast producing species, in which case, the hydrologic regime is inconsequential. Similarly, without regenerative capacity (e.g., an overgrazed understory), the plant community will not be viable over the long term even if hydrology and canopy composition are intact. Therefore, the multiplicative form of the model reflects the interdependence of the three components, where the lowest-scoring component determines the resulting FCI score.

## 3.8 Function 4: Maintain characteristic animal habitat

### 3.8.1 Definition

This function is defined as the ability of a wetland to support the animal species that depend on riverine wetlands during some part of their life cycles. Potential independent, quantitative measures for validating the functional index are comprehensive, long-term faunal surveys that incorporate landscape-scale interactions.

### 3.8.2 Rationale for selecting the function

Terrestrial, semiaquatic, and aquatic animals use wetlands extensively. Maintenance of this function ensures habitat complexity for a diverse array of species, reflects secondary production, and maintains complex trophic interactions. Habitat maintenance spans a range of temporal and spatial scales and includes the provision of refugia and habitat for wide-ranging or migratory animals as well as for highly specialized endemic species. Most wildlife and fish species found in wetlands of alluvial valleys of the Piedmont depend on certain aspects of wetland dynamics and structure, such as periodic flooding or ponding of water, the structure and composition of vegetation, physical characteristics of forest structure, and proximity to supplemental habitats required to complete their life cycles.

### 3.8.3 Characteristics and processes that influence the function

Hydrology is a major factor influencing wildlife habitat quality in Piedmont alluvial valley wetlands. All organisms require water, and wetlands are focal points for obtaining water, even for species that spend most of their lives in uplands. Hydrologic alterations have the potential to impact several wildlife species, but the most serious impacts would be to animals with direct dependence on water. Examples include fish that may spawn on floodplains during late winter and early spring inundations or amphibians and reptiles that use seasonally ponded micro depressions within wetlands for reproduction. These fish and amphibians are highly vulnerable to changes in a wetland's hydroperiod due to drainage, fill, isolation from a stream with levees, and/or stream-flow regulation. Such changes impact breeding activity because egg development and maturation of the young require a specific flooding duration at a particular time of year (Duellman and Trueb 1986). Conversely, artificially increasing the duration that surface water is present in a wetland (due to stream-flow regulation, impoundment, excavation, or increasing runoff) can potentially reduce the suitability for amphibians by allowing resident fish populations to become established and decimate eggs and larvae (Bailey et al. 2004). Besides the direct effects of hydrologic changes on animals, indirect effects can occur through changes in the structure and composition of 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 and density) as expressed in the plant community model. Wildlife species have evolved with and adapted to such conditions. Altering the plant community has the potential to change the composition and structure of the wildlife community. Other factors also indirectly affect wildlife communities, including droughts and catastrophic storms, frequency and intensity of fire, competition, disease, browsing pressure, community succession, natural disturbances, and anthropogenic alterations.

Habitat structure is a critical determinant of wildlife species composition and diversity (Anderson and Shugart 1974; Wiens 1969). The importance of structure 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, presence of specific forest strata, number of snags, and other factors. MacArthur and MacArthur (1961) documented the positive relationship between the vertical distribution of foliage (i.e., the presence of different layers or strata) and avian diversity. Other researchers have since corroborated their findings (Ford 1990, Hunter 1990, Schoener 1986). For example, some bird species use the forest canopies, whereas others are associated with the understory (Cody 1985; Wakeley and Roberts 1996).

Land use surrounding a wetland site also has a major impact on its wetland wildlife community. Historically, the reference domain was largely forested. The wildlife community evolved in a landscape with wetlands surrounded by vast tracts of woodlands. Human activities have dramatically altered the reference domain in other ways as well. Currently, much of the Piedmont has been converted to crop production, pasture, commercial pine plantations, residential and commercial developments, and other non-forested land uses. Adverse effects of “fragmentation” of formerly forested landscapes have been well-documented for avian species and communities (Askins et al. 1987; Keller et al. 1993; Kilgo et al. 1997) and for reptiles and amphibians (Bailey et al. 2004; Laan and Verboom

1990; Rothermel and Semlitsch 2002; Semlitsch 1998; Semlitsch and Jensen 2001).

Core habitat (adjacent, non-wetland habitats) is especially important to amphibians and reptiles that spend most or parts of their life cycles outside wetlands (Boyd 2001; Burke and Gibbons 1995; Gibbons 2003; Gibbons and Buhlmann 2001; McWilliams and Bachmann 1988; Semlitsch and Bodie 1998). Therefore, this assessment procedure also focuses on attributes of core habitat to define the minimum requirements for a maximum number of animal species assumed to use mature, complex, forested riverine wetland ecosystems.

### 3.8.4 Form of the assessment model

The model for assessing the Maintain Characteristic Animal Habitat function includes the following variable and the Plant Community FCI pertinent to the subclass being assessed.

- Available Core Habitat ($V_{CORE}$)

In addition to the condition of the plant community (which also incorporates hydrologic condition), the ($V_{CORE}$) variable is used to model the availability of core habitat ($V_{CORE}$), which indicates the amount of supplemental core habitat required for wetland-dependent species using the subclass being assessed.

For all subclasses, the FCI for the Animal Habitat function is determined as follows:

$$FCI = \{FCI\ Plant\ Community \times V_{CORE}\}^{1/2} \qquad (10)$$

The model for calculating the functional capacity Index (FCI) for this function contains two expressions, the first related to the condition of the plant community (FCI of Plant Community function) and the second to the availability of suitable supplemental core habitat ($V_{CORE}$), located mostly in uplands outside the wetland.

The form of the plant community model, and the rationale for it, was explained in the previous section. The structure and species composition of the plant community in a wetland, as discussed previously, is important to animals because it provides habitat for wetland-dependent species and is used by upland species as well. Structure is important for providing a variety of niches for nesting, breeding, and foraging. Composition is important for providing the appropriate food for animals. The Plant Community function already incorporates hydrology (i.e., appropriate hydrology is already integrated). The critical factor missing in the Plant Community function is a term that represents supplemental habitat required by wetland-dependent species. Thus, this function provides that component in the $V_{CORE}$ variable.

This rationale for the form of the model (i.e., two terms multiplied), is that if the plant community is unsuitable, then it does not matter if core habitat is available. Likewise, if core habitat is unavailable, then it does not matter if the wetland plant community is intact. However, the subindex score for $V_{CORE}$, by convention, cannot score below 0.1 because some (not all) species will be able to use non-forested habitat, although at low population density.

# 4 Assessment Protocol

## 4.1 Introduction

Previous chapters of this regional guidebook have provided background information on the HGM Approach, characterized regional wetland subclasses, and documented the variables, functional indices, and assessment models used to assess regional wetland subclasses in alluvial valleys of the Piedmont. This chapter outlines the procedures for collecting and analyzing the data required to conduct an assessment.

In most cases, permit review, restoration planning, and similar assessment applications require that pre- and post- project conditions of wetlands at the project site be compared to develop estimates of the loss or gain of function associated with the project. The pre- and post-project assessments should be completed at the project site before the proposed project has begun. Data for the pre-project assessment represents existing conditions at the project site, while data for the post-project assessment is normally based on a prediction of the conditions that can reasonably be expected to exist following proposed project impacts. The rationale and assumptions used to establish post-project conditions should be clearly stated. Where the proposed project involves wetland restoration or compensatory mitigation, this guidebook can also be used to assess the functional effectiveness of the proposed restorative actions.

A series of tasks are required to assess regional wetland subclasses in alluvial valleys of the Piedmont using the HGM Approach:

- Document the project purpose and characteristics.
- Screen for red flag features (factors that preclude using a functional assessment).
- Define assessment objectives and identify regional wetland subclass(es) present and assessment area boundaries.
- Collect field data.
- Analyze field data.
- Document assessment results.
- Apply assessment results.

The following sections discuss each of these tasks in greater detail.

## 4.2 Define assessment objectives and identify regional wetland subclass(es) present and assessment area boundaries

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 affect wetland functions.” Other potential objectives could be as follows:

1. Compare several wetlands as part of an alternatives analysis.
2. Identify specific actions that can be taken to minimize project impacts.
3. Document baseline conditions at a wetland site.
4. Determine mitigation requirements.
5. Determine mitigation success.
6. Determine the effects of a particular wetland management technique.

### 4.2.1 Screen for Red Flags

Red flag features are factors that preclude using a functional assessment. That is, they are factors within or in the vicinity of the project area to which special recognition or protection has been assigned (Table 11). 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 whether the wetlands or other natural resources in and around the project area require special consideration or attention that may preclude or postpone an assessment of wetland functions. That is, an assessment of wetland functions may not be necessary if the project is unlikely to occur due to 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 wetland functions may be unnecessary because the project may be denied or modified strictly based on the impacts to threatened or endangered species or habitat.

Table 11. 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 flood prone 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 |

[1]Program Authority / Agency

A = Bureau of Indian Affairs

B = National Marine Fisheries Service

C = US 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 = US Environmental Protection Agency

J = Federal Emergency Management Agency

K = Natural Resources Conservation Service

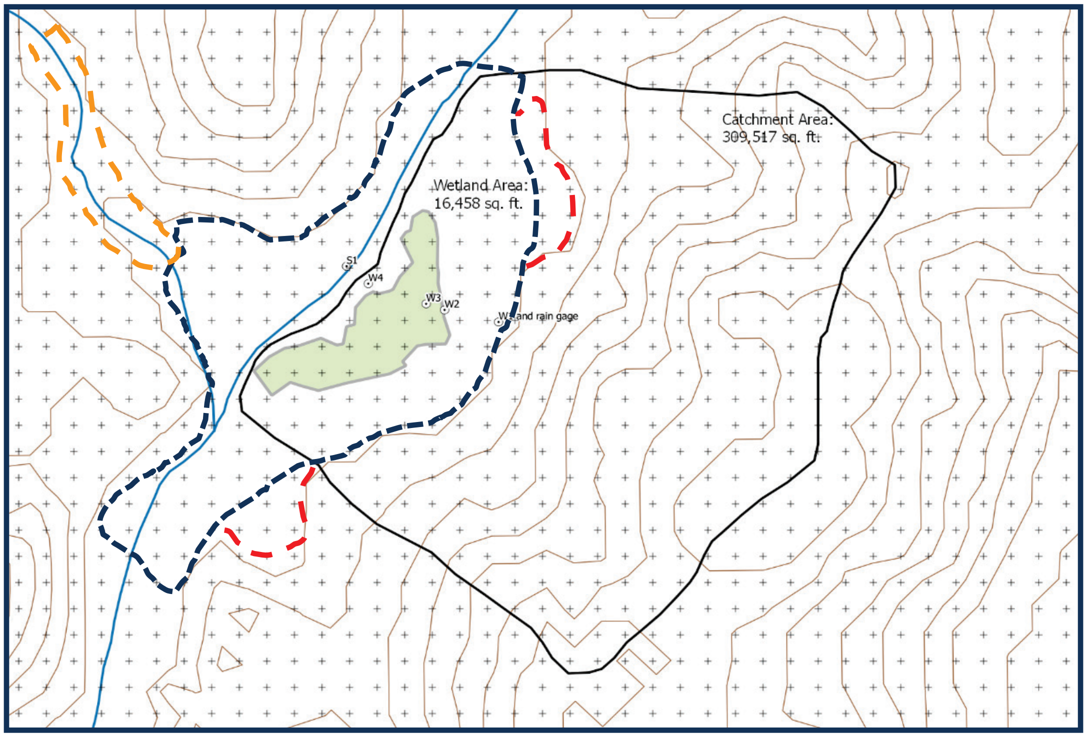
L = Local Government Agencies

### 4.2.2 Identify regional subclass(es) and define the wetland assessment area

Determining the correct subclass being assessed is essential for completing a meaningful HGM assessment. Current aerial imagery, topographic maps, soils maps, NWI maps, local knowledge, or other available information can be used to help identify subclasses. Locate on a map one or more separate Wetland Assessment Areas (WAAs) based on the Key to Wetland Classes, the wetland subclass descriptions, and the project area boundary. The WAA is an area of wetland within a project area that belongs to a single regional wetland subclass and is relatively homogeneous with respect to the site-specific criteria used to assess wetland functions (i.e., hydrologic regime, vegetation structure, topography, soils, successional stage, etc.). In many project areas, there will be just one WAA representing a single wetland subclass. However, for large or heterogeneous project areas, it may be necessary to define and assess multiple WAAs or Partial Wetland Assessment Areas (PWAAs) within the project area (Figure 21).

At least three situations necessitate defining and assessing multiple WAAs or PWAAs within a project area. The first situation exists when widely separated wetland patches of the same regional subclass occur in the project area. The second situation exists when more than one regional wetland subclass occurs within a project area (Figure 22). The third situation exists when a physically contiguous wetland area of the same regional subclass exhibits spatial heterogeneity with respect to hydrology, vegetation, soils, disturbance history, or other factors that translate into significantly different values for one or more of the site-specific variable measures. These differences may be a result of natural variability (e.g., zonation on large river floodplains) or human disturbance (e.g., logging, surface mining, etc.). Designate each of these areas as a separate PWAA and conduct a separate assessment on each area.

Figure 22. Example of a wetland assessment area (WAA) depicting various subclasses. Cornish Creek at Georgia Wildlife Federation, Covington, Georgia. Floodplain Depression and WAA (*filled green*), Mid-gradient riverine (outlined in *blue dashes*), Headwater (outlined in *orange dashes*) and Footslope Seep (outlined in *red dashes*). Catchment of the Floodplain Depression is outlined with a *solid black line* (figure by Carson Pruitt, Environmental Resources GIS Analyst).




In the Piedmont, the most common scenarios requiring designation of multiple Wetland Assessment Areas involve tracts of land with interspersed regional subclasses (such as a Floodplain Depression or Footslope seep on a Low-gradient Riverine floodplain) or a WAA composed of a single regional subclass that includes areas with several land cover classes. For example, within a large Low-gradient Riverine unit, you may define separate Wetland Assessment Areas that are cleared land, early successional sites, and mature forests. However, be cautious about splitting a project area into too many Wetland Assessment Areas based on relatively minor differences, such as local variation due to canopy gaps and edge effects. The reference curves used in this document (Chapter 4) incorporate such variation and splitting areas into numerous Wetland Assessment Areas based on subtle differences will not materially change the outcome of the assessment. However, splitting will greatly increase the sampling and analysis effort.

## 4.3 Collect data

Information used to assess the functions of regional wetland subclasses in alluvial valleys of the Piedmont is collected at several different spatial scales and requires several summarization steps. The checklists and data forms in the appendices are designed to assist the assessment team in assembling the required materials and processing them in an organized fashion. As noted previously, the Project Information and Assessment Documentation form (Appendix B1) is intended to be used as a cover sheet and as an overview of all documents and data forms that will be used in the assessment. Assembling the background information listed on this form should guide the assessment team in determining the number, types, and sizes of the separate WAAs likely to be designated within the project area (see above). Based on background information, the field gear, and data form checklists in Appendix B2 should be used to assemble the needed materials before heading to the field to conduct the assessment.

Note that different wetland subclasses require different field data because the standards differ among subclasses (Table 7). Data sheets are provided in Appendix B3. Data sheets may also be printed directly from the FCI/FCU calculator spreadsheet.

The data forms provided in Appendix C are organized to facilitate data collection at each of the several spatial scales of interest. For example, the first group of variables on Data Sheet 1 contains information about landscape scale characteristics collected using aerial photographs, topographic maps, and/or soil survey maps for each WAA and its vicinity. However, Data sheet 4 also has one variable ($V_{CORE}$), which can be obtained with aerial imagery. Information on the second group of variables on Data Sheets 2-4 are collected during a walking reconnaissance of the WAA and via plot sampling. Data can be transferred from the data sheet to the spreadsheet calculator to calculate functional capacity.

The sampling procedures for conducting an assessment require few tools, but certain tapes, a shovel, reference materials, and an assortment of other items listed in Appendix B2 will be needed. Generally, all measurements should be taken in SI (metric) units.

As in defining the WAA, there are elements of subjectivity and practicality in determining the number of sample locations for collecting plot-based and transect-based site-specific data. The exact numbers and locations of the plots and transects are dictated by the size and heterogeneity of the WAA. If the WAA is large enough, three plots should be used. However, if the WAA is too small to place plot sizes recommended in this guidebook, an alternative, acceptable vegetative method can be used (e.g., smaller plot size, belt transects, rectangular plots).

If the WAA is relatively small (i.e., less than 2–3 acres, or about a hectare) and homogeneous with respect to the characteristics and processes that influence wetland function, then three 314-$m^2$ plots (10 m-radius circles), are probably adequate to characterize the WAA. However, as the size and complexity of the WAA increase, more sample plots may be required to represent the site accurately. Large, forested wetland tracts usually include scattered, small openings in the canopy that cause locally dense understory or ground cover conditions, and perhaps some very large individual trees or groups of old-growth trees. The sampling approach should not bias data collection to emphasize or exclude any of these local conditions differentially, but to represent the site. Therefore, the best approach on large sites is often a simple systematic plot layout, where evenly spaced parallel transects are established (using a compass and pacing) and sample plots are distributed at regular paced intervals along those transects in such a way that the plots do not overlap. For example, a 12-ha tract, measuring about 345 m on each side, might be sampled using two transects spaced 100 m apart (and 50 m from the tract edge), with plots at 75 m intervals along each transect (starting 25 m from the tract edge). This would result in eight sampled plot locations, which should be adequate for a relatively diverse 12-ha forested wetland area.

Smaller or more uniform sites can usually be sampled at a lower plot density. One approach is to establish a series of transects (with non-overlapping plots), as described previously, and sample at intervals along alternate transects. Continue until the entire site has been sampled at a low plot density, then review the data and determine whether the variability in overstory composition has been accounted for. That is, when the number of plots sampled is increased, are new canopy or invasive species encountered or is the average diameter of Big3 canopy trees for the site changed markedly with the addition of recent samples?[*] If not, there is probably no need to add further samples to the set.

If overstory structure and variability in composition remain high, then return to the alternate, un-sampled transects and continue sampling until the data set is representative of the site, indicated by no or very few new additions to the species list. Variation in other variables is reduced more quickly or slowly than tree composition, but the canopy stratum is generally a good indicator of site variation, and it corresponds well to the overall suite of characteristics of interest within a particular WAA. In some cases, such as sites where trees have been planted or composition and structure are highly uniform (e.g., sites dominated by one tree species), relatively few samples are needed to adequately the characterize composition and basal area of a WAA.

The information on Data Sheets (Appendix B3) are entered in the FCI/FCU calculator spreadsheet and automatically tabulated. All the field and summary data forms, as well as the printed output from the final spreadsheet calculations, should be attached to the Project Information and Assessment Documentation Form provided in Appendix B1. Detailed instructions on collecting the data for entry on Data Sheets follow. Not all variables are used to assess all subclasses, as described in Chapter 4 and Table 7, but the data forms in Appendix B3 indicate which variables are pertinent to each subclass. The data forms also provide brief summaries of the methods used to assess each variable, but the user should read through these more detailed descriptions and have them available in the field for reference as necessary.

## 4.4 Site Hydrologic Alterations ($V_{HYDROALT}$)

Measure/Units: Proportion of a WAA hydrologically altered by filling, excavating, draining, damming, or diverting water either into or from the WAA. Different methods are used for determining the subindex score for filling and excavating than for draining, damming, or input of excess water. Use the following alternative procedures to measure $V_{HYDROALT}$:

[*] This is the essence of a species/area curve, i.e., a larger sample area does not add appreciably to the number of species. Only rarer and rarer species are encountered with additional plots.

1. If the WAA has been filled or excavated, determine the proportion of the WAA that has been filled or excavated. The subindex is this proportion.
2. If the WAA has been drained, determine the area of influence of the drainage feature and divide the area of influence by the area of the WAA. Be sure that the feature drains the wetland (i.e., make sure that water in the WAA is being drained down gradient by the ditch).

### 4.4.1 Change in Catchment Size ($V_{CATCH}$)

*Measure/Units:* Proportional change in the effective size of the catchment of the wetland. Use the following procedure to measure $V_{CATCH}$.

If there are no ditches, drains, or water diversions in the wetland's catchment, and no augmentation of hydrology through interbasin transfers of water, then the percent change in catchment size is zero (subindex for $V_{CATCH} = 1.0$) and the following steps may be skipped. Otherwise, use aerial imagery, topographic maps, and field reconnaissance to delineate the catchment or watershed of the Headwater Slope wetland.

1. Determine the total area of the catchment under natural conditions (i.e., overlooking any diversions or drains that may be present).
2. Determine the existing catchment area by subtracting those portions of the natural catchment from which surface or subsurface water is being diverted away from the wetland, or in the case of water transfer into the wetland's catchment from an adjacent basin, add the area of the basin (or portion of the basin) from which water is being transferred.
3. Use Equation 1 in Chapter 3 to calculate the proportional change in effective catchment size to determine the subindex score for $V_{CATCH}$. If the effective size of the catchment is unchanged (i.e., no water diversions), the subindex score is 1.0.

### 4.4.2 Catchment Land use/Landcover ($V_{LULC}$)

*Measure/Units:* Weighted average infiltration/ET potential for a catchment that provides water to the Headwater Riverine and Footslope Seep subclasses. Use the following procedure to measure $V_{LULC}$:

1. Use topographic maps or other sources to delineate the existing catchment or watershed. Do not include areas from which water is being diverted away from the wetland but do include any adjacent

catchment area from which water is being imported into the wetland's catchment (see $V_{CATCH}$ above).
2. Use recent, high-resolution aerial imagery, confirmed during field reconnaissance, to determine the land-use categories present in the catchment.
3. Using GIS tools, aerial imagery, or field reconnaissance, estimate the percentage of the catchment represented by each land use category shown in Table 7.
4. Determine the infiltration potential for each land-use category present in the catchment, based on indices provided in Table 7.
5. Determine an area-weighted average infiltration score for the catchment (i.e., Infiltration potential X area). An example can be found in Table 7.
6. Sum scores and use Table 7 or Figure 9 to determine the subindex score for $V_{LULC}$.

## 4.5 Channel Incision ($V_{INCISION}$)

*Measure/Units:* A ratio derived from bankfull height divided by channel-full height. The variable is always measured in the Mid-gradient subclass and in the Low-gradient subclass only if it is safe to do so. There are several ways to obtain the necessary measurements. Two options are provided. Use the following procedures (Option A) to measure $V_{INCISION}$:

1. Locate bankfull marks at the top of a point bar or mid-channel bar (if multithreaded channel), at ledges along the channel bank, or at a location on the channel bank below which vegetation does not grow.
2. Stretch a tape perpendicularly across the channel from bankfull to bankfull and use a laser level (hand-held will do) pointed across the channel at bankfull elevation to make sure the tape is level.
3. Locate the lowest point at top-of-bank (channel-full height), (i.e., the elevation where high water would flood onto the floodplain).
4. At this elevation, stretch a tape perpendicularly across the channel from top-of-bank to top-of-bank and use a laser level pointed across the channel at top-of-bank elevation to make sure the tape is level.
5. Along the bankfull cross-section and using a plumb stadia rod or graduated pole (e.g., PVC pole with a tape measure attached to it), measure the height from the bottom of the thalweg (deepest point of channel) to the height of tape marking bankfull elevation (upper tape). This is bankfull height (BFH).

6. Along the top-of-bank cross-section and using a plumb stadia rod or graduated pole, measure the height from the bottom of the thalweg (deepest point of channel) to the height of the tape marking top-of-bank elevation. This is channel-full height (CFH).
7. Divide bankfull height by channel-full height (BFH/CFH) to obtain the Incision ratio.
8. Divide the Incision ratio (IR) by 0.5 or use the graph in Figure 10. Neither IR nor $V_{INCISION}$ can equal zero.

If you have a hand-held laser level (one can be purchased in a home improvement store), a simpler way to obtain bankfull and channel-full height is as follows (Option B):

1. Place a stadia rod in the thalweg, making sure it is plumb and the top is higher than top-of-bank.
2. Find the bankfull and top-of-bank indicators (see steps 1 and 3 in Option A, respectively).
3. Using the hand-held laser level, point the level horizontally from the bankfull indicator to the stadia rod and record the elevation on the rod. This is bankfull height (BFH).
4. Using the hand-held laser level, point the level horizontally from the top-of-bank to the stadia rod and record the elevation on the rod. (Top-of-bank is the lowest elevation along the bank.) This is channel-full height (CFH).
5. Divide bankfull height by channel-full height (BFH/CFH) to obtain the Incision ratio.
6. Divide the Incision ratio (IR) by 0.5 or use the graph in Figure 10.

### 4.5.1 Dam Effect ($V_{FLOW}$)

*Measure/Units:* The proportion of the WAA stream network that is upstream from a dam taller than 10% of the stream's width. Use the following procedure to measure $V_{FLOW}$:

1. Determine the stream network length[*] for the drainage basin upstream from the WAA (centered on the stream at the upstream end of the WAA).
2. Identify all dams, taller than 10% of their stream's width, in the stream network above the WAA (Figure 11).
3. Determine the stream lengths above each dam. Where there are multiple dams within a network, disregard any dam up-gradient from it. (A dam is assumed to affect the entire network above it.)
4. Sum the lengths of dam-affected reaches.
5. Divide the sum of dam-affected reaches by the network length of the WAA and subtract this quotient from 1.0. For example, if there are 100 miles of stream network above a WAA and 70 miles of the network have at least one dam, then $V_{FLOW}$= 1-(70/100) = 0.30 (Figure 12).

### 4.5.2 Surface Water Storage ($V_{STORAGE}$)

*Measure/Units:* Change in storage capacity in a Floodplain Depression. Use the following procedures to measure $V_{STORAGE}$:

1. Determine if the Floodplain Depression has been drained by a ditch, if the inlet/outlet has been artificially lowered, if water is being removed mechanically with pumps, or if water is being diverted to the depression.
2. If the depression has been drained by a ditch or the inlet/outlet has been lowered:

    a. Determine the original depth of the depression ($D_{max}$) when the depression was full of water, which is the vertical height measured from the lowest point in the depression to the elevation of the bottom of the natural outlet.
    b. Determine the new (altered) depth of the depression ($D_{alt}$), which is the vertical height measured from the lowest point in the depression to the elevation of the bottom of the drainage ditch or bottom of the lowered (artificial) outlet.
    c. Determine the maximum (original) volume (Vmax) of the depression when the depression was full ($A_{max}$) (i.e., when the depression depth was at $D_{max}$.

[*] Watershed areas could be used, rather than stream network length if that information is more readily available. Since the percentage of stream length or watershed size is used in the calculations, either method is appropriate.

d. At full capacity, before being artificially drained, determine maximum volume (*Vmax*) by using the following formula:

e. $Vmax = \frac{Amax * Dmax}{3}$. (2)

f. Calculate the maximum volume (V*alt*) of the depression with the new (altered) outlet elevation, using the equation:

$$Valt = \frac{Amax * Dmax}{3} x \left(\frac{Dalt}{Dmax}\right)^3 (3)$$

g. Divide *Valt* by *Vmax* to obtain the proportional change in the depression's storage capacity or use Figure 13.

3. If water is being mechanically removed from the depression, determine the altered, average depth, or if that cannot be determined, assign zero to the subindex score.
4. If water is being artificially diverted to the depression, assign a subindex score of 0.5.

### 4.5.3 Soil Quality ($V_{SOILQUAL}$)

*Measure/Units:* Presence of hydric soil indicators relative to presence of organic matter and redox features. This variable is composed of two parameters: proportion (%) of samples with organic matter (OM) and proportion (%) of samples with redoximorphic features (Redox). Use the following procedure to OM and Redox in soils throughout the WAA:

1. Sample in the 10 m-radius (314.16 $m^2$) plot used for measuring $V_{BIG3}$ below. Use more plots if needed but be sure that plots do not overlap.
2. Divide the plot into four quadrants, one in each cardinal direction.
3. Within each plot, excavate a hole to approximately 20 in. following the guidance in USACE (2012). Note: Soil homogeneity is assumed within the plot. In addition, if a wetland determination has already been conducted, the results can be used for this variable.
4. For the OM parameter, determine if an "A" horizon of a minimum of 3 in. is present, an "O" horizon of any thickness, or both are present.
5. For Redox, determine if redox features are present (1.0) or absent (0.1) for each soil sample, using criteria to identify redoximorphic features as outlined in USACE (2012).
6. For both OM and Redox, record the subindex (Table 8) that coincides with the proportion of samples obtained in the WAA, as determined in steps 4 and 5 above.

7. Calculate $V_{SOILQUAL}$ by dividing the sum of the OM subindex plus the Redox subindex by two for each sample and average across samples.

#### 4.5.4 Basal Area of Largest Trees ($V_{BIG3}$)

*Measure/Units:* Cross-sectional area (in basal area in $m^2$/ha) of the three largest diameter trees in one or more 10 m-radius circular plots. Use the following procedure to measure $V_{BIG3}$:

1. Establish a 10 m-radius (314.16 $m^2$) plot. Use more plots if needed but be sure that plots do not overlap.
2. Measure the diameter (in cm) of the three largest trees in each plot using a diameter tape, a Biltmore stick, or caliper. Identify each tree to species (to be used in the $V_{BIG3COMP}$ variable).
3. Determined the cross-sectional area (basal area) of each tree by applying the formula $\prod r^2$, where r=radius of each tree.
4. Sum the basal areas of all trees, by species.
5. Divide basal area of each species, in step #4, by (314.16 *x* the number of plots sampled) to obtain basal area for each tree in $m^2$/ha.*
6. Sum the basal areas.
7. Divide the sum, in step #6 by the $V_{BIG3}$ reference standard for each subclass. If the resulting quotient is greater than one, then the subindex score= 1.0; if the quotient is less than 1.0, then the quotient= the subindex score or use Figure 15 to determine the subindex score.

#### 4.5.5 Canopy Tree Composition ($V_{BIG3COMP}$)

*Measure/Units:* A unitless measure combining the wetland status of the $V_{Big3}$ trees and the proportion of those trees identified as dominating reference standard stands for the subclass being assessed. Use the following procedure to measure $V_{BIG3COMP}$:

1. Obtain the total basal area of each tree sampled in one or more 10 m-radius plots. These values are generated in step #5 of the $V_{BIG3}$ variable.
2. Multiply each species by its wetland indicator value (Table 9), using the following values: Obligate= 5, Facultative wet= 4, Facultative= 3, Facultative upland=2, and Upland species= 1, derived from National

* $cm^2/m^2 = m^2$/ha.

Wetland Indicator plant list,[*] for the USACE District in which the WAA occurs.

3. Sum results of all values derived in Step 2 to get a $V_{BIG3COMP}$ subindex.
4. Divide by the $V_{BIG3COMP}$ subindex score in Step 3 by $V_{BIG3COMP}$ standard in the $V_{BIG3COMP}$ standard row of Table 9 for the evaluated subclass. If the resulting value is greater than 1.0, reduce it to 1.0 (Figure 16).

### 4.5.6 Invasive Plant Species ($V_{INVASIVE}$)

*Measure/Units:* Percent cover of invasive plant species. Use the following procedure to measure $V_{INVASIVE}$:

1. Establish a plot or series of plots, using a plot size that is manageable for estimating coverage of the invasive species on the site.
2. List and estimate percent cover of every invasive species in each plot, by species, using the following cover categories, recording the midpoint (in parentheses) for each species: (0% (0), 0%-5% (2.5), 5%-25% (15), 25% (25), 25%-50% (37.5), 50% (50), 50%-75% (62.5), 75% (75), 75%-95% (85), 95%-100% (97.5), >100% (100).[†]
3. Calculate the mean percent cover of all invasive species across all plots and divide by 100 to obtain a proportion.
4. Use Figure 17 to determine the subindex for $V_{INVASIVE}$.

### 4.5.7 Regeneration Potential ($V_{REGEN}$)

*Measure/Units:* The proportion of sapling tree species present in the in WAA relative to canopy species (>15 cm DBH) identified as reference standard species for the subclass being assessed. Use the following procedure to measure $V_{REGEN}$:

1. Keep a running tally of canopy species (trees >15 cm DBH) that occur on the checklist of canopy species listed in Table 9 for the subclass being assessed. Examine the entire WAA, not just saplings tallied in plots.
2. Keep a running tally of all sapling species (stems > 1 m tall, > 5 cm DBH) that occur on the checklist of canopy species, listed in Table 9,

[*] Wetland status for trees on the USACE Wetland Plant List, by USACE District, can be downloaded at: https://wetland-plants.usace.army.mil/nwpl_static/v34/home/home/.

[†] These are the same cover categories used for $V_{HYDROALT}$.

for the subclass being assessed. Examine the entire WAA, not just saplings tallied in plots.

3. Determine the proportion of sapling species tallied relative to the canopy species tallied for the subclass being assessed. For example, if the WAA has six canopy tree species in the Table 9 list and five are also represented in the sapling stratum, then $V_{REGEN}$ = 5/6= 0.83 (Figure 18). If the same or more sapling species in the Table 9 list are present as canopy species, the subindex is 1.0. If the canopy has been recently clearcut or selectively cut, then the canopy may be absent or degraded. In this case, determine how many sapling species from the Table 9 list for the subclass occur in the WAA, multiply by four (for all subclasses, except for the Floodplain depression subclass), and divide the number of species listed in Table 9 for the subclass. However, for the Floodplain Depression subclass, only one species on the canopy list (Table 9) needs to be in the sapling stratum because some depressions canopies are monotypic.

### 4.5.8 Available Core Habitat ($V_{CORE}$)

*Measure/Units:* Proportion of forested land use from three concentric circular zones, centered on the WAA. Use the following procedure to measure $V_{CORE}$:

1. Obtain a recent, high-resolution aerial imagery of the WAA and adjacent land.
2. Centered on the WAA, outline three concentric circles on the aerial photo, of diameters 46 m (150 ft), 122 m (400 ft), and 366 m (1,200 ft) (Figure 19).
3. Estimate the proportion of land with contiguous, connecting forest cover within each zone.
4. Obtain the mean value of the three circles.
5. Use Figure 20 to determine the subindex score for $V_{CORE}$ (do not score the subindex less than 0.1)

## 4.6 Analyze field data

The data recorded on the field forms must be transferred to the spreadsheet calculator for calculation of functional capacity units (FCU) automatically.

## 4.7 Document assessment results

Once data collection, summarization, and analyses have been completed, it is important to assemble all pertinent documentation. Appendix B1 is a cover sheet that, when completed, identifies the assembled maps, drawings, project description, data forms, and summary sheets (including spreadsheet printouts) that are attached to document the assessment. It is highly recommended that this documentation step be completed.

## 4.8 Apply assessment results

Once the assessment and analysis phases are complete, the results can be used to compare the same WAA at different points in time, compare different WAAs at the same point in time, or compare different alternatives to a project. The basic unit of comparison is the FCU, but it is often helpful to examine specific impacts and mitigation actions by examining their effects on the FCI, independent of the area affected. The FCI/FCU spreadsheets are particularly useful tools for testing various scenarios and proposed actions—they allow experimentation with various alternative actions and areas affected to help isolate the project options with the least impact or the most effective restoration or mitigation approaches.

Note that the assessment procedure does not produce a single grand index of function; rather, each function is separately assessed and scored, resulting in a set of functional index scores and functional units. How these are used in any particular analysis depends on the objectives of the analysis. In the case of an impact assessment, it may be reasonable to focus on the function that is most detrimentally affected. In cases where certain resources are regional priorities, the assessment may tend to focus on the functions most directly associated with those resources. For example, wildlife functions may be particularly important in an area that has been extensively converted to agriculture. Hydrologic functions may be of greatest interest if the project being assessed will alter water storage or flooding patterns. Conversely, this type of analysis can help recognize when a particular function is being maximized to the detriment of other functions, which might occur where a wetland is created as part of a stormwater facility; vegetation composition and structure, woody debris accumulation, and other variables in such a setting would likely demonstrate that some functions are maintained at very low levels, while hydrologic functions are maximized.

Generally, comparisons can be made only between wetlands or alternatives that involve the same wetland subclass, although comparisons between subclasses can be made based on functions performed rather than the magnitude of functional performance. For example, Riverine subclasses have import and export functions that are not present in Footslope seeps. Conversely, Footslope seeps are more likely to support rare wetland species than are drier floodplains.

## 4.9 Special issues in applying the assessment results

Users of this document must recognize that not all situations can be anticipated or accounted for in developing a rapid assessment method. Users must be able to adapt the material presented here to special or unique situations encountered in the field. Most of the reference sites were relatively mature, diverse, and structurally complex hardwood stands. However, there are situations where relatively low diversity and different structural characteristics may be entirely appropriate, and professional judgment in the field is essential to proper application of the models. For example, some depression sites with near-permanent flooding are dominated by buttonbush. Where this occurs because of water control structures or drainage impeded by roads, it should be recognized as having arrested functional status, at least for some functions. However, where the same situation occurs due to beaver activity or changes in channel courses, the buttonbush swamp should be recognized as a functional component of a larger wetland complex.

Another potential way to consider beaver in the modern landscape is to adopt the perspective that beaver complexes are fully functional, but transient components of Riverine wetland systems for all functions. At the same time, if beaver are not present (even in an area where they would normally be expected to occur), the resulting Riverine wetland can be assessed using the models, but the overall WAA is not penalized either way. Other situations that require special consideration include areas disturbed by fire, sites damaged by ice storms, and similar occurrences. Crown fires can cause dramatic changes in some of the indicators measured to assess functions, such as death of canopy trees. Note, however, that natural, noncatastrophic disturbances to Piedmont floodplains (i.e., disease of insect outbreaks causing tree mortality and subsequent canopy openings) are accounted for in the reference data used in this guidebook.

The assessment models and procedures presented in this guidebook are for assessing the most common subclasses that exist within alluvial valleys of the Piedmont. However, the classification system presented in Chapter 2 includes a few riverine wetland subclasses that may occur, rarely, within the reference domain (e.g., riverine flats), but are not specifically covered by this guidebook. Users of this guidebook may be faced with situations where they need to draw some conclusions regarding the effects of proposed actions on these excluded systems. The discussion of their characteristics presented in Appendix A is specifically provided to assist users who encounter these uncommon or unique systems.

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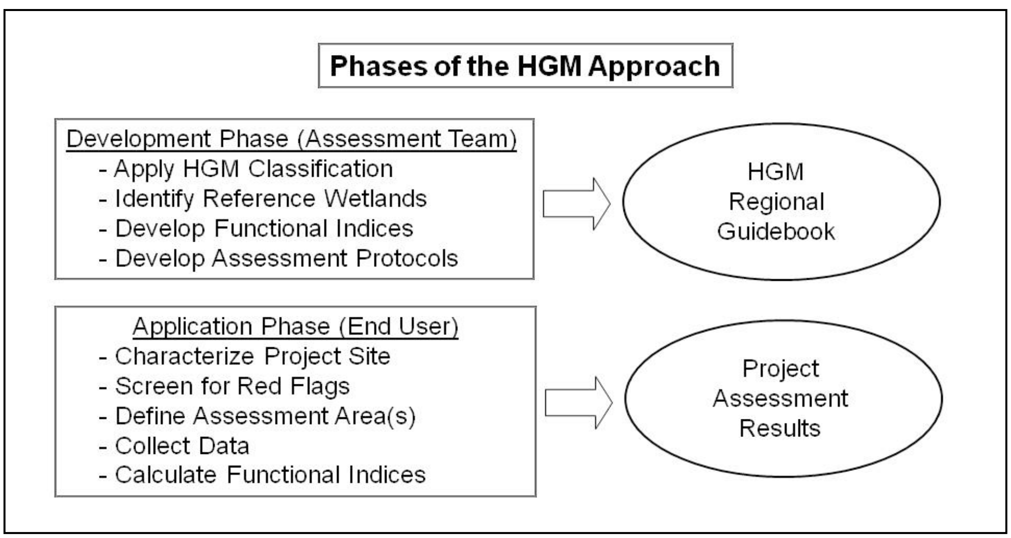
# Appendix A: Overview of the Hydrogeomorphic Approach

## A.1 Development and application phases

The HGM Approach consists of four components: (a) the HGM classification; (b) data for reference wetlands; (c) assessment variables and assessment models from which functional indices are derived; and (d) assessment protocols. The HGM Approach is conducted in two phases. An interdisciplinary Project Development Team (PDT) of experts carries out the Development Phase of the HGM Approach (Figure A1). The task of the PDT is to help develop and integrate the classification, identify possible reference wetlands, identify available data and information, suggest and discuss potentially useful assessment variables, discuss models, and suggest general field methods (Smith et. al. 2013). Several members of the PDT take responsibility for conducting the fieldwork and adjusting the protocol so that appropriate data are being collected for the Regional HGM type under consideration. This includes adding or deleting variables and adjusting field methodology to most-efficiently obtain the data required.

Figure A-1. Development and application phases of the HGM Approach (modified from Ainslie et al. 1999).




In developing a regional guidebook, the PDT completes the tasks outlined in the National Action Plan for Implementation of the HGM Approach (Federal Register 1997). After organization and training, the first task of the team is to classify the wetlands of the region of interest into regional wetland subclasses using the principles and criteria of Hydrogeomorphic Classification (Brinson 1993b; Smith et al. 1995). Next, focusing on specific regional wetland subclasses, the team develops an ecological characterization or functional profile of each subclass. The PDT then identifies the important wetland functions, conceptualizes assessment models, identifies assessment variables to represent the characteristics and processes that influence each function, and defines metrics for quantifying assessment variables. Next, a subset of the PDT conducts fieldwork to identify and collect data on reference wetlands that represent the range of variability exhibited by each regional subclass. The field data are used to calibrate assessment variables and populate indices used in the assessment models. Finally, the team develops the assessment protocols necessary for regulators, managers, consultants, and other end users to apply the indices to the assessment of wetland functions in the context of 404 Permit review, restoration planning, and similar applications. Development of this guidebook followed guidance as described in Smith et al. (2013) (Table A-1).

Table A-1. Steps in Piedmont HGM Guidebook Development (Smith et. al. 2013).

| |
|---|
| Task 1: Organize the Assessment Team<br>A. Identify team members<br>B. Train team in the HGM Approach |
| Task 2: Select and Characterize Wetland Subclass<br>A. Identify and prioritize wetland subclasses<br>B. Select wetland subclass<br>C. Define reference domain<br>D. Characterize wetland subclass |
| Task 3: Select Functions, Variables, and Metrics and Develop Conceptual Assessment Models<br>A. Select and define wetland functions for wetland subclass<br>B. Review existing assessment models for selected functions<br>C. Identify potential assessment variables and metrics<br>D. Develop conceptual relationship between variables and functional capacity<br>E. Construct conceptual assessment models for deriving Functional Capacity Index (FCI)<br>F. Complete Precalibrated Draft Guidebook (PDG) |
| Task 4: Conduct Peer Review of Precalibrated Draft Guidebook<br>A. Distribute PDG to peer reviewers<br>B. Conduct interdisciplinary, interagency workshop of PDG<br>C. Revise PDG to reflect peer review recommendations<br>D. Distribute revised PDG to peer reviewers for comment<br>E. Incorporate final comments from peer reviewers on revisions into the PDG |

| |
|---|
| Task 5: Select and Sample Reference Wetlands<br>A. Identify reference wetland field sites<br>B. Collect data from reference wetland field sites<br>C. Manage and prepare reference wetland data for analysis |
| Task 6: Test and Calibrate Assessment Variables and Models<br>A. Test and calibrate assessment variables using reference wetland data<br>B. Verify and validate (optional) assessment models<br>C. Field test assessment models for accuracy, repeatability, and user-friendliness<br>D. Revise PDG based on calibration, verification, validation (optional), and field test results into a Calibrated Draft Guidebook (CDG) |
| Task 7: Conduct Peer Review and Field Tests of Calibrated Draft Guidebook<br>A. Distribute CDG to peer reviewers<br>B. Field test CDG<br>C. Revise CDG to reflect peer review and field test recommendations<br>D. Distribute CDG to peer reviewers for final comment on revisions<br>E. Incorporate peer reviewers' final comments on revisions<br>F. Publish Operational Draft Guidebook (ODG) |
| Task 8: Technology Transfer<br>A. Train end users in the use of the ODG<br>B. Provide continuing support and technical assistance to the ODG end-user |

During the Application Phase, the assessment variables, models, and protocols are used to assess wetland functions. This involves two steps. The first is to apply the assessment protocols outlined in the regional guidebook to complete the following tasks:

- Define assessment objectives
- Characterize the project site
- Screen for red flags
- Define the Wetland Assessment Area
- Collect field data
- Analyze field data
- Interpret data relative to objectives

The second step involves applying the results of the assessment at various decision-making points in the planning or permit review sequence, such as alternatives analyses, impact minimization, assessment of unavoidable impacts, determination of compensatory mitigation, design and monitoring of mitigation, comparison of wetland management alternatives or results, determination of restoration potential, or identification of acquisition or mitigation sites. Each of the components of the HGM Approach that are developed and integrated into the regional guidebook is discussed briefly below. More extensive treatment of these components can be found in Brinson (1993a; 1993b), Brinson et al. (1998), Smith et al. (1995), and Hauer and Smith (1998).

### A.1.1 Project Delivery Team and Milestones

The PDT tested and vetted this draft guidebook over a period of six years despite restricted travel restrictions due to COVID-19 in 2020 and 2021 (Tables A-2 and A-3). PDT members listed in Table A-2 represent active members as of January 2020. Representative Piedmont HGM subclasses were *Beta* tested in 2021 and 2022. The main objective of *Beta* testing was to determine the user "friendliness" of the field data sheets.

Table A-2. Project Delivery Team (PDT) members, Piedmont HGM Guidebook development.

| Name (Listed in Alphabetical Order) | | | |
|---|---|---|---|
| Last | First | Title | Affiliation |
| Ainslie | Bill | Wetland Scientist | USEPA-Region 4 |
| Bailey | David | Regulatory Project Manager | USACE-Wilmington District |
| Darden | Richard | Biologist/Special Projects PM | USACE-Charleston District |
| Flexner | Morris | Biologist | USEPA-LSASD |
| Gordon | Kyle | WRAP-Program Manager | USACE-ERDC |
| Hammonds | Justin | Environ. Scientist | USACE-Savannah District |
| Knepper | Dave | Environ. Scientist | USACE-Norfolk District |
| Laycock | Kelly | Wetland Scientist | USEPA-Region 4 |
| Lekson | David | Regulatory Chief | USACE-Washington Field Office |
| McKay | Kyle | Research Engineer | USACE-ERDC |
| Pederson | Dee | Soil Scientist | USDA-NRCS |
| Plewa | Frank | Wetland Specialist | USACE- Baltimore District |
| Pruitt | Bruce | Research Ecologist | USACE-ERDC |
| Rheinhardt | Rick | Research Ecologist | Consulting/Adjunct Research Prof. ECU |
| Shaeffer | Dave | Geographer/Project Manager | USACE-Wilmington (Raleigh) |
| Turney | Leslie | Biologist/Project Manager | USACE-Mobile District |
| Wilder | Tim | Biologist/Section Chief | USACE-Nashville District |

Table A-3. Piedmont HGM Guidebook development milestones.

| Milestone | Date(s) |
|---|---|
| Initial Guidebook Development Presentation (Pruitt) | Dec. 17, 2014 |
| Guidebook Kickoff with PDT (Athens, GA) | Feb. 24-26, 2015 |
| Field Data Form Testing & Revisions | Mar 2015––Mar. 2018 |
| Progress Report (to WRAP) | April 2015 |
| Progress Report (to WRAP) | June 2015 |
| Guidebook Development Status Report (to PDT) | Sept. 17, 2015 |
| Progress Report (to WRAP) | December 2015 |
| Progress Report (to WRAP) | March 2016 |
| Progress Report (to WRAP) | April 2016 |
| Progress Report (to WRAP) | September 2016 |
| Guidebook Development Status Report (to PDT) | Apr. 27, 2018 |
| PDT Meeting (Draft Guidebook Review) | Sept. 5 & 6, 2018 |
| Guidebook Version 9.0 Reviewed by PDT | Mar. 20, 2019 |
| Guidebook Version 9.0 Field Beta Testing | Mar.––Oct. 2020 |
| Guidebook Version 13.0 Reviewed by PDT | Mar. 20, 2019 |
| Guidebook Version 13.0 Field Beta Testing | Mar.––Oct. 2022 |

## A.2 Hydrogeomorphic Classification

Wetland ecosystems share several common attributes including hydrophytic vegetation, hydric soils, and relatively long periods of inundation or saturation. Despite these common attributes, wetlands occur under a wide range of climatic, geologic, and physiographic situations and as a result, exhibit a variety of physical, chemical, and biological characteristics and processes (Cowardin et al. 1979; Mitch and Gosselink 1993). The variability of wetlands makes it challenging to develop assessment methods that are both accurate (i.e., sensitive to significant changes in function) and practical (i.e., can be completed in the relatively short time frame available for conducting assessments). Existing "generic" methods designed to assess multiple wetland types throughout the United States are relatively rapid but lack the resolution necessary to detect significant changes in function. One way to achieve an appropriate level of resolution within the available time frame is to compartmentalize reference sites to reduce the level of natural variability that has to be accounted for in the models (Smith et al. 1995).

The HGM Classification was developed specifically to accomplish this compartmentalization (Brinson 1993b). It identifies groups of wetlands using three criteria that fundamentally influence how wetlands function: geomorphic setting, water source, and hydrodynamics. Geomorphic setting refers to the landform and position of the wetland in the landscape. Water source refers to the primary origin of the water that sustains wetland characteristics, such as precipitation, floodwater, or groundwater. Hydrodynamics refers to the level of energy with which water moves through the wetland, and the direction of water movement (inflow and outflow).

Based on these three classification criteria, a finite number of functional wetland groups can be identified at different spatial or temporal scales. For example, at a continental scale, Brinson (1993b) identified five hydrogeomorphic wetland classes. These were later expanded to the seven classes described in Smith et al. (1995) (Table A-4).

Table A-4 Hydrogeomorphic wetland classes at the Continental Scale.

| HGM Wetland Class | Definition |
|---|---|
| Depression | Depression wetlands occur in topographic depressions (i.e., closed elevation contours) that allow the accumulation of surface water. Depression wetlands may have any combination of inlets and outlets or lack them completely. Potential water sources are precipitation, overland flow, streams, or groundwater/interflow from adjacent uplands. The predominant direction of flow is from the higher elevations toward the lowest point of the depression. The predominant hydrodynamics are vertical fluctuations that range from diurnal to seasonal. Depression wetlands may lose water Through evapotranspiration, intermittent or perennial outlets, or infiltration to groundwater. Prairie potholes, playa lakes, vernal pools, and cypress domes are common examples of depression wetlands. |
| Tidal Fringe | Tidal fringe wetlands occur along coasts and estuaries and are under the influence of sea level. They intergrade landward with Riverine wetlands where tidal current diminishes, and river flow becomes the dominant water source. Additional, but less influential, water sources may be groundwater discharge and precipitation. The interface between the tidal fringe and Riverine classes is where bidirectional flows from tides dominate over unidirectional flow controlled by floodplain slope of Riverine wetlands. Because tidal fringe wetlands frequently flood and water table elevations are controlled mainly by sea surface elevation, tidal fringe wetlands are never dry for significant periods. Tidal fringe wetlands lose water during ebb flow, by overland flow to tidal creek channels, and by evapotranspiration. Organic matter (peat) normally accumulates in soils via roots in marshes and via down, dead wood |

| HGM Wetland Class | Definition |
|---|---|
| | in forests. *Spartina alterniflora* salt marshes and tidal freshwater swamps are common examples of tidal fringe wetlands. |
| Lacustrine Fringe | Lacustrine fringe wetlands are adjacent to lakes where the water elevation of the lake maintains the water table in the wetland. In some cases, such wetlands consist of a floating mat attached to land. Additional sources of water are precipitation and groundwater discharge, the latter dominating where lacustrine fringe wetlands intergrade with uplands or slope wetlands. Surface water flow is bidirectional, usually controlled by water-level fluctuations resulting from wind or seiches. Lacustrine wetlands lose water by flow returning to the lake after flooding and by drawdown of water in the lake via evapotranspiration or lake-level manipulation (in man-made reservoirs) Organic matter may accumulate in areas sufficiently protected from shoreline wave erosion and where water levels are relatively constant or where groundwater discharges at the lake edge. Unimpounded marshes bordering the Great Lakes are an example of lacustrine fringe wetlands. |
| Slope | Slope wetlands are found in association with the discharge of groundwater to the land surface or sites with saturated overflow with no channel formation, or near a channel that only serves to convey water away from the slope wetland, rather than deliver water to it. They normally occur on sloping land ranging from slight to steep. The predominant source of water is groundwater or interflow discharging at the land surface. Precipitation is often a secondary contributing source of water. Hydrodynamics are dominated by downslope unidirectional water flow. Slope wetlands can occur in nearly flat landscapes if groundwater discharge is a dominant source to the wetland surface (most flats are precipitation-driven). Slope wetlands lose water primarily by saturated subsurface flows, loss via a low-order stream, and by evapotranspiration. Slope wetlands are distinguished from depression wetlands by the lack of a closed topographic depression and the predominance of the groundwater/interflow water source. Fens are a common example of slope wetlands. |
| Mineral Soil Flats | Mineral soil flats are most common on interfluves, extensive relic lake bottoms, or large floodplain terraces where the main source of water is precipitation. They receive virtually no groundwater discharge, which distinguishes them from depressions and slopes. Dominant hydrodynamics are vertical fluctuations. Mineral soil flats lose water by evapotranspiration, overland flow, and infiltration to underlying groundwater. They are distinguished from flat upland areas by their poor vertical drainage due to impermeable layers (e.g., hardpans or their close proximity to the underlying water table), slow lateral drainage, and low hydraulic gradients. Mineral soil flats that accumulate peat can eventually become organic soil flats. They typically occur in relatively humid climates. Pine flatwoods with hydric soils are an example of mineral soil flat wetlands. |
| Organic Soil Flats | Organic soil flats, or extensive peatlands, differ from mineral soil flats in part because their elevation and topography are controlled by vertical accretion of organic matter. They occur commonly on flat interfluves but may also be located where depressions have become filled with peat to form a relatively large flat surface. Water source is dominated by precipitation, while water loss is by overland flow and seepage to underlying groundwater. They occur in relatively humid |

| HGM Wetland Class | Definition |
|---|---|
| | climates. Raised bogs (e.g., pocosins) share many of these characteristics, but may be considered a separate class due to their convex upward form, which provides distinctive edaphic conditions for plants. Organic soil flat wetlands include portions of the Everglades, pocosins in the Carolinas, and peatlands in northern Minnesota. |
| Riverine | Riverine wetlands occur in floodplains and riparian corridors in association with stream channels. Dominant water sources are overbank flow from the channel or subsurface hydraulic connections between the stream channel and wetlands. Additional sources may be interflow, overland flow from adjacent uplands, tributary inflow, and precipitation. When overbank flow occurs, surface flow down the floodplain dominates hydrodynamics. In headwaters, Riverine Wetlands often intergrade with slope wetlands, depressions, poorly drained flats, or uplands where channel (bed) and bank are absent. Perennial flow is not required. Riverine wetlands lose surface water via the return of floodwater to the channel after flooding and through surface flow to the channel during rainfall events. They lose subsurface water by discharge to the channel, movement to deeper groundwater (for losing streams), and evaporation. Peat may accumulate in off-channel depressions (oxbows) that have become isolated from riverine processes and subjected to long periods of saturation from groundwater sources. Bottomland hardwoods on floodplains are an example of riverine wetlands. |

Generally, the level of variability encompassed by wetlands at the continental scale of hydrogeomorphic classification is too broad to allow development of assessment indices that can be applied rapidly and still retain the level of sensitivity necessary to detect changes in function at a level of resolution appropriate to the 404-permit review. To reduce both inter and intraregional variability, the three classification criteria must be applied at a smaller, regional geographic scale, thus creating regional wetland subclasses. In many parts of the country, existing wetland classifications can serve as a starting point for identifying these regional subclasses (e.g., Golet and Larson 1974; Stewart and Kantrud 1971; Wharton et al. 1982). Regional subclasses, like the continental scale wetland classes, are distinguished based on geomorphic setting, water source, and hydrodynamics. Examples of potential regional subclasses are shown in Table A-5. In addition, certain ecosystem or landscape characteristics may be useful for distinguishing regional subclasses. For example, depression subclasses might be based on water source (i.e., rainfall versus surface flooding) or the degree of connection between the wetland and other surface waters (i.e., the flow of surface water in or out of a depression through defined channels). Tidal fringe subclasses might be based on salinity gradients (Shafer and Yozzo 1998). Slope subclasses might be based on the degree of slope or landscape position (e.g., elevation or aspect). Riverine subclasses might be based on stream order, watershed size, channel gradient, or floodplain width. Regional guidebooks include a thorough characterization of regional wetland subclasses relative to geomorphic setting, water sources, hydrodynamics, vegetation, soil, and other features that are important to functioning. However, transitional zones between subclasses are difficult to classify in that they have characteristics inherent to both subclasses. Thus, rather arbitrary criteria must be used sometimes to define subclass boundaries.

Table A-5. Potential regional wetland subclasses in relation to classification criteria.

| Classification Criteria | | | Potential Regional Wetland Subclasses | |
|---|---|---|---|---|
| **Geomorphic Setting** | **Dominant Water Source** | **Dominant Hydrodynamics** | **Eastern USA** | **Western USA/Alaska** |
| Depression | Groundwater or interflow | Vertical | Prairie potholes, marshes, Carolina bays | California vernal pools |
| Fringe (lacustrine) | Lake | Bidirectional, horizontal | Great Lakes marshes | Flathead Lake marshes |
| Slope | Groundwater | Unidirectional, horizontal | Headwater wetlands | Avalanche chutes |
| Flat (mineral soil) | Precipitation | Vertical | Wet pine flatwoods | Large playas |
| Flat (organic soil) | Precipitation | Vertical | Peat bogs; portions of Everglades, pocosins | Peatlands over permafrost |
| Riverine | Overbank flow from channels | Unidirectional, horizontal | Bottomland hardwood forests | Riparian wetlands |
| Adapted from Smith et al. (1995), and Rheinhardt et al. (1997). | | | | |

## A.3 Reference Wetlands

Reference wetlands are wetland sites selected to represent the range of variability that occurs in a regional wetland subclass due to natural processes and disturbances (e.g., succession, channel migration, fire, erosion, and sedimentation) as well as due to anthropogenic (human-caused) alterations. The reference domain is the geographic area occupied by a set of reference wetlands (Smith et al. 1995). Ideally, the geographic extent of the reference domain will mirror the geographic area encompassed by the regional wetland subclass; however, this is not always possible due to time and resource constraints.

Reference wetlands serve several purposes. First, they establish a basis for defining what constitutes a characteristic and sustainable level of functioning across the suite of functions selected for a regional wetland subclass. Second, they establish the range and variability of conditions exhibited by model variables and provides the data necessary for calibrating model variables and assessment models. Finally, they provide concrete physical examples (sites on the ground) of wetland ecosystems that can be observed, measured, and followed through time.

Reference standard wetlands are the subset of reference wetlands that perform the suite of functions selected for a regional subclass at a level that is characteristic of the least altered conditions in the least altered landscapes. Table A-6 outlines the terms used by the HGM Approach in the context of reference wetlands.

Table A-6. Reference wetland terms and definitions.

| Term | Definition |
|---|---|
| Reference domain | The geographic area from which reference wetlands representing the regional wetland subclass are selected (Smith et al. 1995). |
| Reference wetlands | A group of wetlands that encompass the known range of variability in the regional wetland subclass resulting from natural processes and disturbances and from human alterations. |
| Reference standard wetlands | A subset of reference wetlands that perform a representative suite of functions at a level that is both sustainable and characteristic of the least human-altered wetland sites in the least human-altered landscapes. Functional capacity indices for all functions in reference standard wetlands are assigned a value of 1.0. |
| Reference standard wetland variable condition | The range of conditions exhibited by model variables in reference standard wetlands. Reference standard conditions receive a variable subindex score of 1.0. |
| Site potential (mitigation project context) | The highest level of function possible, given local constraints of alteration history, land use, or other factors (i.e., best attainable condition, *sensu* Stoddard 2006). Site potential may be less than or equal to the levels of function in reference standard wetlands of the regional wetland subclass. |
| Project target (mitigation project context) | The level of function identified or negotiated for a wetland restoration project. |
| Project standards (mitigation context) | Performance criteria and/or specifications used to guide the restoration activities toward the project target. Project standards should specify reasonable contingency measures if the project target is not being achieved. |

## A.4 Assessment models and functional indices

In the HGM Approach, an assessment model is a simple representation of a function typically performed by a specific subclass of a wetland ecosystem. The assessment model defines the relationship between the characteristics and processes of a wetland ecosystem and the surrounding landscape that influence the functional capacity of that ecosystem. Characteristics and processes are represented in the assessment model by assessment variables. Functional capacity is the ability of a wetland to perform a specific function relative to the ability at which reference standard wetlands perform the same function. Application of assessment models results in a Functional Capacity Index (FCI) ranging from 0.0 to 1.0. Wetlands with an FCI of 1.0 perform the assessed function at a level that is characteristic of reference standard wetlands. A lower FCI indicates that the wetland is performing a function at a level different from that of reference standard wetlands.

For example, the following equation shows an assessment model that could be used to assess the capacity of a wetland to support a characteristic plant community.

$$FCI = \left\{FCI\ Hydrology \times \left[\left(\frac{V_{BIG3}+V_{BIG3COMP}+V_{INVASIVE}}{3}\right) \times\ V_{REGEN}\right]\right\}^{1/3} \qquad (1)$$

This assessment model has five assessment variables: FCI of Hydrology for the subclass being assessed (*FCI Hydrology*), mean basal area of the three largest trees/plot ($V_{BIG3}$), and canopy composition of those trees related to wetland status and relative basal area ($V_{BIG3COMP}$), percent cover of invasive species ($V_{INVASIVE}$), and regeneration potential for typical canopy species ($V_{REGEN}$). Together, these terms represent the maturity and quality of the wetland's plant community. The state or condition of an assessment variable is indicated by the value of the metric used to assess a variable, and the metric used is normally one commonly used in ecological studies.

For example, tree basal area (cross-sectional area in $m^2$/ha) is often used to assess tree biomass in a wetland, with larger cross-sectional areas usually indicating greater stand maturity and increasing functionality for several different wetland functions wherein tree biomass is an important structural component. The value of the variable subindex is assigned based on the value of the assessment variable metric. When the metric value of an assessment variable is within the range of conditions exhibited by reference standard wetlands, a variable subindex of 1.0 is assigned. As the metric value deflects in either direction from the reference standard condition, the variable subindex decreases based on a defined relationship between metric values and functional capacity. Thus, as the metric value deviates from the conditions documented in reference standard wetlands, it receives a progressively lower subindex score, which reflects the decreased functional capacity of the wetland.

# Appendix B: Preliminary Project Documentation and Field Sampling Guidance

**Contents**

# Appendix B1

**SITE or PROJECT INFORMATION and ASSESSMENT DOCUMENTATION**

**(Complete one form for entire site or project area)**

Date: ____________________________________

Project/Site Name: _________________________

Person(s) involved in assessment:

Field ____________________________________________________________________

__________________________________________________________________________

Computations/summarization/quality control____________________________________

__________________________________________________________________________

The following checked items are attached:

_____ A description of the project, including land ownership, baseline conditions, proposed actions, purpose, project proponent, regulatory or other context, and reviewing agencies.

_____ Maps, aerial photos, and /or drawings of the project area, showing boundaries and identifying labels of Wetland Assessment Areas and project features.

_____ Other pertinent documentation (describe): ___________________________________

__________________________________________________________________

_____ Field Data Forms and assessment summaries (listed in table below):

<table>
<tr><th rowspan="3">Wetland Assessment Area (WAA) ID Number</th><th rowspan="3">HGM Subclass</th><th rowspan="3">WAA Size (ha)</th><th rowspan="3">Number of plots sampled</th><th colspan="4">Attached Data Forms and Summary Forms</th></tr>
<tr><th colspan="3">Data Forms (number attached)</th><th rowspan="2">FCI/FCU Calculator Output (from spreadsheet)</th></tr>
<tr><th>WAA or Tract Data<br><br>(1 per WAA)</th><th>Plot Data (sets of 2 sheets per plot)</th><th>WAA Plot Data Summary (from spreadsheet)</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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</table>

Page 1 of 1 plus attachments

# Appendix B2

## FIELD ASSESSMENT PREPARATION CHECKLIST

Prior to conducting the field studies, review the checklist below to determine field gear requirements and number of copies of each data form needed. It may be helpful to complete as much of the Project or Site Description Form (Appendix B1) as possible prior to field work.

| Field Gear | Comments |
|---|---|
| Distance Tape (metric)<br>[(length of $\geq$ 20 m (50 feet)] | More than one will be useful for measuring multiple variables simultaneously. |
| DBH tape, DBH calipers or Biltmore Stick™ (metric) | For the measurement of tree diameter. |
| Folding Rule | A folding rule is necessary for measuring the height of obstructions or depth of ditches, plus bankfull and channel-full dimensions |
| Shovel | For examining soil profiles for presence of organic matter redox features, for determining the $V_{SOILQUAL}$ variable. Shovels are also useful in anchoring distance tapes at the plot center. |
| Spirit level and string, or hand-held laser level | A small spirit level (such as a string level) and a length of string will be useful in determining incision ratio and depth of depression relative to outlet height |
| Plant identification guides | The correct identification of canopy species, invasive and exotic species is necessary. |
| Data forms | See data forms requirements in Table B1 (bringing extra forms to the field are often a good idea). |
| HGM Guidebook | Familiarity with the guidebook prior to field work is a time-saving step. |
| Aerial photos, soil survey and topographic maps | Confirmation of remotely collected data, such as land use and buffers, is necessary. Confirmation in the field of pre-identified WAAs and PWAAs is also necessary and will be aided using maps and aerial photographs. |
| GPS and camera | Although not strictly necessary to conduct an assessment, both items are highly recommended for documentation of site characteristics and data collection points. |
| Binoculars | Useful for determining species of tall canopy trees. |
| Miscellaneous | Clipboards, pencils, notebooks, flagging, insect repellant, and drinking water. |

## Appendix B3

### DATA FORMS

Print or copy the following summary page and data forms. Extra copies are always a good idea. Data can also be entered in the field directly into the calculator using a PC.

| FCI/FCU Calculator for the Piedmont Alluvial Plains HGM Guidebook | | | |
|---|---|---|---|
| Note: | "Yellow" cells = User Entry | | |
| | "Green" cells = Model Calculated | | |
| | "Gray" cells = information | | |
| Project Type: | | | |
| Select Timing: | | | |
| Field Team: | | | |
| Project Name: | | | |
| Lat/Long: | | | |
| Location: | | | |
| Sampling Dates: | | | |
| | | | Reset |
| Select Subclass*: | Footslope Seep on Headwater | WAA number: | |
| | | WAA size (ha): | |
| | | Watershed size above WAA (ha): | |

***Functional and Variable Results:*** Please Fill Out Site and Project Information Above

| | Function | FCI | |
|---|---|---|---|
| | **Maintain Characteristic Hydrology** | | |
| | **Maintain Biogeochemical Transformations & Cycling** | | |
| | **Maintain Characteristic Plant Community** | | |
| | **Maintain Characteristic Animal Community** | | |
| $V_{CATCH}$ | Percent area of wetland catchment altered | Worksheet 4 | |
| $V_{LULC}$ | Percent change in water surface water runoff | Worksheet 4 | |
| $V_{FLOW}$ | Percent of stream network affected by dams | Worksheet 4 | |
| $V_{HYDROALT}$ | Percent hydrologic alteration | Worksheet 5 | |
| $V_{INCISION}$ | Ratio of bankfull to channelfull | Worksheet 5 | |
| $V_{STORAGE}$ | Percent of storage capacity altered | Worksheet 5 | |
| $V_{SOILQUAL}$ | Percent soil coverage with organic matter and redox featur | Worksheet 5 | |
| $V_{BIG3}$ | Basal area of 3 largest trees | Worksheet 6 | |
| $V_{BIG3COMP}$ | Relationship between Big3 and wetland status | Worksheet 6 | |
| $V_{INVASIVE}$ | Percent cover of invasive species | Worksheet 7 | |
| $V_{REGEN}$ | Percent of canopy species found in sapling stratum | Worksheet 7 | |
| $V_{CORE}$ | Percentage of core habitat present in zones | Worksheet 7 | |

Variable Page 1 of 4

# FCI/FCU Calculator for the Piedmont Alluvial Plains HGM Guidebook

**Field Team:** | **Sampling Dates:**
**Project Name:**
**Location:**

**Subclass:**

**1 $V_{CATCH}$**
Watershed Catchment

Proportional change in the effective size of the WAA's catchment or basin. If there is no alteration, then $V_{CATCH}$ = 1.0.

Catchment or Watershed size (A):
If no hydrologic alterations to catchment, enter 1.0:
ditches, drains or diversions are present , enter size of catchment that has been altered (B):
If augmentation present: Enter size of catchment addition (C):
Adjusted Catchment Size (A-B+C):
$V_{CATCH}$ =

**2 $V_{LULC}$**
Landuse/Landcover

Weighted average infiltration/ET potential for a catchment (Include any augmented areas).

| LULC | Infiltration | Area* | Proportion |
|---|---|---|---|
| Forest | 1 | | |
| Grassland, Shrubland | 0.8 | | |
| Agriculture, Nurseries | 0.3 | | |
| Bareground | 0.2 | | |
| Impervious, Urban | 0.1 | | |
| | **Total** | | |

Cover Types = Total Adjusted Catchment Size Above

*Sum of LULC areas must equal adjusted area entered for $V_{CATCH}$ above.

**$V_{LULC}$ =**

**3 $V_{FLOW}$**
Stream Flow Relative to Dams

The proportion of the WAA's stream network that is upstream from the dam taller than 10% of the stream's width.

Total watershed area above WAA (excludes dams):
Number of dams within the drainage basin above the WAA (if 0, $V_{FLOW}$ = 1.0):

| **Dam No.** | |
|---|---|
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |
| 6 | |
| 7 | |
| Sum | |

**$V_{FLOW}$ =**

# FCI/FCU Calculator for the Piedmont Alluvial Plains HGM Guidebook

| | | | |
|---|---|---|---|
| **Field Team:** | | **Sampling Dates:** | |
| **Project Name:** | | | |
| **Location:** | | | |

**4 $V_{HYROALT}$**

Hydrologic Alteration

The proportion of the immediate WAA impacted by draining, damming, filling, excavating, and/or diverting water directly to it.

| | |
|---|---|
| WAA Area | |
| dammed | |
| drained | |
| filled | |
| excavated | |
| flooded by diversion | |
| $V_{HYROALT}$ = | |

**5 $V_{INCISION}$**

Stream Channel Incision

Bankfull height/channel-full height (unitless). Use for Footslope seep, Mid-gradient, Riverine Depression, and Low-Gradient (if can be safely measured)

| | |
|---|---|
| Bankfull height (BFH) = | |
| Channel-full height (CFH) = | |
| Incision Ratio (BFH/CFH) unitless $V_{INCISION}$ = | |

**6 $V_{STORAGE}$** Variable Not Used

Surface Water Storage

Change in storage capacity or effect of artificial water input into a Floodplain depression.

| | |
|---|---|
| Has WAA been artificially drained, enter yes or no: | |
| Has surface water been artificially introduced to the WAA, enter yes or no: | |
| WAA maximum depth before alteration ($D_{max}$): | |
| WAA altered depth ($D_{alt}$): | |
| Surface area of depression at depth ($A_{max}$): | |
| WAA pre-altered maximum volume ($V_{max}$): | |
| WAA altered maximum volume ($V_{alt}$): | |
| $V_{SURFCONN}$ = | |

**7 $V_{SOILQUAL}$**

Soil Quality

Presence of hydric soil indicators relative to presence of organic matter and redox features. Four quadrants required.

| | |
|---|---|
| Number of holes dug to characterize soils (A): | |
| Number of holes exhibiting organic matter (B): | |
| Number of holes with redox features (C), enter 0.1 if no redox features: | |
| OM Frequency (B/A): | |
| Redox Frequency (C/A): | |
| $V_{SOILQUAL}$ = | |

**Only used with Maintain Characteristic BGC Cycling Function**

Variable Page 3 of 4

# FCI/FCU Calculator for the Piedmont Alluvial Plains HGM Guidebook

**Field Team:** | **Sampling Dates:**

**Project Name:**

**Location:**

**8** $V_{BIG3}$ **Subclass:** Used for Maintain Char. Plant Community Only

3 Biggest Trees

Basal area in ($m^2$/ha) of the three largest diameter trees in one or more 10-m-radius circular plots.

**Enter number of plots used in WAA =**

| Largest Diameter | Species (Plot 1)* | Diameter (cm) | Species (Plot 2)* | Diameter (cm) | Species (Plot 3)* | Diameter (cm) |
|---|---|---|---|---|---|---|
| Tree 1 | | | | | | |
| Tree 2 | | | | | | |
| Tree 3 | | | | | | |

Basal Area ($m^2$/ha)

#DIV/0!

*Enter species abbreviation from Table 10.

$V_{BIG3}$ =

**9** $V_{BIG3COMP}$ **Subclass:** Used for Maintain Char. Plant Community Only

Big 3 Species Composition

A unitless measure combining the wetland status of the $V_{Big3}$ trees and the proportion of those trees identified as dominating reference standard stands for the subclass. **Species data from $V_{BIG3}$ used for this variable.**

Multiply basal area of each BIG3 tree species by its wetland indicator status (value).

| Tree species in BIG3 plots | BA ($m^2$/ha) | Indicator value* | Product (unitless) |
|---|---|---|---|
| #N/A | | | |
| #N/A | | | |
| #N/A | | | |
| #N/A | | | |
| #N/A | | | |
| #N/A | | | |
| #N/A | | | |
| #N/A | | | |
| #N/A | | | |
| | | **Sum:** | |

| Subclass | Standard ($m^2$/ha) |
|---|---|
| Footslope | 274 |
| Headwater Slope | 283 |
| Mid-Gradient Riverin | 277 |
| Low-Gradient Riverin | 273 |
| Depression | 195 |

Total number of tree species (A):

Number of BIG3 trees from Table 10 (B):

Ratio (A/B):

Product of Indicator Sum and Ratio:

*Note: if less than 3 plots are assessed, "#N/A" will be returned as indicator value.

$V_{BIG3COMP}$ =

Variable Page 4 of 4

## FCI/FCU Calculator for the Piedmont Alluvial Plains HGM Guidebook

| | | | |
|---|---|---|---|
| **Field Team:** | | **Sampling Dates:** | |
| **Project Name:** | | | |
| **Location:** | | | |

**10 $V_{INVASIVE}$** **Subclass:** Footslope Seep on Headwater

Invasive Species

Use Maintain Char. Plant Community Only

Percent cover of invasive plant species from Table 6 or enter known species not listed.

Estimated percent coverage for each species must be rounded to the nearest 10%:

| No. | Abbrev. | Species | % Coverage |
|---|---|---|---|
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | | | |
| 7 | | | |
| 8 | | | |
| | | Sum | |

$V_{INVASIVE}$ =

**11 $V_{REGEN}$** **Subclass:** Footslope Seep on Headwater

Regeneration

Use for Maintain Char. Plant Community and Maintain Char. Animal Community from FCI Plant Community

Number of tree species identified in BIG3:

Number of sapling species in understory same as canopy species:

$V_{REGEN}$ =

**12 $V_{CORE}$** **Subclass:** Footslope Seep on Headwater

Core Area

Use for Maintain Char. Animal Community Only

This variable expresses the availability of core habitat to animals that are normally expected to use the habitat of the subclass. Native forested areas of any age class and wetlands of any type are suitable habitat.

| | |
|---|---|
| Enter Percent forested area in Zone 1 | |
| Enter Percent forested area in Zone 2 | |
| Enter Percent forested area in Zone 3 | |
| $V_{CORE}$ = | |

| Wetland species and associated status and values | | | | Subclass and Reference Standards for $V_{BIG3}$ & $V_{BIG3COMP}$ | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Headwater | Mid-gradient | Low-gradient | Floodplain Depression | Footslope Seep |
| | | | $V_{BIG3}$ standard score | 13 | 21 | 16 | 17 | 17 |
| | | | $V_{BIG3COMP}$ standard score | 40 | 69 | 61 | 71 | 59 |
| **Species** | **Common Name** | **Wetland Status** | **Value** | | | | | |
| *Acer negundo* | Ash-leaf Maple | FAC | 3 | ✓ | | ✓ | | |
| *Acer rubrum* | Red Maple | FAC | 3 | ✓ | ✓ | ✓ | ✓ | ✓ |
| *Acer saccharinum* | Silver Maple | FAC | 3 | | | ✓ | | |
| *Betula lutea* | Yellow Birch | FACU | 2 | | | | | ✓ |
| *Betula nigra* | River Birch | FACW | 4 | | | ✓ | ✓ | |
| *Celtis laevigata* | Sugarberry | FACW | 4 | | | ✓ | | |
| *Diospyros virginiana* | Persimmon | FAC | 3 | | | ✓ | | |
| *Fagus grandifolia* | American Beech | FACU | 2 | | | | | ✓ |
| *Fraxinus pennsylvanica* | Green Ash | FACW | 4 | ✓ | ✓ | ✓ | ✓ | ✓ |
| *Juglans nigra* | Black Walnut | UPL | 1 | | | ✓ | | |
| *Liquidambar styraciflua* | Sweetgum | FAC | 3 | ✓ | ✓ | ✓ | | ✓ |
| *Liriodendron tulipifera* | Yellow poplar | FACU | 2 | ✓ | ✓ | ✓ | | ✓ |
| *Nyssa aquatica* | Water Tupelo | OBL | 5 | | | | ✓ | |
| *Nyssa biflora* | Swamp Tupelo | OBL | 5 | ✓ | ✓ | ✓ | ✓ | |
| *Nyssa sylvatica* | Black Tupelo | FAC | 3 | | | | | ✓ |
| *Platanus occidentalis* | American Sycamore | FACW | 4 | ✓ | ✓ | ✓ | | |
| *Populus deltoides* | Eastern cottonwood | FAC | 3 | | | ✓ | | |
| *Prunus serotina* | Black Cherry | FACU | 2 | ✓ | | | | |
| *Quercus alba* | White Oak | FACU | 2 | ✓ | | | | |
| *Quercus laurifolia* | Laurel oak | FACW | 4 | | ✓ | | ✓ | |
| *Quercus lyrata* | Overcup Oak | OBL | 5 | | | | ✓ | ✓ |
| *Quercus michauxii* | Swamp chestnut oak | FACW | 4 | ✓ | | | | ✓ |
| *Quercus nigra* | Water Oak | FAC | 3 | | ✓ | ✓ | | |
| *Quercus palustris* | Pin Oak | FACW | 4 | | | ✓ | | |
| *Quercus phellos* | Willow Oak | FACW | 4 | ✓ | ✓ | | | |
| *Quercus rubra* | Northern Red Oak | FACU | 2 | | ✓ | | | |
| *Salix nigra* | Black Willow | OBL | 5 | | | | ✓ | |
| *Ulmus americana* | American Elm | FAC | 3 | ✓ | | ✓ | | ✓ |
| *Ulmus rubra* | Slippery Elm | FAC | 3 | ✓ | ✓ | ✓ | ✓ | ✓ |
| *Total No. of species* | | | | 13 | 11 | 17 | 9 | 11 |

# Appendix C: Glossary

**Assessment Area Reach:** For the purposes of this guidebook, defined as an area that has a width equal to the average width of the alluvial valley and a length five times its width, centered on the wetland assessment area (WAA) and axis of the alluvial valley.

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

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

**Basal Area (BA):** The cross-sectional area of a tree trunk calculated from diameter breast height (DBH) at 4.5 feet (1.4 m) above ground level or just above the buttress if the buttress exceeds that height. The calculated value is in square inches, square centimeters, etc. BA is used as a surrogate for canopy cover or relative dominance (if basal area for each species is identified). A diameter tape, precalibrated to convert circumference to diameter, or a caliper can be used to quickly measure DBH. Diameter must be mathematically converted to BA using the equation $\prod r^2$, where r = radius (1/2 diameter).

**Benefits:** Outcomes associated with changed outputs described in terms of their relative value; the outcomes and changed outputs are a result of the Corps project or action being discussed. Example: diversity of stream invertebrates, water quality, migratory habitat in riparian zones.

**Catchment:** The geographic area where surface water would flow or run off, under natural conditions, into a headwater wetland.

**Chemical Reduction:** Any process by which one compound or ion acts as an electron donor. In such cases, the valence state of the electron donor is decreased.

**Chroma:** The relative purity or saturation of a color; intensity of distinctive hue as related to grayness; one of the three variables of color.

**Compensatory Mitigation:** Restoration or creation of a wetland to replace functional capacity that is lost due to project impacts.

**Curve number:** A dimensionless parameter that varies from zero to 100 and provides an indication of runoff potential.

**Detritus:** 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. This material would classify as fibric or hemic material (peat or mucky peat).

**Diameter at Breast Height (DBH):** The width of a plant stem as measured at 4.5 feet (1.4 m) above the ground surface or just above the buttress if over 4.5 feet (1.4 m).

**Direct impacts:** Project impacts that result from direct physical alteration of a wetland, such as the placement of dredge or fill.

**Ecological (Functional) Lift:** The difference between future with project (FWP) and future without project (FWOP).

**Ecosystem:** A biotic community, together with its physical environment, considered as an integrated unit. Implied within this definition is the concept of a structural and functional whole, unified through life processes. Ecosystems are hierarchical and can be viewed as nested sets of open systems in which physical, chemical, and biological processes form interactive subsystems. Some ecosystems are microscopic, and the largest comprises the biosphere. Ecosystem restoration and rehabilitation can be directed at different-sized ecosystems within the nested set, and many encompass multistates, more localized watersheds, or a smaller complex of aquatic habitat.

**Ecosystem Sustainability:** The physical, chemical, and biological limits set on natural capital by its inherent structure and processes to deliver ecosystem goods and services.

**Exotic:** See Invasive species.

**Fill Material:** Any material placed in an area to increase surface elevation.

**Flooded:** A condition in which the soil surface is temporarily covered with flowing water from any source, such as streams overflowing their banks, runoff from adjacent or surrounding slopes, inflow from high tides, or any combination of sources.

**Frequency of inundation or soil saturation:** The number of times per time period that an area is covered by surface water or times soil is saturated. Frequency is usually expressed as the number of times the soil is inundated or saturated at least once each year (e.g., 50 times) during a part of the growing season per time period (e.g., per 100 years or per a 1-, 2-, 5-year period, etc.

**Frequently flooded:** A flooding class in which flooding is likely to occur often under normal weather conditions (more than 50-percent chance of flooding in any year or more than 50 times in 100 years).

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

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

**Functional Capacity Index (FCI):** An index of the capacity of a wetland to perform a function relative to reference standard wetlands in a regional wetland subclass. Functional Capacity Indices are scaled from 0.0 to 1.0. An index of 1.0 indicates the wetland is performing a function at the appropriate/characteristic sustainable functional capacity, the level equivalent to a wetland under reference standard conditions in its reference domain. An index of 0.0 indicates the wetland does not perform the function at a measurable level and will not recover the capacity to perform the function through natural processes.

**Functional Capacity Unit (FCU):** An expression of a wetland's functional capacity incorporating the size of the Wetland Assessment Area (WAA) in acres, hectares, or other units of area for each function (FCU = FCI *x* size of wetland assessment area). FCUs are calculated for each homogenous area of a wetland assessment area (see definition of Partial Wetland Assessment Area), then summed to obtain FCUs for the entire WAA.

**Ground layer:** The layer of vegetation consisting of all herbaceous plants, regardless of height, and woody plants less than 1 meter (39 in.) tall.

**Ground Water:** That portion of the water below the ground surface that is under greater pressure than atmospheric pressure.

**Growing Season:** The portion of the year when soil temperatures at 19.7 in. below the soil surface are higher than biologic zero (5°C) (US Department of Agriculture & Soil Conservation Service 1985). For ease of determination, this period can be approximated by the number of frost-free days (U.S Department of the Interior 1970).

**Habitat:** The environment occupied by individuals of a particular species, population, or county.

**Highest sustainable functional capacity**: The level of functional capacity achieved across the suite of functions performed by a wetland under reference standard conditions in a reference domain. This approach assumes the most-sustainable functional capacity is achieved when a wetland ecosystem and the surrounding area are mostly unaltered.

**Hydric Soil:** A soil that is saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions that favor the growth and regeneration of hydrophytic vegetation. Hydric soils that occur in areas having positive indicators of hydrophytic vegetation and wetland hydrology are wetland soils.

**Hydrogeomorphic unit:** Hydrogeomorphic units are areas within a wetland 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.

**Hydrogeomorphic wetland class:** The highest level in the hydrogeomorphic wetland classification. There are five basic hydrogeomorphic wetland classes: Depression, Riverine, Slope, Fringe, and Flat.

**Hydrologic Regime:** The distribution and circulation of water in an area on average during a given period including normal fluctuations and periodicity.

**Hydroperiod:** The annual duration of flooding (in days per year) at a specific point in a wetland.

**Hydrology:** The science dealing with the properties, distribution, and circulation of water both on the surface and under the earth.

**Hydrophytic Vegetation (Hydrophyte):** The sum of macrophytic plant life growing in water or on a substrate that is at least periodically deficient in oxygen due to excessive water content. Hydrophytic plants are not "water-loving," but are able to outcompete nonhydrophytic plants under conditions of oxygen stress (anaerobic conditions). When hydrophytic vegetation comprises a community where indicators of hydric soils and wetland hydrology also occur, the area has wetland vegetation.

**Incision (entrenchment):** Used herein to indicate the degree of stream channel degradation. Entrenchment ratio is the width at two times the maximum depth at bankfull divided by the width at bankfull.

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

**Indirect impacts:** Impacts resulting from a project that occur concurrently, or at some time in the future, away from the point of direct impact. For example, indirect impacts of a project on wildlife can result from an increase in the level of activity in adjacent, newly developed areas, even though the wetland is not physically directly affected.

**Indirect measure**: A qualitative measure of an assessment model variable that corresponds to an identifiable variable condition, usually a structural characteristic.

**Indigenous Species:** Native to a region.

**Inundation:** A condition in which water from any source temporarily or permanently covers a land surface.

**Invasive species**: Generally, nonnative (exotic) species without natural controls that out-compete native species. However, under certain conditions (stressed ecosystem), a native species can be invasive.

**Mitigation plan:** A plan for replacing lost functional capacity resulting from project impacts.

**Mitigation wetland:** A restored or created wetland that serves to replace functional capacity lost because of project impacts.

**Mitigation Banking:** Wetland restoration, creation or enhancement undertaken expressly for the purpose of providing compensation credits for wetland losses from future development activities.

**Mitigation Plan:** A plan for replacing lost functional capacity resulting from project impacts.

**Mitigation Wetland:** A restored or created wetland that serves to replace functional capacity lost because of project impacts.

**Model variable**: A measurable characteristic of the wetland ecosystem or surrounding landscape that influences the capacity of a wetland 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 (by weight) of 18% or more with 60% or more clay, or 12% or more organic carbon with 0% 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% or more (by weight) organic carbon.

**Oxidation**: The loss of one or more electrons by an ion or molecule.

**Partial Wetland Assessment Area (PWAA)**: A relatively homogeneous portion of a WAA that is different from the rest of the WAA with respect to one or more variables. Differences may be natural or result from anthropogenic alteration.

**Professional Development Team (PDT):** An interdisciplinary group of regional and local scientists responsible for classification of wetlands within a region, identification of reference wetlands, construction of assessment models, definition of reference standards, and calibration of assessment models.

**Project alternative(s)**: Different ways in which a given project can be performed. 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 function 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 wetland or surrounding landscape to which special recognition or protection is assigned based on 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 wetlands within a defined geographic area that belong to a single regional wetland subclass.

**Reference standards**: Conditions exhibited by a group of reference wetlands that correspond to the characteristic level of functioning (highest sustainable capacity) across the suite of functions appropriate for the regional wetland subclass. Characteristic levels of functioning are assigned an index of 1.0.

**Reference wetlands**: Wetland sites that encompass the variability of a regional wetland subclass in a reference domain. Reference wetlands 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 wetlands function.

**Regional wetland subclass:** Regional hydrogeomorphic wetland classes that can be identified based on landscape and ecosystem scale factors. There may be more than one regional wetland subclass for each of the hydrogeomorphic wetland classes that occur in a region, or there may be only one.

**Relative Density:** A quantitative descriptor, expressed as a percent, of the relative number of individuals in an area; it is calculated by: (Number of Species A/Total number of individuals of all species) 100 ×).

**Relative Dominance:** A quantitative descriptor, expressed as a percent, of relative biomass, basal area, or cover of individuals of a species in an area; it is calculated by: (biomass, basal area, or cover of species A / Total biomass, basal area, or cover of all species) 100 ×).

**Relative Frequency:** A quantitative descriptor, expressed as a percent, of the relative occurrence of individuals in plots; it is calculated by: (Frequency of species A / Total frequency of all species) 100 ×.

**Restored Wetland:** A wetland returned from a disturbed or altered condition to a previously existing natural or unaltered condition by some action of man (i.e., fill removal).

**Runoff**: The sum of surface water and groundwater contributions to a body of water such as a stream channel or wetland.

**Sapling:** For the purposes of this guidebook, juveniles of canopy species that are greater than 1 meter (39 in.) in height but less than 15 cm (6 in.) in diameter at breast height.

**Shrub:** For the purposes of this guidebook, woody understory plant life forms that will never grow large enough to reach the canopy, are less than 1 meter (39 in.) in height and less than 10 cm (4 in.) in diameter at breast height.

**Seasonal high-water table:** The shallowest depth to free water that stands in an unlined borehole or where the soil moisture tension is zero for a significant period (for more than a few weeks).

**Site potential:** The highest level of functioning possible, given local constraints of alteration 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 a wetland 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.

**Stressors:** The physical, chemical, and biological changes that result from natural and human-caused forces and effect other changes in ecosystem structure and/or function. Stressors have associated time dimensions and usually can be quantified (i.e., nutrient loading rates, water quality degradation, shifts in population dynamics, etc.). Stressors may affect a single resource or component, or the stressor may act on multiple ecosystem components, so that stressor effects may be limited or widespread.

**System:** A set of elements or parts that is coherently organized and/or interconnected in a pattern or structure that produces a characteristic set of behaviors, often classified as its “function” or “purpose.”

**Targets (end points or performance criteria):** Readily observable, usually quantifiable, events or characteristics that can be aimed for as part of a goal or objective. Targets are a subset of the broad set of indicators, which are prior identified system characteristics that can provide feedback on progress toward goals and objectives.

**Threshold:** The level of magnitude of a system process at which sudden or rapid change occurs. A point or level at which new properties emerge in an ecological, economic, or other system, invalidating predictions based on mathematical relationships that apply at lower levels.

**Topography:** The configuration of a surface, including its relief and the position of its natural and man-made features.

**Trade-offs:** Used to adjust the model outputs by considering human values. There are no right or proper answers, only acceptable ones. If trade-offs are used, outputs are no longer directly related to optimum habitat or wetland function (Robinson et al. 1995).

**Transect:** A line on the ground along which observations are made at a given interval.

**Transition Zone:** The zone in which a change from wetlands to nonwetlands occurs. The transition zone may be narrow or broad.

**Tree:** A woody plant >15 cm in diameter at breast height, regardless of height (exclusive of woody vines).

**Typology:** The study or systematic classification of types that have characteristics or traits in common.

**Upland:** As used herein, any area that does not qualify as a wetland because the associated hydrologic regime is not sufficiently wet to elicit development of vegetation, soils, and/or hydrologic characteristics associated with wetlands. Such areas occurring within floodplains are more appropriately termed nonwetlands.

**Value:** Principles for evaluating the desirability or any possible alternatives or consequences. They define all that one cares about in a specific decision situation, more fundamental than alternatives, and they should be the driving force for decision-making. Alternatives are relevant only because they are means to achieving values.

**Value of wetland function:** The relative importance of a wetland function or functions to society (or an individual or group).

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

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

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

**Watershed**: The geographic area that contributes surface runoff to a common point, known as the watershed outlet.

**Wetland**: In Section 404 of the Clean Water Act "areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal conditions do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas." The presence of water at or near the surface creates conditions leading to the development of redoximorphic soil conditions, and the presence of a flora and fauna adapted to the permanently or periodically flooded or saturated conditions.

**Wetland assessment area (WAA):** The wetland area to which results of an assessment are applied.

**Wetland ecosystems:** In Section 404 of the Clean Water Act: "……. areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas" (Corps Regulation 33 CFR 328.3 and EPA Regulations 40 CFR 230.3). In a more general sense, wetland ecosystems are three-dimensional segments of the natural world where the presence of water at or near the surface creates conditions leading to the development of redoximorphic soil conditions, and the presence of a flora and fauna adapted to the permanently or periodically flooded or saturated conditions.

**Wetland functions:** The normal activities or actions that occur in wetland ecosystems. Wetland functions result directly from the characteristics of a wetland ecosystem and the surrounding landscape, and their interaction.

**Wetland restoration:** The process of restoring wetland functions in a degraded wetland. Restoration is typically accomplished as compensatory mitigation.

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**14. ABSTRACT**

The Hydrogeomorphic (HGM) approach is used for developing and applying models for the site-specific assessment of wetland functions. It was initially designed for use in the context of the Clean Water Act Section 404 Regulatory Program permit review process 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 design of wetland restoration projects, projecting ecological outcomes, developing success criteria and performance standards, and adaptive monitoring and management of wetlands. This guidebook provides an overview of the HGM approach including classification and characterization of the principal alluvial riverine wetlands identified in the Piedmont physiography. Eight potential subclasses of Piedmont wetlands, including Headwater, Low- and Mid-gradient Riverine, Floodplain Depression, Footslope Seeps, Flats, Precipitation Depressions, and Fringe wetlands were recognized. However, the occurrence of Flats, Precipitation Depressions, and Fringe wetlands in the Piedmont, are uncommon and not generally associated with alluvial riverine systems which is the subject of this Guidebook. Detailed HGM assessment models and protocols are presented for the five most common Piedmont riverine subclasses: Headwater, Low- and Mid-gradient Riverine, Floodplain Depression, and Footslope Seep. For each wetland subclass, the guidebook presents (a) the rationale used to select the wetland functions considered in the assessment process, (b) the rationale used to select assessment models, and (c) the functional index calibration curves developed from reference wetlands used in the assessment models. The guidebook outlines an assessment protocol for using the model variables and functional indices to assess each wetland subclass. The appendices provide field data collection forms. In addition, an automated spreadsheet model is provided to make calculations.

**15. SUBJECT TERMS**

Wetlands—Classification
Wetlands--Evaluation
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Wetland ecology
Piedmont (US: Region)

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