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A Regional Guidebook for Applying the Hydrogeomorphic Approach to Assessing Wetland Functions of Forested Wetlands in Alluvial Valleys of the Coastal Plain of the Southeastern United States

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Abstract

The Hydrogeomorphic (HGM) Approach is a method for developing and applying indices for the site-specific assessment of wetland functions. The HGM Approach was initially designed to be used 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, and management of wetlands. This Regional Guidebook presents the HGM Approach for assessing the functions of most of the wetlands that occur in alluvial valleys of the Coastal Plain of the Southeast United States. The report begins with an overview of the HGM Approach and then classifies and characterizes the principal wetlands that have been identified within the region. Detailed HGM assessment models and protocols are presented for four of those wetland types, or subclasses: Headwater Slope, Low-gradient Riverine, Mid-gradient Riverine, and Connected Depression. 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 (d) the functional index calibration curves developed from reference wetlands that are used in the assessment models. The guidebook outlines an assessment protocol for using the model variables and functional indices to assess each of the wetland subclasses. The appendices provide field data collection forms and spreadsheets for making calculations.

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Preface

This work was performed by the U. S. Army Engineer Research and Development Center (ERDC). Funding was provided through the Wetlands Regulatory Assistance Program. This report was prepared in accordance with guidelines established by ERDC and the methods and protocols used to develop this Guidebook were closely coordinated with similar projects undertaken for Low-gradient Riverine wetlands in western Kentucky (Ainslie et al. 1999), the Coastal Plain of western Tennessee (Wilder and Roberts 2002), eastern Arkansas (Klimas et al. 2005) and eastern Texas (Williams et al. 2010), and for Coastal Plain Headwater Slope wetlands in Mississippi and Alabama (Noble et al. 2007), and South Carolina (Noble et al. 2011). Therefore, portions of the text and some figures are similar or identical to sections of those HGM guidebooks. Select models were adapted for application across the entire Coastal Plain, and variables were chosen to improve efficiency of assessment. Reference data sets from these guidebooks, except for that of Ainslie et al. (1999), were added to the reference data collected from across the Coastal Plain for calibration of the models for use across the greater region. This guidebook reflects current concepts in HGM wetland assessment, the application of which are generally quicker than earlier guidebooks without loss of precision. Previous assessments using the earlier guidebooks are valid and need not be repeated or duplicated. Results will be similar to those obtained using this guidebook.

The Assessment Team (A-Team) members for the development of this guidebook were (in alphabetical order and with their affiliation), Bill Ainslie (EPA, Region IV), the late Dr. Mark Brinson (East Carolina University), Dr. Richard Darden (Corps of Engineers, Charleston District), Justin Hammonds (Corps of Engineers, Savannah District), Dave Lekson (Corps of Engineers, Wilmington District), Les Parker (Corps of Engineers, Charleston District), Dr. Richard Rheinhardt (East Carolina University), Dr. Thomas Roberts (Tennessee Technological University), Dr. Hans Williams (Stephen F Austin University), Timothy Wilder (ERDC-EL), Tad Zebryk (Corps of Engineers, Mobile District), and Mike Zeman (Natural Resource Conservation Service, Nashville, TN). Significant contributions to field data collected for this guidebook were made by Jill Clancy (Corps of Engineers, St. Paul District), Keith Daily, Darinda Dans, Levi Gibson, Penny

Gibson, Rachael McNeese Erwin, and Adam Miller, all affiliated with Stephen F Austin University. Elizabeth O. Murray of ERDC-EL created some of the figures, the field data sheets in Appendix C, and FCI spreadsheet calculator for use with the guidebook. Critical reviews were provided by Darrell Evans and Dr. Bruce Pruitt of ERDC-EL and externally by Dr. Kenneth Morgan (Tennessee Technological University) and Dr. Christopher Anderson (Auburn University).

At the time this final draft was prepared, Patrick O'Brien, P.E., was Chief of the Wetlands and Coastal Ecology Branch, Environmental Laboratory (EL); Dr. Edmond Russo was Chief of the Ecosystem Evaluation and Engineering Division, EL; Sally Yost was Program Manager, WRAP, and the Director of the EL was Dr. Elizabeth C. Fleming.

COL Kevin J. Wilson was Commander of ERDC. Dr. Jeffery P. Holland was Director.

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1 Introduction

Background

The Hydrogeomorphic (HGM) Approach is a system for developing functional indices to assess the capacity of a wetland to perform functions comparable to similar wetlands in a region. The approach was initially designed to be used in the context of the Clean Water Act Section 404 Regulatory Program permit review process to consider alternatives, minimize impacts, assess unavoidable project impacts, determine mitigation requirements, and monitor the success of mitigation projects. However, a variety of other potential applications for the approach have been identified, including determining minimal effects under the Food Security Act, designing wetland restoration projects, and managing wetlands.

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 Regional Guidebooks were published in the National Action Plan developed cooperatively by the U.S. Army Corps of Engineers (USACE), U.S. Environmental Protection Agency (USEPA), U.S. Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS), Federal Highway Administration (FHWA), and U.S. Fish and Wildlife Service (USFWS) (Federal Register 1997). The Action Plan, available online at http://www.epa.gov/OWOW/wetlands/science/hgm.html, outlines a strategy for developing Regional Guidebooks throughout the United States, 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, and local agencies, academia, and the private sector.

This *Regional Guidebook* presents a hydrogeomorphic classification of wetlands that occur within alluvial valleys of the Coastal Plain of the southeastern United States, except for tidally influenced wetlands. Detailed functional assessment criteria and models are presented for four of the most common of those wetland types. The rationale for concentrating on these four 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 subclasses in the alluvial valleys of the Coastal Plain. 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 wetland subclasses in the alluvial valleys of the Coastal Plain. Appendix A contains a glossary. Appendix B presents preliminary project documentation and field sampling guidance. Field data forms are presented in Appendix C, and Appendix D contains lists of scientific names of woody plant species observed on reference standard sites and supplementary information and examples on assessing specific variables.

It is possible to assess the functions of Coastal Plain alluvial valley wetlands using only the information contained in Chapter 5, but users should familiarize themselves with the information in Chapters 2-4 prior to conducting an assessment.

2 Overview of the Hydrogeomorphic Approach

Development and Application Phases

The HGM Approach consists of four components: (a) the HGM classification; (b) 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 Assessment Team (A-Team) of experts carries out the Development Phase of the HGM Approach. The task of the Assessment Team is to develop and integrate the classification, reference wetland data and information, assessment variables, models, and protocols of the HGM Approach into a Regional Guidebook (Figure 1) (Smith and Noble in preparation).

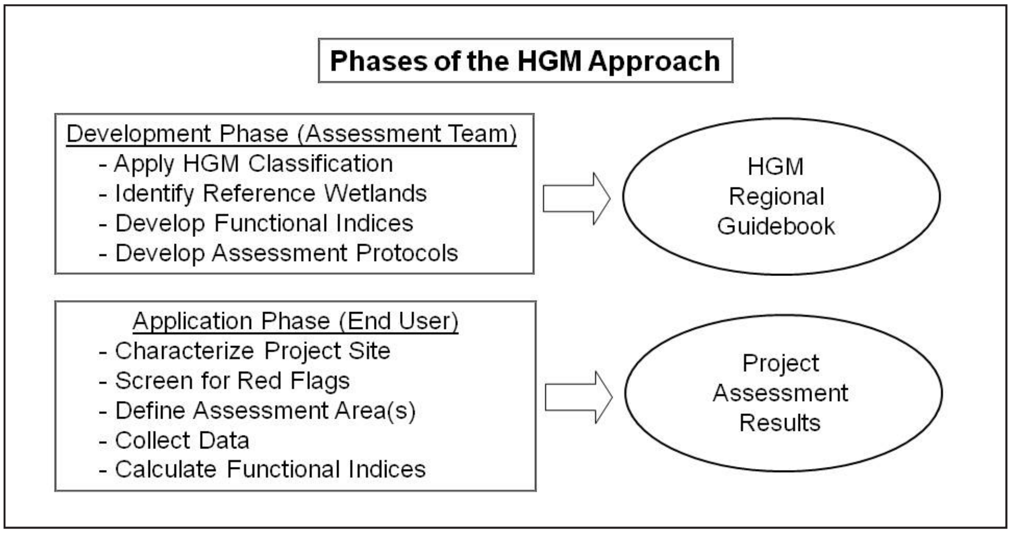


Figure 1. Development and application phases of the HGM Approach (modified from Ainslie et al. 1999).

In developing a Regional Guidebook, the Assessment Team 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 Assessment Team 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, reference wetlands are identified to represent the range of variability exhibited by each regional subclass, and field data are collected and used to calibrate assessment variables and 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.

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; and
- Analyze field data.

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).

Hydrogeomorphic Classification

Wetland ecosystems share a number of common attributes including hydrophytic vegetation, hydric soils, and relatively long periods of inundation or saturation. In spite of these common attributes, wetlands occur under a wide range of climatic, geologic, and physiographic situations and 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 reduce the level of variability exhibited by the wetlands being considered (Smith et al. 1995).

The HGM Classification was developed specifically to accomplish this task (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.

Based on these three classification criteria, any 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 Table 1 (Smith et al. 1995).

Generally, the level of variability encompassed by wetlands at the continental scale of hydrogeomorphic classification is too great 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. In order 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,

Table 1. 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 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. Since tidal fringe wetlands frequently flood and water table elevations are controlled mainly by sea surface elevation, tidal fringe wetlands seldom dry for significant periods. Tidal fringe wetlands lose water by tidal exchange, by overland flow to tidal creek channels, and by evapotranspiration. Organic matter normally accumulates in higher elevation marsh areas where flooding is less frequent and the wetlands are isolated from shoreline wave erosion by intervening areas of low marsh. *Spartina alterniflora* salt marshes are a common example 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, these 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 seiche. Lacustrine wetlands lose water by flow returning to the lake after flooding and by evapotranspiration. Organic matter may accumulate in areas sufficiently protected from shoreline wave erosion. 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 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. Slope wetlands lose water primarily by saturated subsurface flows, loss via a low-order stream, and by evapotranspiration. Slope wetlands are distinguished from depressional 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

HGM Wetland Class	Definition
	impermeable layers (e.g., hardpans), 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 climates. Raised bogs share many of these characteristics but may be considered a separate class because of the convex upward form and distinct edaphic conditions for plants. Portions of the Everglades and northern Minnesota peatlands are examples of organic soil flat wetlands.
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 flows down the floodplain may dominate hydrodynamics. In headwaters, Riverine Wetlands often intergrade with slope wetlands, depressions, poorly drained flats, or uplands as the channel (bed) and bank disappear. 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.

are distinguished on the basis of geomorphic setting, water source, and hydrodynamics. Examples of potential regional subclasses are shown in Table 2. 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 the 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. Riverine subclasses might be based on position in the watershed, stream order, watershed size, channel gradient, or floodplain width. Regional Guidebooks include a thorough characterization of the regional wetland subclass in terms of geomorphic setting, water sources, hydrodynamics, vegetation, soil, and other features that were taken into consideration during the classification process.

Table 2. 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 (tidal)	Ocean	Bidirectional, horizontal	Chesapeake Bay and Gulf of Mexico tidal marshes	San Francisco Bay marshes
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	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).

Reference Wetlands

Reference wetlands are wetland sites selected to represent the range of variability that occurs in a regional wetland subclass as a result of natural processes and disturbance (e.g., succession, channel migration, fire, erosion, and sedimentation) as well as cultural alteration. The reference domain is the geographic area occupied by the reference wetlands (Smith et al. 1995). Ideally, the geographic extent of the reference domain will mirror the geographic area encompassed by the regional 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 function 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 a concrete physical representation of wetland ecosystems that can be observed and measured.

Reference standard wetlands are the subset of reference wetlands that perform the suite of functions selected for the regional subclass at a level that is characteristic in the least altered wetland sites in the least altered landscapes. Table 3 outlines the terms used by the HGM Approach in the context of reference wetlands.

Table 3. 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 disturbance and from human alterations.
Reference standard wetlands	The 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. By definition, 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. By definition, 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 disturbance history, land use, or other factors. 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 restoration or creation project.
Project standards (mitigation context)	Performance criteria and/or specifications used to guide the restoration or creation activities toward the project target. Project standards should specify reasonable contingency measures if the project target is not being achieved.

Assessment Models and Functional Indices

In the HGM Approach, an assessment model is a simple representation of a function performed by a wetland ecosystem. The assessment model defines the relationship between the characteristics and processes of the wetland ecosystem and the surrounding landscape that influence the functional capacity of a wetland 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 in a manner comparable to that of reference standard wetlands. 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 than that characteristic 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.

$$FCI = \left[\frac{\left(\frac{V_{TD} + V_{TDEN}}{2} \right) + V_{COMP}}{2} \right] \qquad (1)$$

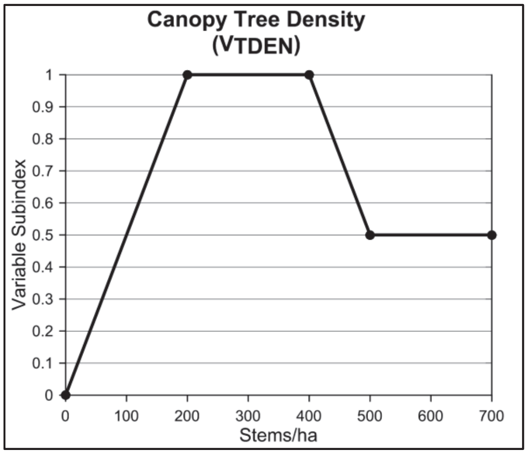


Figure 2. Example subindex graph for the tree density (V_{TDEN}) assessment variable for a particular wetland subclass.

This assessment model has three assessment variables: mean tree diameter (V_{TD}), tree density (V_{TDEN}), and tree species composition (V_{COMP}) that together 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 (m^2/ha) is often used to assess tree biomass in a wetland, with larger numbers usually indicating greater stand maturity and increasing functionality for several different wetland functions where tree biomass is an important consideration.

The value of the variable subindex is assigned based on the value of the assessment variable metric value. 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 reflecting the decreased functional capacity of the wetland. Figure 2 illustrates the relationship between metric values of tree density (V_{TDEN}) and the variable subindex for an example wetland subclass. As shown in the graph, tree densities of 200 to 400 stems/ha represent reference standard conditions, based on field studies, and a variable subindex of 1.0 is assigned for assessment models where tree density is a component. Where tree densities are higher or lower than those found in reference standard conditions, a lesser variable subindex value is assigned.

Assessment Protocol

All of the steps described in the preceding sections concern development of the assessment tools and the rationale used to produce this *Regional Guidebook*. Although users of the guidebook should be familiar with this process, their primary concern will be the protocol for application of the assessment procedures. The assessment protocol is a defined set of tasks, along with specific instructions, that allows resource professionals to assess the functions of a particular wetland area using the assessment models and functional indices in the Regional Guidebook. The first task includes characterizing the wetland ecosystem and the surrounding landscape, describing the proposed project and its potential impacts, and identifying the wetland areas to be assessed. The second task is collecting the field data for assessment variables. The final tasks involve the calculation of FCIs using the protocols described in detail in Chapter 5, and calculation of Functional Capacity Units (FCUs) for the wetland assessed. FCUs incorporate the size of the wetland assessment area by multiplying it by the FCI (Smith et al. 1995).

3 Characterization of Alluvial Valley Wetlands of the Atlantic and Gulf Coastal Plains

Reference Domain

This HGM guidebook applies to selected freshwater wetland types of alluvial valleys, excluding those influenced by marine tides, in the Atlantic and Gulf Coastal Plain Physiographic Provinces. These provinces of the southeastern United States, lying between the Fall Line of the Piedmont and the coastal margin (Figure 3), comprise the reference domain for this guidebook. This reference domain extends south from Virginia to Georgia (Atlantic section) and west from Georgia to eastern Texas (Gulf section). The Gulf section is bisected by the Mississippi Delta Region, which is the former alluvial floodplain of the Mississippi River. The Delta divides the Texas, Louisiana, and Arkansas portions of the Coastal Plain from the Coastal Plain portions of Kentucky, Tennessee, and Mississippi. The Delta itself is not included in this guidebook, as the authors judged it to be sufficiently different in character to warrant treatment as its own reference domain.

The southeastern U.S. Coastal Plain varies from 30 km in width in northern Virginia to about 300 km in width in Alabama. In addition, the upland landscape of the Coastal Plain varies widely in topographic relief, ranging from the extremely broad, flat, low-elevation, outer coastal terraces of the Tidewater Region to moderately hilly terrain of the inner Coastal Plain in north-central Alabama (elevations to 600 ft). Across this variable upland landscape, stream gradients are low (< 0.5%) (Rheinhardt et al. 1998), especially among third and higher order streams. In the sandy, hill country of the Coastal Plain of northern Alabama, intermittent and perennial streams occur in valleys separating the high-elevation hills, but these stream gradients are subdued, like Coastal Plain streams elsewhere in the reference domain.

Though the reference domain covered in this guidebook is large (658,000 km^2), alluvial valleys are remarkably similar across it. Wetlands associated with Coastal Plain alluvial valleys function similarly and HGM models can be designed to work effectively across the entire domain. The key to

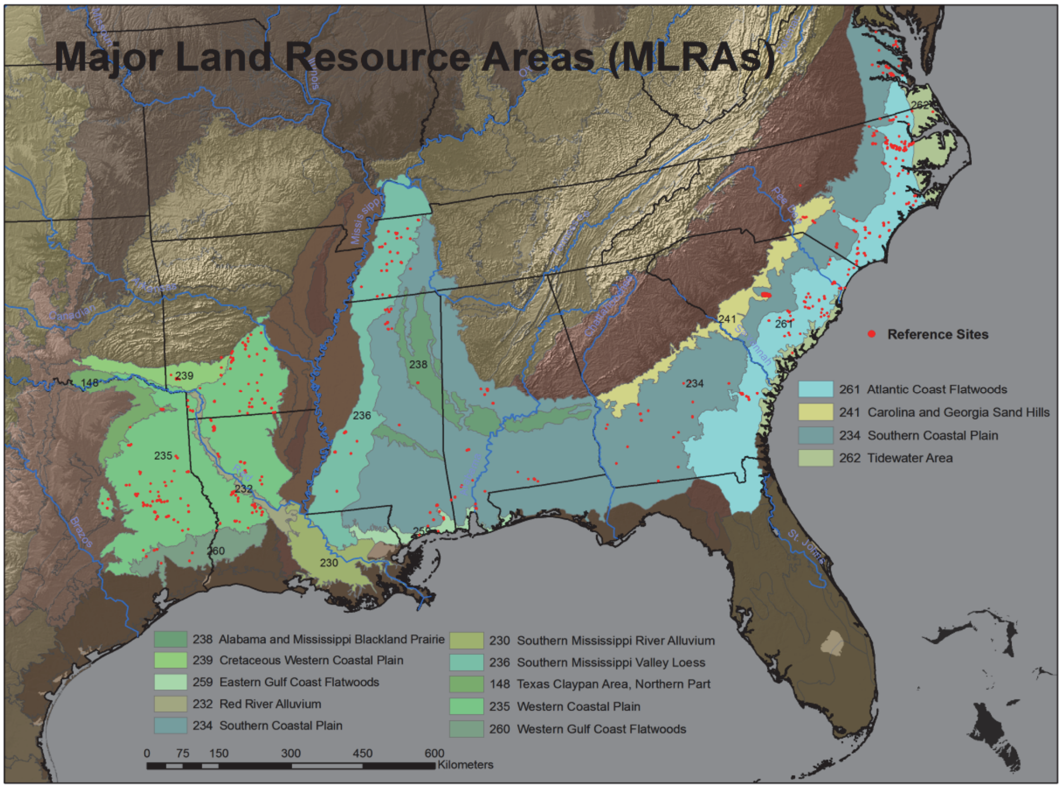


Figure 3. Reference domain for alluvial valley wetlands of the Coastal Plain. Reference wetland sites are indicated with red dots.

designing effective models is to sub-classify wetlands, using reference data, so that 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 that drove the authors' classification, model development, and the identification of reference standards. The classification section summarizes the criteria used to sub-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 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 Waters of the United States.

Geologic History

Since the beginning of the Pleistocene Epoch (2.58 Ma), the sea has advanced and retreated across the Coastal Plain at least six times with the advance and retreat of continental glaciers (Balco and Rovey II 2010). During each glacial advance, sea level dropped as more planetary water was tied up as continental ice, exposing more of the Continental Shelf, and during each interglacial period, sea levels rose as glaciers melted, re-submerging the exposed coastal plain.

The last retreat of seas began about 100 ka at the beginning of the Wisconsin glacial period, eventually exposing much of the Continental Shelf by the time of glacial maximum (21 ka). The sea did not recede at a uniform rate. Retreat stalled numerous times, and the ancient coastlines of these stalled retreats are marked on the present landscape with sharp changes in elevation, called scarps (Phillips 1997). The elevation of some scarps change by only a few meters over tens of meters distance, but are distinct geomorphic features in a landscape where elevations change less than one meter over several kilometers distance. Marine terraces, sloping slightly seaward, lie between these scarps. The age and dissection of these formations increase with distance from the modern coast to the Piedmont. Terraces located further inland are more dissected and stream channels — especially in headwater reaches — tend to have slightly steeper gradients than streams on terraces located more coastward.

The geomorphic evolution of Coastal Plain rivers during the last 30,000 years has been attributed almost solely to climatically driven changes (Alford and Holmes 1985; Baker and Penteado-Orellana 1977; Leigh 2008; Suther et al. 2011; Sylvia and Galloway 2006). That is, glacial melting and periglacial conditions are not considered to have been significant in driving floodplain and channel evolution following the Pleistocene, except in some mountainous headwaters inland from the Atlantic coast.

Before 16 ka (Late Pleistocene), the climate was dry, cold, and windy. Floodplains were sparsely vegetated with patches of spruce (*Picea mariana* and *P. glauca*), fir (*Abies* spp.), and jack pine (*Pinus banksiana*), interspersed within grassland. As a result of being sparsely vegetated, Coastal Plain reaches of these rivers were braided and much of their floodplains were covered by eolian sand dunes, derived from sand exposed during channel erosion and then transported and deposited by winds (Leigh 2006, 2008; Leigh et al. 2009; Leigh et al. 2004).

Around 16 ka the climate shifted to wetter and warmer conditions, and floodplains became densely covered with cool-deciduous forest. Dense forest cover led to a stabilization of channels, converting braided channels into single-thread, meandering channels. Rivers formed large scroll meanders and terraces and eroded much of the eolian dunes deposited previously during the Pleistocene (Leigh 2008). During this period, rivers eroded sediment from floodplains at a rate of 0.56 mm/yr (Suther et al. 2011). During the Early Holocene, from 11-5.5 ka, increased rainfall and spring snowmelt led to larger bankfull floods of longer duration and a renewal of sediment accretion, which in turn produced a full range of fluvial geomorphic features, including larger channels, meanders, and backswamps (Leigh 2008; Leigh et al. 2009).

By about 4 ka, the climate became warmer, but much less wet, similar to present-day climate. Because less water was available to streams than during the early part of the Holocene, channels and meanders became much smaller. Many of the features created by the larger, paleo-streams still remain because modern streams have not yet had the time to erode them. The most distinctive of these paleo-features are valleys and floodplains that are much too large to have been produced by present day streams. Present day channels are under-fit (undersized) relative to the size of their floodplains (Dury 1977; Hupp 2000). In hydrologically unaltered Coastal Plain streams and floodplains, incipient flooding onto the floodplains occurs — in general — at the one to two year recurrence interval. This frequency helps maintain characteristic floodplain structure, function and processes including maintenance of large backswamps and a mosaic of topographic and drainage features.

Soils

Because the Coastal Plain was part of the Continental Shelf (i.e., periodically covered by the sea during marine transgressions), much of the upland soils are derived from weathered marine sediments. In contrast, floodplains are composed of a mixture of alluvial deposits eroded from uplands and organic material produced in situ (Hodges 1997). Textures and composition of floodplain soils vary widely both among floodplains and spatially within a given floodplain (Phillips 1997). Nonetheless, floodplain wetlands typically support field indicators of hydric condition, such as changes in soil color (hue, value, chroma) with depth, depleted matrices, iron or manganese masses, etc. (U.S. Department of Agriculture 2010b).

Climate

Climate across the Southeast and Gulf Coastal Plains is humid subtropical, with hot summers and mild, wet winters. Areas near the coast experience wetter summers than areas further inland, probably due to convective thunderstorms produced by sea breezes. A reduction in temperature extremes also occurs nearer the coast. Large amounts of precipitation accompany tropical cyclones, which peak during summer and fall, and usually deposit more rain on coastal areas.

Variation exists across the reference domain in the lengths of summer and winter, due mainly to the wide variation in latitude, ranging from N38 deg in the Northern Neck of Virginia to N29 deg in southern Georgia and southeastern Texas. Summers in the southern part of the region are longer and more humid than areas further north and winters are shorter and milder. Snow and freezing temperatures are rare, even in coastal Virginia. As a result, subtropical species, such as dwarf palmetto (*Sabal minor*) and Spanish moss (*Tillandsia usneoides*), occur in wetlands as far north as North Carolina and southeast Virginia, respectively. Further, soils remain warm enough throughout the winter that microbial organisms responsible for nutrient cycling are active year round.

Although climatic variation affects the geographic ranges of plant species, in general, many of the dominant canopy species occur throughout the reference domain. For example, there are differences related to the geographic ranges of species and ecotypic variation within a species (Dale and Ware 2004), but such differences may be taken into account when defining reference standards for FCI models of habitat condition.

Hydrogeomorphic Variation within Drainage Networks

The alluvial valley subclasses covered in this guidebook are physically interconnected ecosystems in that they are all part of stream networks of drainage basins. The headwater portion of stream networks (first to third order) are composed of many small streams draining small watersheds and fed primarily by groundwater. Headwater reaches constitute 70-90% of stream length in a typical Coastal Plain network (Leopold et al. 1964; Rheinhardt et al. 1999). The remaining 10-30% of stream length in a drainage network consists of Mid-gradient (third to sixth order) and Low-gradient (> sixth order) streams. The Low-gradient, higher order streams are usually not wadeable during normal flow periods, although some Mid-gradient streams are wadeable during low flow conditions. In hydrologically unaltered stream networks, mid- to Low-gradient reaches overtop their banks in late winter and early spring of most years, and occasionally during the summer and fall during tropical storm events. Small depressions on floodplains pond water after rainfall and retain water for a time after floodwaters recede. Larger depressions, associated with abandoned channels (Connected Riverine Depression subclass), hold water for longer periods, often year-round.

Unaltered wetlands of the alluvial valleys on the Coastal Plain differ primarily in their source of water and frequency and duration of flooding or saturation. These hydrologic characteristics variy significantly by stream order and watershed size, and from headwaters to tidal reaches, affecting geomorphology, species composition, and wetland function.

Headwater streams coalesce to form larger streams, which in turn join additional streams to become even larger and more energetic (Strahler 1952). Down-gradient of the groundwater-driven headwater systems, the water source to alluvial valley wetlands is primarily overbank flooding from adjacent streams and groundwater moderated by river stage and evapotranspiration (ET). The water table of floodplains rises after leaf senescence during autumn and remains high until ET increases in the spring. The hydrology of stream reaches at the coast is affected by tides. In the field, it may be difficult to tell where tidal influence begins without water level data, particularly since in some tributaries tidal influence may only occur during summer when seawater has expanded to its maximum extent. However, there are physiognomic and physical field indicators that are usually observable in freshwater tidal forested wetlands (Day et al. 2007; Duberstein and Conner 2009; Rheinhardt and Hershner 1992): (1) canopy trees are generally short in stature and trees appear stressed; (2) the canopy tends to be more open than in nontidal wetland forests; (3) the microtopography of the forest substrate exhibits a distinctive hummock/hollow pattern, with woody species restricted to the hummocks; and (4) there is a bidirectional (tidal) flow in channels (Rheinhardt and Hershner 1992).

In the Coastal Plain Region that borders the Mississippi alluvial valley (Delta Region), streams and rivers terminate at the Mississippi River or at the Atchafalaya River, rather than at sea level. These stream networks are not subjected to tidal fluctuations; instead, in their natural states, they are hydrologically controlled by the stage of the receiving rivers. The levees and other control structures on these rivers influence the amount, timing, and dynamics of backwater flooding in the tributaries (e.g., Yazoo River).

Major Land Resource Areas

Major Land Resource Areas (MLRA) encompassed by the reference domain (Figure 3, Table 4) represent geologic and climatic differences among Coastal Plain Regions, differences that were initially considered in sub-classifying wetland types. For example, stream network characteristics differ between the Atlantic Coast Flatwoods (MLRA 261), also known as the inner or upper Coastal Plain, and the Tidewater Region (MLRA 262), known also as the “outer” or “lower” Coastal Plain. Land surface in the Tidewater Region is flatter and less dissected than the inner Coastal Plain Regions. Further, the lowest reaches of higher order tributaries of the Tidewater Region are tidal, as the name implies. On the outer Coastal Plain, drainages are small and streams flow short distances before reaching sea level. In contrast, inner Coastal Plain stream networks are larger and usually terminate at a receiving river.

Table 4. Major Land Resource Areas (MLRA) and Land Resource Regions (LRR) of the reference domain.

MLRA Name	MLRA Code	LRR Name	LRR Code
Alabama and Mississippi Blackland Prairie	238	South Atlantic and Gulf Slope Cash Crops, Forest, and Livestock Region	P
Atlantic Coast Flatwoods	261	Atlantic and Gulf Coast Lowland Forest and Crop Region	T
Carolina and Georgia Sand Hills	241	South Atlantic and Gulf Slope Cash Crops, Forest, and Livestock Region	P
Cretaceous Western Coastal Plain	239	South Atlantic and Gulf Slope Cash Crops, Forest, and Livestock Region	P
Eastern Gulf Coast Flatwoods	259	Atlantic and Gulf Coast Lowland Forest and Crop Region	T
Red River Alluvium	232	Mississippi Delta Cotton and Feed Grains Region	O
Southern Coastal Plain	234	South Atlantic and Gulf Slope Cash Crops, Forest, and Livestock Region	P
Southern Mississippi River Alluvium	230	Mississippi Delta Cotton and Feed Grains Region	O
Southern Mississippi Valley Loess	236	South Atlantic and Gulf Slope Cash Crops, Forest, and Livestock Region	P
Texas Claypan Area, Northern Part	148	Southwestern Prairies Cotton and Forage Region	J
Tidewater Area	262	Atlantic and Gulf Coast Lowland Forest and Crop Region	T
Western Coastal Plain	235	South Atlantic and Gulf Slope Cash Crops, Forest, and Livestock Region	P
Western Gulf Coast Flatwoods	260	Atlantic and Gulf Coast Lowland Forest and Crop Region	T

Classification

Brinson (1993b) identified five wetland classes based on hydrogeomorphic criteria, as described in Chapter 2. These are Flat, Riverine, Depression, Slope, and Fringe wetlands, and all five classes are represented in alluvial valleys of the Coastal Plain. Within each class, one or more subclasses are recognized. Wetlands often intergrade or have unusual characteristics; therefore, a set of specific criteria have been established to assist the user in assigning any particular wetland to the appropriate class (Figure 4). Subclass designations can best be assigned using the descriptions of wetlands and their typical landscape positions presented in the following paragraphs and summarized in Table 5.

The classification system recognizes that certain sites functioning primarily as fringe or depression wetlands also are regularly affected by stream flooding, and therefore have a Riverine functional component. This is incorporated in the classification system by establishing "river-connected" subclasses within the Fringe and Depression Classes. Similarly, sites that function primarily as Riverine wetlands and flats often incorporate small, shallow depressions, sometimes characterized as vernal pools and microdepressions. These features are regarded as normal components of the Riverine and flat ecosystems, and are not separated into the Depression Class unless they meet specific criteria. Other significant criteria relating to classification are elaborated upon in the following wetland descriptions.

Key to the HGM wetland classes of alluvial valleys of the Coastal Plain	
1. Wetland is associated with point bars or floodplain of a stream and principal water source is the stream	Riverine
1. Wetland is not associated with point bars or floodplain of a stream and principal water source is not the stream	2
2. Wetland is not in a topographic depression nor is it impounded	4
2. Wetland is in a topographic depression or it is impounded	3
3. Wetland is associated with a water body that has permanent open water more than 2-m deep in most years	Fringe
3. Wetland is associated with a water body that is ephemeral, or less than 2-m deep in most years	Depression
4. Topography is flat, principal water source is precipitation	Flat
4. Topography is sloping to flat, principal water source is groundwater discharge or subsurface flow	Slope

Figure 4. Key to the HGM wetland classes of alluvial valleys of the Coastal Plain.

Table 5. Hydrogeomorphic classification and typical geomorphic settings of wetlands in alluvial valleys of the Coastal Plain.

Wetland Class	Subclass	Typical Hydrogeomorphic Setting
Flat	Alluvial flat	Stream terraces, levee-protected former floodplains, and other poorly drained sites not subject to regular flooding (outside the floodplain).
Riverine	Mid-gradient Riverine	Point bar and natural levee deposits within the floodplain of streams transitioning from headwaters to broad basins.
	Low-gradient Riverine	Point bar, backswamp, and natural levee deposits associated with meandering streams (within the floodplain).
Depression	Unconnected Depression	Abandoned channels and large swales in former and current meander belts of larger rivers not subject to regular stream flooding.
	Connected Depression	Abandoned channels and large swales in former and current meander belts of larger rivers that are within the current floodplain and are currently subjected to regular stream flooding.
Fringe	Unconnected Lacustrine Fringe	Margins of natural and man-made lakes where water levels are not actively managed, and that are not within the floodplain of a stream.
	Connected Lacustrine Fringe	Natural and man-made lakes where water levels are not actively managed and that are within the floodplain of a larger stream.
	Reservoir Fringe	Fluctuation zone of a man-made reservoir manipulated for water supply, power production, and other purposes. Mostly on former hillslopes of valleys impounded by large dams.
Slope	Headwater Slope	At the head of small streams, including areas up-gradient of distinct channel formation down to 3rd order streams, transitioning to Mid-gradient Riverine as overbank flow increases.
	Valley wall or Terrace Seep	Slopes and adjacent colluvial deposits at groundwater discharge points, usually at the contact between clay layers and more permeable overlying strata.

The most discernible differences among alluvial valley wetlands across the Coastal Plain are due to watershed position and water sources rather than subregion (MLRAs). The following sections briefly describe the classification system developed for the alluvial valleys of the Coastal Plain. Much of the discussion was taken from Klimas et al. (2005), Noble et al. (2007), and Williams et al. (2010). All of the wetland types that occur in alluvial valleys of the Coastal Plain are described in the following text, but assessment models and supporting reference data were developed for only four alluvial valley wetland subclasses. These are: Headwater Slope, Mid- and Low-gradient Riverine, and Connected Depression. The rationale for the exclusion of the remainder of the subclasses is presented with their descriptions.

Class: Riverine

The classification used in this guidebook defines wetlands as Riverine if they occur within the floodplain of a stream and their principal water source is overbank or backwater flooding. Such flooding in the reference domain occurs primarily during the winter and spring. Floodplain inundation begins with floodwaters accessing the floodplain through distributaries and other breaches in the natural levee (e.g., crevasse splay). The rise in stage of many events may be sufficient to overtop much of the natural levee, while in other events, significant flooding may occur without submersion of the higher elevations of the natural levees. As the river stage rises, the backwater flooding of tributaries increases, contributing to floodplain inundation, as does saturated overland flow from adjacent uplands and direct precipitation. The soil water table is usually near the surface across the entire width of the floodplain during the winter and early spring. The Riverine wetlands in the reference domain are typically forested and referred to as bottomland hardwood wetlands. The floodplains and low terraces of the reference domain consist of recent (Holocene) and late Pleistocene deposits of sand, silt, and clay alluvium. Geomorphic features include point bars, natural levees, and backswamps (Figure 5). The following discussion of the origins and characteristics of those features is adapted from Klimas et al. (2005).

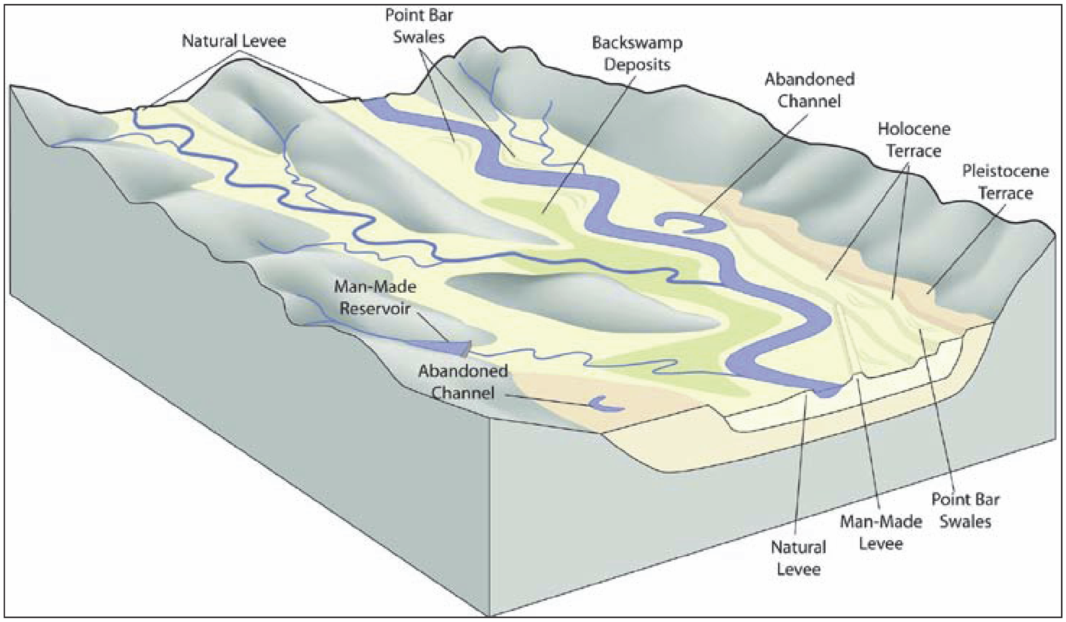


Figure 5. Typical form and locations of geomorphic and man-made features within river valleys of the Coastal Plain (vertical scale is exaggerated).

Point bars

Point bars form on the inside bends of stream channels as they migrate laterally and downstream, eroding the opposite bank and depositing material on the inside of the bend. The deposited material accumulates as a series of sand ridges and intervening swales. The swales usually become lined or filled with silty or clayey sediments left by floodwaters trapped behind the ridges. In contrast, the overall texture of point bar deposits tends to be sands or gravels. The typical ridge and swale topography of point bar deposits is sometimes referred to as a meander scroll or point bar complex. New point bar surfaces are often dominated by sediment and flood-tolerant wetland species (Robertson 2006), such as black willow (*Salix nigra*), river birch, box elder (*Acer negundo*), silver maple (*Acer saccharinum*), and cottonwood (*Populus* spp). These species may be succeeded by water hickory (*Carya aquatica*), green ash (*Fraxinus pennsylvanica*), sugarberry (*Celtis laevigata*), water locust (*Gleditsia aquatica*), planer tree (*Planera aquatica*), and sycamore (*Platanus occidentalis*) (Shankman 1993).

Backswamps

Backswamps are flat, poorly drained areas bounded by higher alluvial features. Since sedimentation rates are highest along the active stream channel, meander belts tend to develop into an alluvial ridge, where elevations are higher than the adjacent floodplain. The result is that local drainage is directed away from the major stream channel, and the areas between meander belts become basins (backswamps) that pool floodwaters and accumulate fine sediments. They characteristically have clay substrates and are incompletely drained by small streams and interconnected swales. They may include large areas that do not fully drain through channel systems but remain ponded well into the growing season. Where backswamps are bounded on one side by the valley wall or terraces, they are referred to as rimswamps, which receive drainage from uplands and sometimes groundwater discharge from valley walls. The wetter areas of backswamps are dominated by the same species as the Depression class (described below). Common species in the canopy of the remainder of the backswamp include sweetgum (*Liquidambar styraciflua*), elms (*Ulmus* spp), water hickory (*Carya aquatica*), swamp blackgum (*Nyssa biflora*), ash (*Fraxinus* spp), red maple (*Acer rubrum*), and a variety of oaks, including overcup oak (*Quercus lyrata*), swamp chestnut oak (*Q. michauxii*), water oak (*Q. nigra*), willow oak (*Q. phellos*), laurel oak (*Q.*

laurifolia), shumard oak (*Q. shumardii*), and Nuttall oak (*Q. texana*). Understories are often sparsely vegetated by ironwood (*Carpinus caroliniana*), hawthorns (*Crataegus* spp), dogwoods (*Cornus* spp), hollies (*Ilex* spp), and various blueberries (*Vaccinium* spp).

Abandoned channels

These features are the result of cutoffs, where a stream abandons a channel segment either because flood flows have scoured out a point bar swale and created a new main channel (chute cutoff), or because migrating bendways intersect and channel flow moves through the neck (neck cutoff). Chute cutoffs tend to be relatively small and fill rapidly with sediment. They do not usually form lakes, but may persist as large depressions. The typical sequence of events following a neck cutoff (which is much more common than a chute cutoff) is that the upper and lower ends of the abandoned channel segment fill with sediment, leaving an open-water oxbow lake in the remainder of the channel. Where an abandoned stream channel incorporates two or more meander loops, it is referred to as an abandoned course (see Depression Class below).

Natural levees

A natural levee forms where overbank flow results in deposition of relatively coarse sediments (sand and silt) adjacent to the stream channel. The material is deposited as a continuous sheet that thins with distance from the stream, resulting in a low, wedge-shaped ridge paralleling the channel and blanketing areas of point bar features and backswamp. Where channels have changed course, natural levee ridges are left behind on the banks of oxbow lakes or as low ridges within the floodplain. Weakly flood tolerant to moderately flood tolerant species occur on the natural levees and ridges, such as water oak, sweetgum, ash, American elm (*Ulmus americana*, hackberry (*Celtis laevigata*), winged elm (*Ulmus alata*), river birch, sycamore, willow oak, Shumard oak, and cherrybark oak (*Quercus pagoda*).

Terraces

Alluvial terraces are former floodplains abandoned by a stream when it passed through a period of bed erosion and established a new floodplain at a lower level. The abandoned floodplain surface is composed of the sediments and landforms described in the preceding text, and it frequently sustains wetlands in the relic swales, channels, and backswamps. However, the wetland character is maintained primarily by groundwater and precipitation rather than flooding. On very old terraces, the alluvial features may be so subdued from erosion that the surface appears flat. Where internal drainage is well developed, the terrace becomes dissected and may not sustain any wetland environments. The plant species of terraces are similar to those found throughout the active floodplains of the Riverine class.

Rivers and streams of the Coastal Plain differ in the amount of sediment they naturally carry, due primarily to the location of their headwaters. Streams originating in the Coastal Plain tend to be low energy systems with generally lower amplitude of stages, sandy bottoms, low mineral sediment loads, and water stained with tannin from the decomposition of organic materials. These tannin-rich streams are usually referred to as blackwater streams (or rivers) (Kellison et al. 1998). In contrast, rivers that originate inland from the Coastal Plain (in the Piedmont or Mountains) are high energy systems with high amplitude of stages and carry a much higher mineral sediment load coloring the waters brown to reddish brown. These rivers are often referred to as brownwater rivers, or less commonly, as redwater rivers. Geomorphic features of brownwater rivers are distinct, whereas they are often absent or subtle in blackwater rivers (Kellison et al. 1998). Differences between brownwater (sediment rich) and blackwater (organic rich) could potentially affect sub-classification of the Riverine class.

The Riverine wetland class is separated into two subclasses: Low-gradient Riverine, and Mid-gradient Riverine. The separation is generally based on the size of the stream and its associated floodplain and sinuosity. Depressions within the floodplain were considered as a separate class. Beaver complexes are considered part of the Riverine system where they occur, but are not assessed using HGM criteria (see Chapter 6).

1. *Low-gradient Riverine*. Low-gradient Riverine wetlands occur within the floodplains of >5th order rivers, which comprise from 1-5% of the total stream length of their watersheds, but the floodplains can be very wide, a common feature of Coastal Plain river systems (Bridge 2003; Kellison et al. 1998). The extent of Low-gradient Riverine wetlands to stream length is much greater, however, than the other alluvial subclasses. Typically, these systems have large, distinctive geomorphic features and often receive both backwater and overbank flooding (though no subclass distinction between overbank flooding and backwater flooding is made in this document). The frequency of flooding is between less than 1 and up to 5 years (i.e.,

probability of exceedance of less than 20% up to 100% in a given year). The duration of flooding ranges from days to several weeks. Areas of higher elevation—ridges and natural levees—will drain first after flooding. Swales will hold water longer after flooding and ponding of precipitation is common during winter and spring. During years of normal rainfall, the swales will be dry from early summer to late fall. The water table is near the surface during the winter and spring, but rapidly drops as the growing season progresses. The soil orders typically observed are Vertisols, Inceptisols and Entisols. The herbaceous stratum on the ridges may have a high abundance of switchcane (*Arundinaria* spp) green briar (*Smilax* spp) and wild oats (*Chasmanthium* spp). Ironwood, deciduous holly, sweetgum and red maple are common in the understory. The tree and sapling/shrub densities are lower in the swales and overcup oak usually dominates. The herbaceous stratum cover in the swales is often sparse. Backswamps can be dominated by green ash (*F. pennsylvanica*) and red maple. Sweetgum is ubiquitous throughout the floodplain.

2. *Mid-gradient Riverine.* The Mid-gradient Riverine subclass occupies the floodplains of 3rd to 5th order streams, which typically constitute about 10-20% of total stream length in a drainage basin. These systems may be referred to as minor bottoms (Hodges 1998). The frequency of flooding is from one to five years with annual flooding common. Mid-gradient Riverine sites typically receive overbank flooding with flood durations of hours to days. Multiple flood events interspersed with long dry periods can occur throughout the year. They have geomorphic features and soil characteristics that are similar to, but smaller in scale than, the Low-gradient Riverine subclass. They are typically forested and support many of the same plant species as the Low-gradient Riverine subclass. However, species such as slippery elm (*Ulmus rubra*), winged elm (*Ulmus alata*), cedar elm (*Ulmus crassifolia*), river birch, box-elder (*Acer negundo*), hawthorn and loblolly pine (*Pinus taeda*) can be found in greater abundance. Some Mid-gradient Riverine locations have been converted to pasture or pine plantations.

Class: Depression

Depression wetlands are located throughout the Coastal Plain, some examples are known as Cypress Domes, Carolina Bays and Grady Ponds. In alluvial valleys, depressions occur primarily within the floodplain of the major rivers. They are distinguishable from the ephemeral (vernal) pools on flats and floodplains by clearly being deeper, larger, concave landforms that hold surface water for much or all of the growing season in most years. Many depressions are recently abandoned channels that still maintain a discernible hydrologic connection to the river. The soils in depressions typically have more clay, lower chroma, and many redox concentrations compared to the soils in the surrounding floodplain. Plant cover tends to be sparse, at least in the deepest parts of the depression, and usually, the herbaceous stratum is absent or limited to localized populations of hydrophytes such as lizard's tail (*Saururus cenruus*). The common tree and shrub species are overcup oak, water elm, baldcypress (*Taxodium distichum*), water tupelo (*Nyssa aquatica*), swamp black gum, water hickory, and green ash. Where canopy trees are largely lacking due to disturbance, buttonbush (*Cephalanthus occidentalis*) and smartweeds (*Polygonum* spp.) often dominate.

Two depression subclasses may be recognized strictly on the basis of flood frequency. There are minor differences in vegetation structure and composition between them.

1. *Connected Depression.* Connected Depressions occur within the floodplain of a stream.
2. *Unconnected Depression.* Unconnected Depressions occur outside the floodplain of a stream, such as a Carolina Bay, for example.

Class: Flat

Flats can occur in any setting where poor drainage and level topography cause rainwater to pond at or near the soil surface until it is removed by evapotranspiration. In alluvial valleys in the southern United States, most such sites are on river terraces. As alluvial features, terrace flats usually have a very subtle, rolling topography that causes precipitation to pond for much of the winter and spring. Summer storms also can cause these ephemeral pools (sometimes called vernal pools) to refill and remain ponded for days or weeks during the peak of the growing season, which can eliminate certain plant species and create a diverse patchy pattern within the plant community. Fire may also be an important factor in maintaining patch diversity in terrace flats. Most of the same species found in the less-frequently-flooded parts of Low-gradient Riverine sites can be found in terrace flats, particularly willow oak and water oak.

One other category of flat occurs in areas that were historically frequently flooded, but which have had flooding reduced or eliminated by channel incision or engineered flood control projects such as reservoirs and levees.

These sites are classified as functional flats due to the lack of regular interaction with channel systems, but their plant communities are generally similar to frequently flooded sites because their alluvial soils and topography effectively pond precipitation and maintain the wetland character of the system.

Many stream terraces outside the Holocene floodplains within the reference domain no longer support natural forests, having long ago been converted to agriculture or pine plantations. Therefore, no flat-specific assessment models are presented here. However, the natural vegetation of flats within alluvial valleys is very similar to the forests of active floodplains; therefore, the models developed for Riverine systems can reasonably be applied to flats if they are modified to eliminate model terms related to flood frequency.

Class: Fringe

Fringe wetlands occur along the margins of marine and fresh waterbodies (lentic). By convention, a lake must be more than 2 m (6 ft) deep; otherwise, associated wetlands are classified as depressions.

In alluvial valleys of the Coastal Plain, natural lakes occur mostly in the abandoned channels of large rivers (oxbows), but numerous man-made impoundments also support fringe wetlands. There are three subclasses in the fringe class (Table 5). No assessment models have been developed for any of the fringe wetland subclasses, primarily because no single reference system can reflect the range of variability they exhibit. In particular, many water bodies that support fringe wetlands are subject to water level controls, but the resulting fluctuation patterns are highly variable depending on the purpose of the control structure.

1. *Reservoir shore*. Man-made reservoirs include a wide array of features, such as large farm ponds; state, Federal, and utility company lakes; and municipal water storage reservoirs. In almost all cases, these lakes are managed specifically to modify natural patterns of water flow; therefore, their shoreline habitats are subjected to inundation at times and for durations not often found in nature. Steep reservoir shores usually support little perennial wetland vegetation other than a narrow fringe of willows. The most extensive wetlands within reservoirs usually occur where tributary streams enter the lake, and sediments accumulate to form deltas. These sites may be colonized by various marsh species, and sometimes

black willow or buttonbush; but even these areas are vulnerable to extended drawdowns, ice accumulation, erosion caused by boat wakes, and similar impacts.

2. *Connected lake margin*. Large connected lake margin wetlands are uncommon in the reference domain. However, smaller lakes such as natural oxbow lakes, man-made stock ponds and borrow pits that are frequently inundated during floods may support connected lake margin wetlands. Connected lake margins differ from unconnected systems in that they routinely exchange nutrients, sediments, and aquatic organisms with the river system. Shoreline willow stands and fringe marshes are the typical vegetation.
3. *Unconnected lake margin*. Unconnected lakes are lakes that are not inundated by a river on a regular basis. They are similar in appearance to connected lake margins but are classified separately because they do not regularly exchange nutrients, sediments, or fish with river systems. In the reference domain, most unconnected lake margin wetlands are in small man-made ponds.

Class: Slope

Slope wetlands occur on or below sloping land surfaces where groundwater discharge or shallow subsurface flow creates saturated conditions. In the alluvial valleys of the Coastal Plain, these wetlands occur primarily in the headwaters and on the lower parts of valley walls or on terraces where they contact valley walls.

1. *Headwater Slope*. Headwater Slope wetlands on the Coastal Plain are associated with the headwaters and streams up to 3rd order, which constitute 70-90% of stream length in Coastal Plain drainage networks. Headwater Slope wetlands are characterized by water tables at or near the surface that respond rapidly to precipitation (direct and/or return flow) and evapotranspiration (ET). They attenuate surface flow to the stream channels down-gradient, dampening the hydrograph during high precipitation events and extending base flow of streams as the groundwater is released (Miwa et al. 2003). Many headwater reaches cease flowing in mid-summer during periods of maximum ET and under drought conditions. Even Coastal Plain streams up to third order may stop flowing during drought periods. However, in winter, when the water table is already high and ET is low, heavy rains can lead to channel overflow, briefly inundating the wetland. Channels associated with Headwater Slope wetlands are generally poorly developed in the upper reaches, becoming

more distinct with progression down-gradient. Channels range in width from 0.75 to 7.8 m (mean=3.4 m), are usually not more than a 0.1-0.5 m deep at bankfull stage, and are typically first to third order. Valley widths of headwater reaches are usually narrow (tens of meters in width). Natural levees are generally absent. Water rarely ponds within these wetlands, except in shallow depressions and divots produced by tree tip-ups.

Common species of Headwater Slope wetlands include sweetbay magnolia (*Magnolia virginiana*), redbay (*Persea borbonia*), tulip poplar (*Liriodendron tulipifera*), red maple, sweetgum, swamp blackgum, laurel oak, loblolly pine, slash pine (*P. elliottii*), and sometimes longleaf pine (*P. palustris*). Subcanopy species include spicebush, (*Lindera benzoin*), sweet pepperbush (*Clethra alnifolia*), ironwood, American holly (*Ilex opaca*), winterberry (*Ilex verticillata*), Virginia willow *(Itea virginica*), possumhaw (*Viburnum nudum*), wax myrtle (*Myrica cerifera*), highbush blueberry (*Vaccinium corymbosum*), luecothoe (*Luecothoe racemosa* and coastal dog hobble *L. axillaris*), fetterbush (*Lyonia lucida*), *Rhododendron* spp., titi (*Cyrilla racemiflora*), inkberry (*Ilex glabra*), large gallberry (*Ilex coriacea*), red chokecherry (*Aronia arbutifolia*), and American snowbell (*Styrax americana*). The structure of Headwater Slope communities also can be strongly influenced by fire (Wharton et al. 1977), though the frequency of fires is only about once every 60 to 100 years (Hutchinson et al. 2003).

2. *Valley wall and terrace slope*. Valley wall and terrace slope wetlands tend to be found where permeable materials (especially sands) sit atop relatively impermeable layers, causing lateral movement of groundwater. Typically, where groundwater flow is relatively constant (perennial seeps) these sites support diverse communities of herbaceous plants, but the specific composition can vary widely. Beakrushes (*Rhynchospora* spp.) are commonly present, as are various carnivorous plant species such as pitcher plants (*Sarracenia* spp.) and sundews (*Drosera* spp.). Where the seepage is more seasonal or intermittent (wet-weather seeps), woody species also may occur, including sweetbay magnolia, blackgum, and a variety of shrubs such as wax myrtle and possumhaw (Diggs et al. 2006). Valley wall and terrace slope wetlands tend to be very small, and few of them occur on alluvial surfaces. Where they do occur, they are sufficiently rare and support such unusual species that they are likely to be considered to be of special concern based on one or more criteria. Therefore, this guidebook does not include assessment models for this wetland subclass.

Modern Disturbance

Rivers and streams (and their floodplain wetlands) were largely free from major man-induced flow alteration during the Holocene. Rivers flowed freely to the sea, reworked their floodplains en route, and were a major sink for sediments (Leigh 2008). Some authors now refer to the time since the beginning of the Industrial Age as the “Anthropocene,” to reflect the magnitude of human impacts globally (Isendahl 2010).

Table 6 summarizes the major types of human alterations that alluvial valley wetlands have been subjected to during the “Anthropocene” on the Coastal Plain differentiated by HGM wetland subclass. Most alterations are common to several, but not all subclasses. The most significant alterations to these wetlands are to the hydraulic connections between wetlands and their water sources commonly through channelization, ditching, levee construction, and placement of fill. Timber harvest is a common alteration in all subclasses, but this alteration primarily affects habitat and biogeochemical-related functions, and is more of a temporal alteration than one in which the fundamental drivers of the wetland system are altered. Other alterations may be more typical within a subset of the subclasses. For example, due to their size, only headwater streams are diverted through culverts, and impoundments are usually only built on streams and rivers with perennial flow and where topography provides sufficient water storage capacity.

Ditching and draining. Ditching and draining is usually done in headwater wetlands or in floodplain depressions to remove water and convert them to other uses. Ditching and draining are usually done in concert with filling and channelization to convert wetlands to agricultural production or industrial silviculture use. In urban areas, channels are diverted through culverts to remove water and convert wetlands to urban infrastructure. In both urban and rural areas, pollution associated with land management activities (fertilizers and biocides in agricultural areas and petrochemicals, fertilizers, and biocides in urban areas) is shunted directly to stream channels by ditches. Polluted water is then carried downstream.

Because headwater streams constitute 70-90% of stream length in Coastal Plain drainage networks (Leopold et al. 1964; Rheinhardt et al. 1999), headwater riparian zones are the primary gateway by which nonpoint source pollution can potentially enter stream networks. Much of the poor

Table 6. Alterations typical in the Coastal Plain, organized by subclass.

Alteration	Affected Subclass				Effects
	Headwater	Mid-gradient	Low-gradient	Connected Depression	
1. Ditching and draining	X			X	Eliminates wetland and wetland habitats, shunts pollution, sediment directly into stream.
2. Filling floodplain/riparian zone to convert to cropland, silviculture, or impervious surface (e.g.,, roads)	X	X	X	X	Eliminates wetland and wetland habitats.
3a. Excavating, straightening, and/or stabilizing channels to move water downstream quickly (i.e., channelization, levees)	X	X	X	X	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.
3b. Timber removed or selectively cut from floodplain, natural succession allowed	X	X	X	X	Removes biomass, changes species composition, decreases biodiversity, temporarily increases carbon detrital pool (from slash), disrupts nutrient cycling and sequestration until forest regenerates.
4. Floodplain converted to intensively managed industrial silviculture	X	X			Changes species composition, reduces biodiversity, reduces detrital carbon pool.
5. Damming channel for flood control, recreation, waterfowl management, and/or power		X	X		Reduces sediment aggradation downstream, changes frequency, timing, and duration of overbank flow events, changes species composition on floodplain.
6. Groundwater withdrawal from contributing aquifer (center pivot irrigation, pulp mills, etc.)	X	X		X	Reduces water table and duration of saturated conditions, perhaps changing species composition.
7. Deadfall removed from channel	X	X			Reduces instream habitat, decreases residence time of flooding, reduces source of dissolved and particulate organic matter.
8. Stormwater runoff shunted directly to channel (often from impervious surfaces)	X	X			Increases flashiness of hydrologic regime, incises channels which decreases duration of overbank flow events, increases pollution loading.
9. Excessive cover (>25%) of invasive species	X	X	X	X	Reduces biodiversity by reducing habitat heterogeneity for animals, reduces native plant species populations, and may alter nutrient cycling.

water quality of rivers and estuaries in the southeast U.S. can be attributed to headwater reaches that have been ditched, their riparian buffers removed, and former floodplains converted from potential sinks of nutrients to pollutant sources (i.e., converted from forest to cropland or impervious infrastructure) (Alexander et al. 2007). The potential of poor headwater condition to affect downstream reaches was revealed in a study by Phillips (1997) that quantified sediment deposition on Mid-gradient floodplain wetlands in the outer Coastal Plain of North Carolina. Phillips found 1-2 m of eroded sediment on these Mid-gradient floodplains, representing a hundredfold increase in the sediment accretion rate since 1700. He attributed 92-95% of the excess sediment to erosion from headwater drainage basins (areas < 3 km2) over the last 300 years.

Placement of fill on floodplains and riparian zones. Fill is often associated with conversion of headwater riparian zones to row-crop agriculture and road construction across streams. In agricultural fields, headwater reaches are often channelized and the spoil is sometimes used in the construction of levees or as fill on the floodplain. Ditches and tiles are placed at regular intervals across floodplains to facilitate drainage and are usually connected to a canal that has replaced the natural stream channel. It may often be difficult to distinguish a field ditch from a channelized headwater stream. In both ditches and channelized headwater reaches, crops are cultivated close to the edge of the channel, leaving little riparian area in native vegetation.

Roads crossing headwater wetlands often restrict the flow of water, culverts are often undersized, or the invert is higher than the wetland surface, causing ponding up-gradient. Ponding generally will cause a shift in plant community composition, and will probably alter amphibian animal communities as well. In addition, road networks often intercept subsurface interflow, short-circuit delayed flow, and route flow and associated sediment and pollutants rapidly down valley to a stream crossing. Headwater reaches encompass the greatest linear distance of the stream network on the Coastal Plain. These types of impacts are common.

Mid-gradient Riverine wetlands and Low-gradient Riverine wetlands are often affected in similar ways by road crossings. Approaches to bridge crossings are nearly always constructed of fill, and bridge openings at main channels are sized using short recurrence intervals years as a design standard, resulting in flow constrictions during moderate floods. Beaver may aggravate restricted flow from the floodplain on mid-order streams by constructing their dams at crossings where the floodplain is artificially narrow.

Dredging, channelization, and channel armoring. Many Coastal Plain streams have been channelized, snagged, and leveed. Channelization reduces shading, homogenizes benthic habitat, changes flow regime, nutrient and sediment distribution and exchage, disrupts run/pool patterns, and prevents access to floodplains by fish and other aquatic biota (Bolton and Shellberg 2001). Further, in channelized streams where the hydrologic connection between channel and floodplain has been significantly decoupled, pollutants that might otherwise be trapped or transformed in floodplain wetlands are shunted further downstream. Pollution is transported quickly and directly from headwaters to estuaries where it may promote eutrophication. This leads to the loss of submerged aquatic vegetation, hypoxia, disruption of estuarine food webs, and fish kills (Elliott and de Jonge 2002; Pinckney et al. 2001). Drainages in which both headwater and Mid-gradient Riverine wetlands are in poor condition contribute most to the reduced chemical integrity of downstream rivers and estuaries.

Channelization of high-order stream channels was not always the most cost-effective means of conversion of floodplain wetlands to agriculture in the Southeast U.S. (Hidinger and Morgan 1912). Instead, levees were often constructed a short distance from the channel to isolate floodplains and facilitate agriculture or other land use.

Timber harvest and intensive silviculture. Timber removal is the most common alteration to all four subclasses described in this guidebook. The effects of this can be seen with a review of the USDA Forest Service's Forest Inventory Analysis Database (FIADB) (Bechtold and Patterson 2005; US Department of Agriculture 2010a, 2011) which shows that very few forests in these subclasses across the Coastal Plain are greater than 100 years old. Figure 6 illustrates FIADB data from alluvial valley wetlands of the Coastal Plain. If timber harvest is not accompanied with hydrologic modifications to facilitate land-use conversion, and if natural succession is allowed to occur, effects are temporary, and the wetland may function similarly to a wetland that has experienced a setback in the seral stage of the vegetation due to a natural disturbance from wind or fire. In contrast, conversion to silviculture, agriculture or urban infrastructure represents relatively permanent alterations to biological integrity.

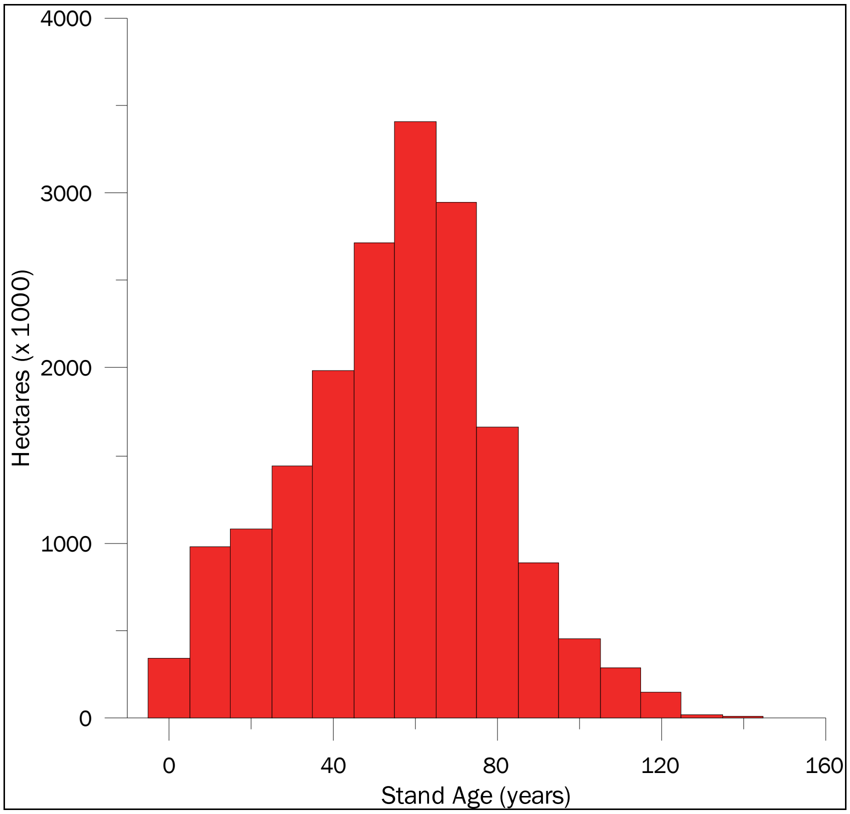


Figure 6. Plot of age distribution of forests on alluvial valley wetlands of the Coastal Plain. Data was summarized from the Forest Inventory Analysis Database (U.S. Department of Agriculture 2010a).

Headwater areas are often imbedded in a mosaic of intensively managed silvicultural lands of pine monoculture, usually comprised of loblolly pine or slash pine. High density pine plantations can increase evapotranspiration in source areas which may lower the water table in Headwater Slope wetlands. Mid- and Low-gradient floodplains are less frequently converted from bottomland hardwood forest to managed silviculture, unless channelization, ditching, and/or levee construction makes it feasible. Alluvial valley depressions are not likely to be converted to agricultural or silvicultural uses because of the generally clayey soils and the expense involved with draining them. They are often all that remains of a floodplain forest after land-use conversion.

Impoundments. Impoundment of headwater streams is generally done to create small ponds for agricultural, recreational, and residential uses. Larger streams are often impounded for purposes serving the general population, including flood control, hydropower generation, water supply, recreation, and water-borne transportation. The dams of the largest reservoirs affecting the larger Coastal Plain streams are generally located on the Fall Line or higher on the Piedmont. Regulation of flow through these larger structures, especially for flood control and hydropower generation, substantially alters flow regimes on floodplains (Graf 2006; Magilligan and Nislow 2005). Regulated streams are generally “sediment starved” downstream of the dam leading to channel incision, bank failure, reduction in maintenance of bedforms (aquatic habitat), and sediment delivery onto adjacent floodplains. Altered flow regimes lead to changes in the composition of vegetation in floodplain habitats in downstream reaches (Hupp et al. 2009; Stallins et al. 2010).

Groundwater withdrawal. Regional and local groundwater withdrawal may affect wetlands of alluvial valleys, especially of headwater and Mid-gradient reaches. However, research in this area is lacking. Center-pivot irrigation withdraws water from surficial aquifers and may intercept groundwater flow to headwater reaches. Regional water withdrawals for industrial use, e.g., pulp mills, has been shown to cause land subsidence over large areas and could likewise affect groundwater flows.

Deadfall removal (snagging). Snagging (or de-snagging) is the practice of removing large wood from channels and live trees and shrubs from channel banks to facilitate flow and navigation. Removing snags detrimentally affects aquatic biota by reducing habitat diversity (Angermeier and Karr 1984). Removing such features also increases organic carbon export (Bilby and Likens 1980), reduces shade, reduces benthic and fish habitat (Angermeier and Karr 1984; Benke et al. 1985; Sechnick et al. 1986), and can increase stream bank instability.

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 have reduced time of recession after flood events and less baseflow, which limits aquatic biota access to floodplain and stream channel habitats. Incised channels behave like channelized streams in that channels are hydrologically disconnected from their floodplains (O'Driscoll et al. 2009; O’Driscoll et al. 2010). This de-coupling affects floodplain wetland functions, such as cycling and transformation of elements. Among them is the nitrogen cycle; the reduction of floodwaters results in reduced denitrification potential of the floodplain (Harnsberger and O’Driscoll 2010). In rural areas, most of the stormwater infrastructure is associated with the road network. Ditches in agricultural fields are often routed to roadside ditches, which transport sediment and nutrients to streams. The total length of roadside ditches in rural areas is often similar to the total length of natural headwater streams in a drainage network. There is a notable lack of published studies on the effects of road runoff on headwater streams and their wetlands, particularly in Coastal Plain drainages.

Invasive species. All wetlands may potentially harbor invasive species (Miller 2003). The presence of invasive species often indicates past disturbances or stress, e.g., past vegetation clearing, changes in nutrient availability, etc. (Alpert et al. 2000). Common canopy tree species that may invade and persist in Riverine wetlands in the Coastal Plain include: Chinese tallow (*Triadica sebifera*), tree-of-heaven (*Ailanthus altissima*), mimosa (*Albizia julibrissin*), and Russian olive (*Elaeagnus angustifolia*). However, shrubs, vines, and grasses are more commonly problematic on floodplains. Of particular concern are Chinese privet (*Ligustrum sinense*), Japanese honeysuckle (*Lonicera japonica*), Japan grass (*Microstegium vimineum*), and garlic mustard (*Alliaria petiolata*). Nonnative invasive plant species, when prevalent, reduce space for native plant species and reduce heterogeneity of habitat for animal species, although the fruits of some invasive species are eaten by birds, e.g., berries of Chinese privet. Some invasive plant species are alleopathic; i.e., they produce chemicals that prevent other plants from growing near them. There is also evidence that invasive species alter nutrients cycles (Zedler and Kercher 2004), but more work is needed in this area.

Subclass Applicability

This *Regional Guidebook* contains assessment models in the following chapter that are applicable to the most common forested wetlands in the alluvial valleys of the Coastal Plain. These are the Low-gradient Riverine, Mid-gradient Riverine, Connected Depression, and Headwater Slope subclasses. The other wetland subclasses that occur within the reference domain are uncommon or are excluded for other reasons, as follows:

1. Fringe wetlands comprise a complex of community types that occur in zones that reflect a wide variety of potential water depths, energy regimes, and fluctuation patterns. No generalized reference system can adequately reflect that complexity; therefore, fringe wetlands are beyond the scope of a rapid assessment approach. Proposed impacts to fringe wetlands should be evaluated on a site-specific basis, using the existing community as the

reference wetland, particularly if the proposed impacts involve changes to water regimes.

2. Valley wall and terrace slope wetlands occur within alluvial valleys, but they often differ from the Headwater Slope subclass in that they are characterized by the presence of unique and sometimes rare plant species. The most appropriate approach for assessing these systems should involve evaluation of the water source and impacts to the source area, and a detailed floristic inventory. Both of these are beyond the scope of a rapid field assessment technique like HGM; therefore, no assessment criteria for valley wall and terrace slope wetlands are included in this guidebook.
3. Unconnected Depression wetlands and flats were excluded from this *Regional Guidebook* by the A-Team. The A-Team made the decision to focus efforts on Headwater Slope wetlands, primarily because of the high density of Headwater Slope wetlands in stream networks on the Coastal Plain and the ongoing development pressure on this subclass. However, the few sites that were sampled prior to this decision indicate that the same pattern found in Arkansas would likely apply – that is, the plant community composition and structure are very similar to the more frequently flooded wetlands on similar sites. Therefore, while no reference-based models are presented in this guidebook, the models for Connected Depressions and Low-gradient Riverine wetlands could be applied if no alternative assessment approach is satisfactory. In order to do so, the assessment models must be modified to eliminate hydrologic variables. Any analysis that uses modified models to assess relatively uncommon wetlands should be clearly identified as such and the pertinent modifications and assumptions should be described.
4. No models are available that are specific to managed wildlife impoundments (greentree reservoirs and moist soil management units). However, where existing wetlands are proposed to be converted to managed impoundments, the models appropriate to the impact area can be used to assess the functional change likely to occur from altered water regimes (see "Apply Assessment Results" in Chapter 5).
5. Beaver-influenced wetlands cannot be assessed using simple structural and compositional indicators, because of the highly dynamic and spatially diverse nature of those systems. They should be regarded as fully functional components of the Riverine system. The HGM models presented here can be used to assess areas significantly modified by beaver activity, but the user should acknowledge the natural occurrence of beavers in the reference domain.

4 Wetland Variables, Subindex Curves, Functions, and Assessment Models

Reference Data

The reference data collected for each variable has been independently summarized by subclass. For each variable used, functional capacity subindex curves are presented 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. The subindex curves were constructed based primarily on the field data; in cases where the field data were not definitive, the subindex curves were constructed from other reference data sets (such as the Forest Inventory Analysis Database (U.S. Department of Agriculture 2010a, 2011), from curves established in previous HGM guidebooks for portions of the Coastal Plain, or from the literature (e.g., the assessment of spatial relationships (e.g., buffer widths and connectivity) are not entirely based on field data).

Variables

The following variables are used to assess the functions that are performed by alluvial valley wetlands on the Coastal Plain of the United States:

- Change in Catchment Size (V_{CATCH})
- Upland Land Use (V_{UPUSE})
- Habitat Connections ($V_{CONNECT}$)
- Soil Integrity ($V_{SOILINT}$)
- System Hydrologic Alterations ($V_{HYDROSYS}$)
- Site Hydrologic Alterations ($V_{HYDROALT}$)
- Canopy Tree Diameter (V_{BIG3})
- Canopy Tree Density (V_{TDEN})
- Sapling/Shrub Cover (V_{SSC})
- Ground Vegetation Cover (V_{GVC})
- Vegetation Composition and Diversity (V_{COMP})
- Woody Debris (V_{WD})

Each variable is defined and the rationale for its selection is discussed in the following paragraphs. The relationship of each variable to functional capacity is also given, based on reference data from within 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 5. Certain variables are applicable to the Headwater Slope subclass but not the Riverine subclasses and vice-versa (Table 7).

Table 7. Applicability of assessment variables by wetland subclasses of the Coastal Plain alluvial valleys.

Variable	Headwater Slope	Mid-gradient Riverine	Low-gradient Riverine	Connected Depression
V_{CATCH}	+	Not used	Not used	Not used
V_{UPUSE}	+	Not used	Not used	Not used
$V_{CONNECT}$	1	2	2	2
$V_{SOILINT}$	+	+	+	+
$V_{HYDROSYS}$	Not used	+	+	+
$V_{HYDROALT}$	1	2	2	2
V_{BIG3}	+	+	+	+
V_{TDEN}	+	+	+	+
V_{SSC}	*	*	*	*
V_{GVC}	*	*	*	*
V_{COMP}	+	+	+	+
V_{WD}	+	+	+	+

Note: Variables not used in assessment of a particular subclass are identified. Variables always used in assessment of the subclass are indicated by +. Variables measured with different procedures depending on subclasses are marked with a number. Variables that are used only under certain site conditions are indicated by *.

Change in Catchment Size (V_{CATCH}).

This variable is defined as the change in the size of the wetland catchment, watershed, or basin as a result of human activities in the wetland's landscape. The purpose of this variable is to express the change affecting the amount of water delivered to the wetland due to alterations to the watershed that either reduce or augment surface or subsurface flows. V_{CATCH} only applies to the hydrology function in the Headwater Slope subclass.

In the case of water diversions away from the Headwater Slope wetland by ditches, berms, or other features in the catchment, the change is quantified as a percentage loss of catchment area by using the following formula (Equation 2):

$$Percent\ Change = \left(\frac{Natural\ catchment\ size - Existing\ catchment\ size}{Natural\ catchment\ size} \right) \times 100 \qquad (2)$$

In the case of water transfers into the wetland catchment from another basin, the change is calculated as a percentage increase in effective catchment area as follows (Equation 3):

$$Percent\ Change = \left(\frac{Area\ of\ catchment\ from\ which\ water\ is\ being\ transfered}{Natural\ catchment\ size} \right) \times 100 \qquad (3)$$

For example, if the natural catchment area (denominator in Equation 3) is 100 hectares and an area equal to 10 hectares is diverted into the effective catchment area from an adjacent catchment area, the numerator in Equation 3 would be 10. Therefore, the percent change would be 10% (solving for Equation 3, 10/100 x 100 = 10). If the effective size of the catchment is unchanged (i.e., no water diversions), then the subindex score is 1.0. In Headwater Slope wetland reference sites, percentage change in the size of the wetland catchment ranged from 0 to 73 percent.

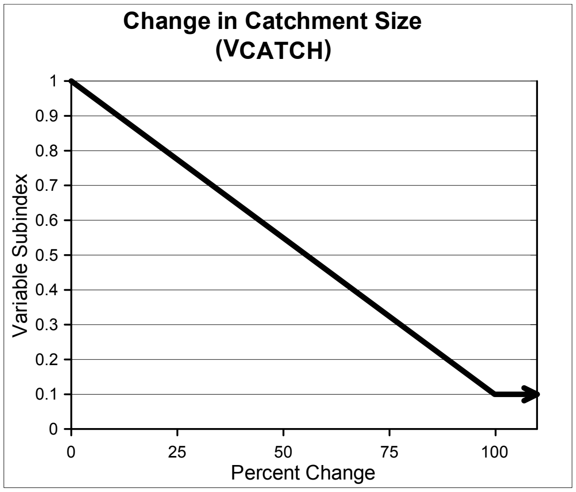


Figure 7. Change in effective size of the wetland catchment and functional capacity.

The size of the catchment of reference standard wetland sites had no change (i.e., percent change = 0). The relationship between functional capacity and the percent change in catchment area is assumed to decline linearly to 0.1 when the percentage change equals 100 percent (Figure 7). This is based on the assumption that, as the effective size of the catchment decreases, the amount of water entering the wetland is proportionately reduced and is not available for storage in the wetland. However, the subindex does not go to zero because the wetland still receives direct precipitation and could still receive some subsurface input from the surrounding area. Additions of water to the wetland catchment are assumed to impact the natural hydrology of the wetland to the same extent as diversions. In the case of water transfers into the wetland catchment, the percentage change in effective catchment area can exceed 100 percent.

Upland Land Use (V_{UPUSE})

This variable is defined as the change in the surface water runoff potential from the wetland catchment into the wetland as a result of human activities. V_{UPUSE} only applies to the hydrology function in the Headwater Slope subclass.

The volume and rate of surface water delivery to a Headwater Slope wetland increases with increased disturbance and increased impervious surfaces surrounding the wetland. The variable metric is a weighted average of runoff scores based on runoff curves developed by the Natural Resources Conservation Service (U.S. Department of Agriculture 1986). Runoff curve numbers are a function of land use and soil type. For this guidebook, curve numbers are estimated based on land use and hydrologic soil groups A through D (Table 8). Hydrologic soil groups are based on soil properties such as texture and depth to restrictive layers. Aerial photographs depicting land use are available from a number of internet sources including TerraServer (http://terraserver.homeadvisor.msn.com/), Google Maps (http://maps.google.com/), and Web Soil Survey (http://websoilsurvey.nrcs.usda.gov/). The Web Soil Survey provides the most current soil survey maps and incorporates measurement tools accessible through a web browser. Hydrologic soil groups for soil series can be found in local soil surveys or at the Soil Data Mart (http://soildatamart.nrcs.usda.gov/) in the Water Features report. The subindex score for V_{UPUSE} is based on the weighted average of runoff scores for land uses and soils identified in the upland catchment of the Headwater Slope wetland (see Appendix D for an example calculation).

Table 8. Runoff curve numbers by Hydrologic Soil Group.

Upland Land Use Hydrologic soil groups	Hydrologic Soil Group			
	A	B	C	D
Open space (pasture, lawns, parks, golf courses, cemeteries:				
Poor condition (grass cover <50%)	68	79	86	89
Fair condition (grass cover 50% to 75%)	49	69	79	84
Good condition (grass cover >75%)	39	61	74	80
Impervious areas (parking lots, roofs, driveways, etc)	98	98	98	98
Gravel	76	85	89	91
Urban districts:				
Commercial and business (85% cover)	89	92	94	95
Industrial (72% cover)	81	88	91	93
Residential districts by average lot size:				

Upland Land Use Hydrologic soil groups	Hydrologic Soil Group			
	A	B	C	D
1/8 acre or less (town houses and apartments) (65% cover)	77	85	90	92
1/4 acre (38% cover)	61	75	83	87
1/3 acre (30% cover)	57	72	81	86
1/2 acre (25% cover)	54	70	80	85
1 acre (20% cover)	51	68	79	84
2 acres (12% cover)	46	65	77	82
Newly graded areas (no vegetation or pavement)	77	85	90	92
Fallow crop areas (poor)	76	85	90	93
Fallow crop areas (good)	74	83	88	90
Row crops	70	80	86	90
Small grain	64	75	83	87
Groves and orchards (<50% ground cover)	57	73	82	86
Groves and orchards (50% to 75% ground cover)	43	65	76	82
Groves and orchards (>75% cover)	32	58	72	79
Forest and native range (<50% ground cover)	45	66	77	83
Forest and native range (50% to 75% ground cover)	36	60	73	79
Forest and native range (>75% ground cover)	30	55	70	77

Modified from USDA Natural Resources Conservation Service (1986)

Headwater Slope reference standard wetlands were surrounded in their catchments by native vegetative communities. Under reference standard conditions, native upland plant communities have runoff scores of 55 or less and would receive a subindex of 1.0 (Figure 8). Instances of land use that significantly increase the amount of runoff into a Headwater Slope wetland are assumed to be detrimental to the characteristic hydrologic regime of the wetland. The subindex for this variable is assumed to decline linearly to zero as the weighted average runoff score increases from 55 to 98 when there is less than 75% cover of forest or native range cover in the catchment.

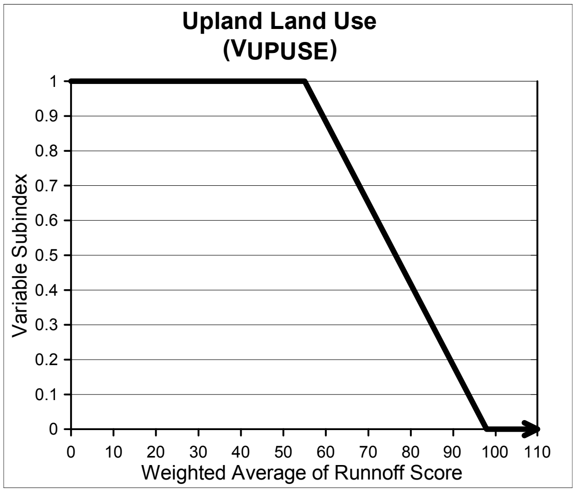


Figure 8. Relationship between the weighted average runoff score of the upland land use and functional capacity.

Habitat Connections ($V_{CONNECT}$)

The variable is assessed differently in the Headwater Slope subclass than in the other Riverine subclasses.

This variable expresses the connectivity of the wetland assessment area's habitat with other suitable habitat (wetland or upland). Suitable habitat is defined as natural plant communities that provide minimally suitable food, cover, and breeding sites for native wetland wildlife species that depend on wetlands. Native forested areas of any age class, prairie, savanna, and scrub/shrub habitats are all suitable. Managed forests and pine plantations are considered suitable only if soils, litter, and ground-layer vegetation have not been disturbed extensively (e.g., bedded) such that cover has been eliminated and animal movement is impeded. Areas devoted to row crops, closely mowed areas, grazed pastures, and urban areas are not suitable habitat. $V_{CONNECT}$ applies only to the wildlife habitat function.

Headwater Slope Subclass

The connectivity of these small-scale wetlands to suitable habitat is critical for wetland-dependent salamanders and other amphibians. The width of adjacent, suitable habitat also is considered in this variable. Ideally, a zone or buffer of suitable habitat should surround the wetland and extend 150 m (492 ft) or more beyond the wetland boundary (Semlitsch and Bodie 2003). A narrower zone and/or an incomplete buffer can, however, provide habitat for many amphibian, reptile, and avian species that depend on these wetlands. For this subclass, therefore, $V_{CONNECT}$ is defined as the percentage of the wetland perimeter connected to suitable wetland or upland wildlife habitat weighted by the average width of the buffer. To be considered in this calculation, a zone or buffer of suitable habitat must extend at least 10 m beyond the wetland boundary (Figure 9). If the majority of the wetland buffer of suitable habitat is 150 m (492 ft) or greater, the subindex is weighted by a factor of 1.0 (solid line in Figure 10). If the majority of the buffer width is 30-150 m (98.4-492 ft) in width, the subindex is weighed by a factor of 0.66 (dashed, middle line in Figure 10), and if it is 10-30 m (32.8-98.4 ft) in width, the weighting factor is 0.33 (dotted, lowest line in Figure 10).

For example, the wetland illustrated in Figure 9A has suitable habitat adjacent to about 80% of its perimeter. Of the perimeter that is buffered, the majority of it is 150 m in width or greater. The subindex is read where

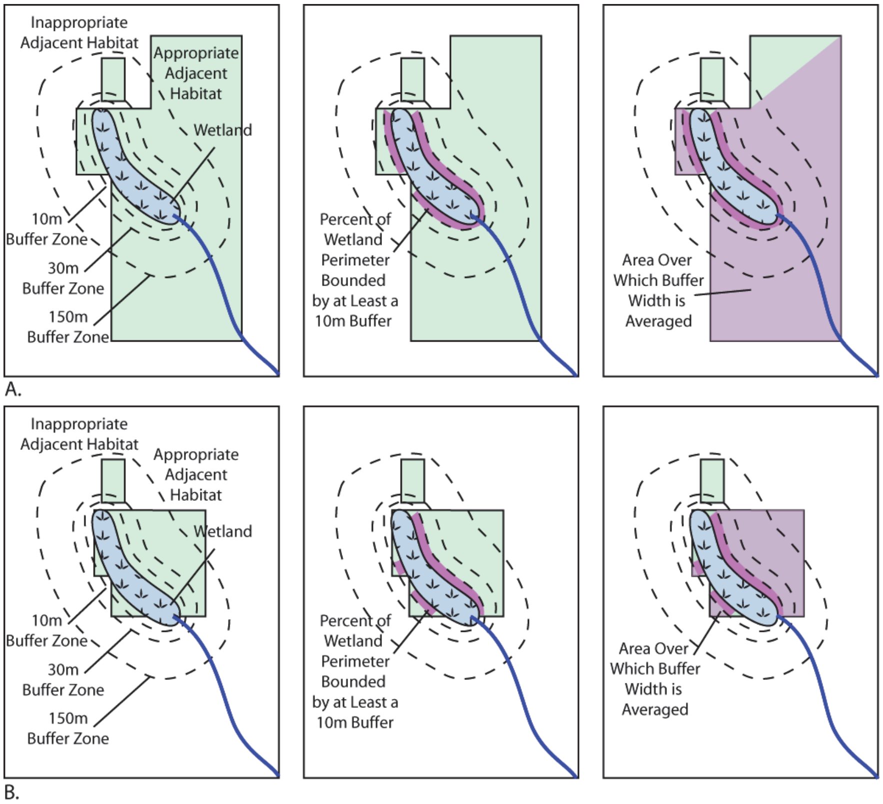


Figure 9. Illustration of values needed to calculate $V_{CONNECT}$ for the Headwater Slope subclass. A. In this example, 80% of the wetland perimeter bounded by at least a 10-m-wide buffer (second panel), and the majority of the buffer is more than 150 m (third panel). B. In this example, only 50% of the wetland perimeter is adjacent to suitable habitat, and the majority of the buffer is between 30 and 150 m in width.

80% on the x-axis intersects the top-most solid-line (Buffer > 150 m). The result is a variable subindex of 0.94 for $V_{CONNECT}$ (Figure 10). The wetland in Figure 9B has 50% of its perimeter buffered by suitable habitat. The majority of the buffer is between 30 and 150 m in width. The subindex is read where 50% on the x-axis intersects the middle dashed line (Buffer 30-150 m). The result is a variable subindex of 0.39 (Figure 10).

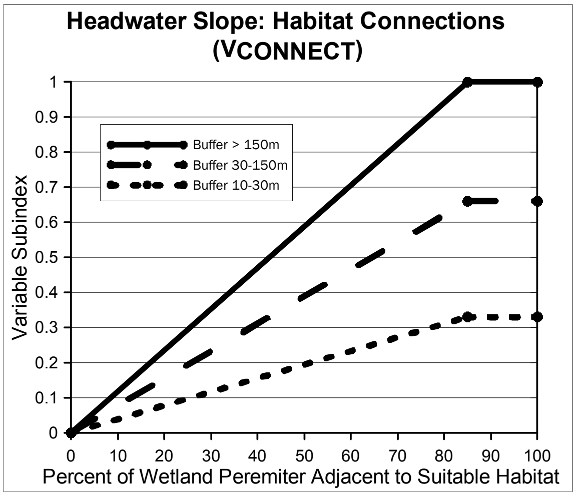


Figure 10. Relationship between the percentage of the wetland perimeter that is connected to suitable wildlife habitat, the width of the buffer, and functional capacity.

Riverine Subclasses

The $V_{CONNECT}$ variable for the Riverine subclasses, Low-gradient Riverine, Mid-gradient Riverine, and Connected Depression is defined as the degree of fragmentation of the forested habitat of the Riverine "neighborhood" (De Jager and Rohweder 2011). It 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 Riverine system. When the proportion of suitable habitat is low, then generally the patches of suitable habitat are small and isolated (Gustafson 1998).

The diversity of complex Riverine wetland habitats that exist on an intact floodplain provides critical breeding and foraging sites for many taxonomic groups. The habitat quality of a wetland site depends to a large extent on the integrity of the floodplain habitat surrounding it. The extent of fragmentation of southeastern floodplain habitat is a reliable indicator of the diversity of environmental conditions and plant species richness on the floodplain (Rudis 1995). In addition to the direct loss of foraging and nesting sites, increasing fragmentation of habitat decreases the likelihood of the flow of genes among populations (De Jager and Rohweder 2011). Individuals from adjacent populations may be excluded from particular breeding sites when their access is cut off by intervening areas of altered land use.

Different species inhabiting Riverine wetlands are impacted differently at different scales of habitat fragmentation. Minimum areas for viable populations, edge effects, and optimum configuration of habitat vary by species (De Jager and Rohweder 2011). The minimum area requirements for viable populations of black bears (*Ursus americanus*) or Florida panthers (*Felis concolor coryi*), for example, are much greater than that of smaller mammals such as river otters (*Lutra canadensis*), or amphibians such as salamanders.

Since multiple taxonomic groups are of interest at multiple scales in the Riverine subclasses, and due to the fact that no study has quantified the availability of forest habitat for multiple species that vary in terms of habitat-scale requirements (De Jager and Rohweder 2011), the scale of assessment for $V_{CONNECT}$ for the Riverine subclasses is not based on a particular taxonomic group, as it is for the Headwater Slope wetland subclass (salamanders) which is finite in scale. The scale of assessment is based instead on the scale of the Riverine habitat itself, which is not finite, but increases with watershed size. For the purposes of assessments conducted with this guidebook, the scale is termed here as the "assessment area reach" and is 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 (see example in Appendix D). The proportion of suitable habitat (defined above) within this window (De Jager and Rohweder 2011; Riitters et al. 2002), the "assessment area reach," represents the degree of fragmentation of the Riverine habitat. The procedures for assessing $V_{CONNECT}$ are in Chapter 5 and an example is given in Appendix D. Reference wetlands within the Riverine and Connected Depression subclasses had percentages of suitable habitat at this scale ranging from 12 to 100 percent. Riverine and Connected Depression wetlands are assumed to be fully functional when suitable habitat is $\geq$ 80% (Figure 11).

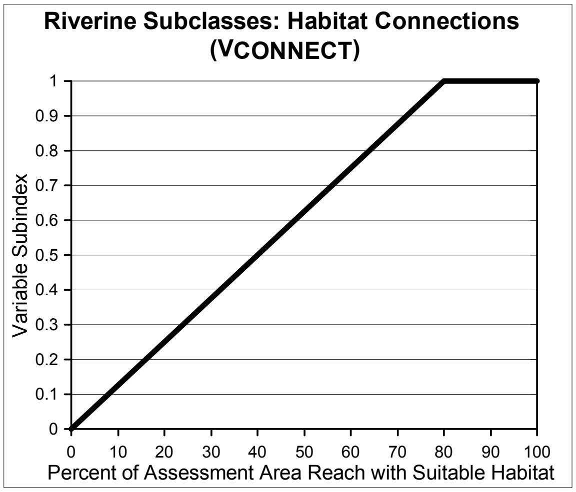


Figure 11. Relationship between the percentage of the assessment area reach with suitable wildlife habitat and functional capacity.

Soil Integrity ($V_{SOILINT}$)

This variable is defined as the percent of the wetland assessment area with altered soils, a measure of whether soil integrity has been altered at the site due to anthropogenic activity. Altered soils are defined as areas where the native soils have been excavated, replaced, buried, or are severely compacted. Areas may include roads, berms, ditches, parking areas and similar features, as well as other areas of excavation, fill, or severe compaction.

Alterations to the soil can change both soil permeability and soil porosity, thereby affecting the subsurface movement and storage of water in the soil. Soil permeability will affect the rate at which subsurface water moves down the hydraulic gradient through wetland soil and into the stream channel. When the velocity of subsurface water is high, subsurface water moves through the wetland quickly, and the period of time that subsurface water discharges to the adjacent stream is short. Likewise, highly compacted soil can reduce soil permeability to the point that water does not infiltrate the soil, and moves quickly across the top of the soil, entering the adjacent stream rapidly. In unaltered soils, the velocity of subsurface water is low, and discharge time to the adjacent stream extends over a longer period. Soil porosity will affect the volume of space available below the ground surface for storing water after adjusting for antecedent moisture conditions (Dunne and Leopold 1978).

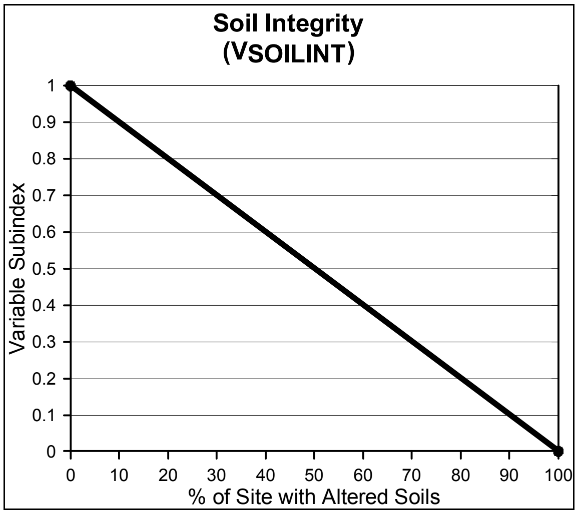


Figure 12. Relationship between the percentage of the assessment area with altered soils and functional capacity.

Evaluating soils in a rapid assessment context is difficult for three reasons. First, a variety of soil properties contributing to integrity should be considered (i.e., structure, horizon development, texture, bulk density). Second, the spatial variability of soils within many wetlands makes it difficult to collect the number of samples necessary to adequately characterize a site. Third, the natural variability of soils properties across the reference domain may mean that none are universally applicable within the region. Therefore, the approach used here is to assume that soil integrity exists where evidence of alteration is lacking, and that its properties are consistent with wetland function. Stated another way, if the soils in the assessment area do not exhibit any of the characteristics associated with alteration, it is assumed that the soils are similar to those occurring in the reference standard wetlands and have the potential to support wetland functions such as maintenance of a characteristic plant community.

System Hydrologic Alterations ($V_{HYDROSYS}$)

This variable is defined as man-induced alterations of stream hydrology. These often occur on a system-wide scale of the stream network, such as flow regulation through upstream dams for flood control or hydropower generation, or at the local scale of the adjacent stream reach, such as with channelization. The intent of this variable is to capture man-induced alterations to a stream's natural capacity for the delivery of floodwaters to Riverine wetlands (floodplains). This variable is used only in the models for the Riverine subclasses and is assessed in all four functions.

The quantification of a stream's capability to deliver floodwaters to a particular portion of its floodplain requires data that is time-consuming and often expensive to develop. In some cases, these data may have been developed and may be available. In most cases, however, the use of absolute quantities to describe floodwater interaction with a specific location on a floodplain, such as durations, depths, frequencies, and timing, is outside the scope of a rapid assessment. Adding to the difficulty is the spatial complexity of variation in hydrologic regimes in Riverine systems. The hydrologic regime of a Coastal Plain stream varies naturally within the floodplain of a particular stream reach and also by position within the watershed. The effects on floodplain wetland ecology from altered hydrologic regimes due to flow regulation through large reservoirs would also vary depending on floodplain and watershed position (Bales and Walters 2003; Townsend 2001; Wilder et al. 2012). Similarly, local channel degradation (incision) in response to channelization can have significant impacts to floodplain hydrology, with impacts across all wetland functions (Fredrickson 1979a; Hupp et al. 2009; Kuenzler et al. 1977; LaSage et al. 2008; Light et al. 2006; Oswalt and King 2005; Shields et al. 1997; Wilder and Roberts 2005). The nature of these impacts also varies with the site's floodplain and watershed position. At some floodplain locations, drier conditions may result from an alteration, while at other locations conditions may be wetter due to the same alteration.

The use of a particular method for the assessment of $V_{HYDROSYS}$ depends on availability of data and also on the context of the assessment. For example, the use of channel characteristics in comparing pre- and post-project conditions would not be appropriate when the project under consideration modifies the flow regime rather than the channel itself. The modified flow will likely result in changes in the channel morphology, but these changes will require time. In cases involving streams with long-established flow regulation (e.g., downstream of flood control reservoirs), a comparison of discharge data from periods pre- and post-flow regulation is appropriate, as the purpose of flow regulation is to modify the discharge (see example in Appendix D). Conversely, in cases involving channelized systems, comparison of stage data from periods pre- and post-channelization is appropriate as the primary effect of channelization is on stage rather than discharge. In most cases, sufficient gage data or modeling data will not already be available, and the use of measurements of channel morphology or comparison to qualitative descriptions is appropriate.

The approach used here is to assume that hydrologic regimes of the Riverine wetland subclasses vary with stream condition. The approach utilizes measures of departure from an unaltered state, based on the assumption that regimes are natural where evidence of alteration is lacking. Evidence of alteration could be developed with hydrologic modeling data or stream gage data. When this data is not available, which will most often be the case, evidence of alteration must be developed from field data, which — for the purposes of this guidebook — include comparison of channel dimensions to regional curves, or assessment in the field of channel conditions. Reference standard wetlands were adjacent to streams with no evidence of alteration (see Table 13, Chapter 5).

Site Hydrologic Alterations ($V_{HYDROALT}$)

This variable is defined as man-induced alterations to the natural hydrology of the wetland due to activities within the wetland assessment area. Examples in the reference domain include ditches, road crossings, excavations, fill, levee construction, and channelization. The intent of this variable is to capture impacts that prevent, retard, or accelerate the natural movement of water in and out of the alluvial valley wetland. This variable differs from $V_{HYDROSYS}$, V_{CATCH}, and V_{UPUSE} in that the impacts occur within the wetland and not in the surrounding landscape. $V_{HYDROALT}$ applies to all functions, but is assessed differently in Headwater Slope subclass than in the Riverine subclasses.

Within the Riverine subclasses, alterations ranged from complete isolation from the adjacent stream channel to ineffective ditching or partial obstruction of floodwaters. Mid-gradient and Low-gradient Riverine subclasses are inundated by surface flow from the adjacent stream during flood events. The duration of inundation generally increases with watershed size, with the longest events occurring mainly in late winter and early spring. The frequency and duration of inundation depends also on position within the floodplain. The highest features such as natural levees are inundated least frequently, and for only short periods during the largest events. The lowest features, such as backswamps, sloughs, swales, and abandoned channel segments are often inundated multiple times in a year. Inundation of these features typically persists long after floodwaters recede in the adjacent channel, partly because their soils tend to be fine silts and clays, and also because drainage back to the stream channel is often impeded by higher features that are superimposed across them, blocking surface flow. At sites exhibiting reference standard conditions (subindex = 1.0), there were no alterations to the natural hydrology (see Table 14 Chapter 5). The hydrology of unaltered Headwater Slope wetlands is dominated by groundwater and in Riverine wetlands by overbank flooding from the adjacent stream. In Headwater Slope reference standard sites, surface water is only present briefly, or in isolated pools in late winter and early spring, and after summer storm events.

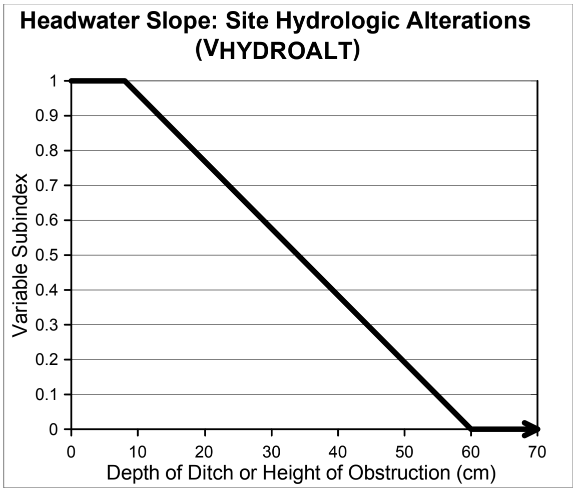


Figure 13. Relationship between height of obstruction or depth of ditch and functional capacity.

Within the Headwater Slope subclass, ponding of surface water throughout the wetland was not observed at any reference standard site, but there was evidence (drift lines, water marks) that surface water was as high as 8 cm (3 in.) for short periods. Temporary surface water depths of 8 cm (3 in.) or less is assumed to be natural, and small temporary pools are considered to be a natural component of these wetlands. Sites exhibiting these would receive a subindex score of 1.0 (Figure 13). Impacts to the natural hydrologic regime are assumed to be proportional to the depth of surface water greater than 8 cm (3 in.) that could be retained in the wetland due to a dam or other structure, or to the depth of effective drainage due to ditches or other excavations within the wetland. Impacts that would impound the Headwater Slope wetland to depths of 60 cm (24 in.) or more can alter the wetland to the extent that the hydrogeomorphic classification would change to depression or lacustrine fringe. Likewise, ditches of 60 cm (24 in) or greater would also alter the wetland within the effective drainage area of the ditch to the extent that it may no longer have wetland hydrology. Impacts of this magnitude were assigned a subindex value of 0.0 within the effective range of the ditch (Figure 13). Some impacted sites in the reference domain had impounded water greater than 1 m (39 in.) deep. Examples of these that had been impounded for multiple years were dominated by plant communities that are typical of depressions.

Canopy Tree Diameter (V_{BIG3})

This variable is defined as the average diameter at breast height (dbh) (measured at 1.4 m (55 in.) above the ground) of the three largest trees in each 0.04-ha (0.1-acre) plot, and summarized by stand. This variable is only measured if percent tree cover is 20 percent or greater. Canopy trees are defined as self-supporting woody plants ≥15 cm (6 in.) dbh.

Tree diameter is a common measure of dominance in forest ecology that expresses the relative age or maturity of a forest stand (Bonham 1989; Spurr and Barnes 1981; Tritton and Hornbeck 1982; Whittaker 1975; Whittaker et al. 1974). Tree basal area, measured as the cross-sectional area of tree stems at 1.4 m (55 in.) above the ground per unit area (e.g., m^2/hectare) is also a common measure of abundance and dominance in forest ecology that has been shown to be proportional to tree biomass (Bonham 1989; Spurr and Barnes 1981; Tritton and Hornbeck 1982; Whittaker 1975; Whittaker et al. 1974). V_{BIG3} was chosen as the assessment metric to represent stand maturity and age in the assessment models based on the strength of these relationships and for efficiency of its use in the field.

In the alluvial valley reference wetlands, the average dbh of the three largest trees of each plot in a stand ranged from 0.0 cm on sites where all trees had been removed to 70 cm (27.6 in.) in mature forest stands. The mean dbh of the three largest trees of each plot at reference standard wetlands of the Headwater Slope subclass were ≥ 35 cm (14 in.). A variable subindex of 1.0 is assigned at sites where the mean dbh is ≥35 cm (Figure 14). Tree size was generally smaller than at the reference standard wetlands in the three Riverine subclasses (Low-gradient, Mid-gradient, and Connected Depression), where the mean was ≥ 40 cm (15.7 in). A variable subindex of 1.0 is assigned at sites where the mean dbh is ≥40 cm (Figure 14).

The relationship between canopy tree diameter and functional capacity is assumed to be linear; thus, the subindex increases linearly from 0.1 to reference standard values (Figure 14). V_{BIG3} applies to all functions and always is used in combination with V_{TDEN}.

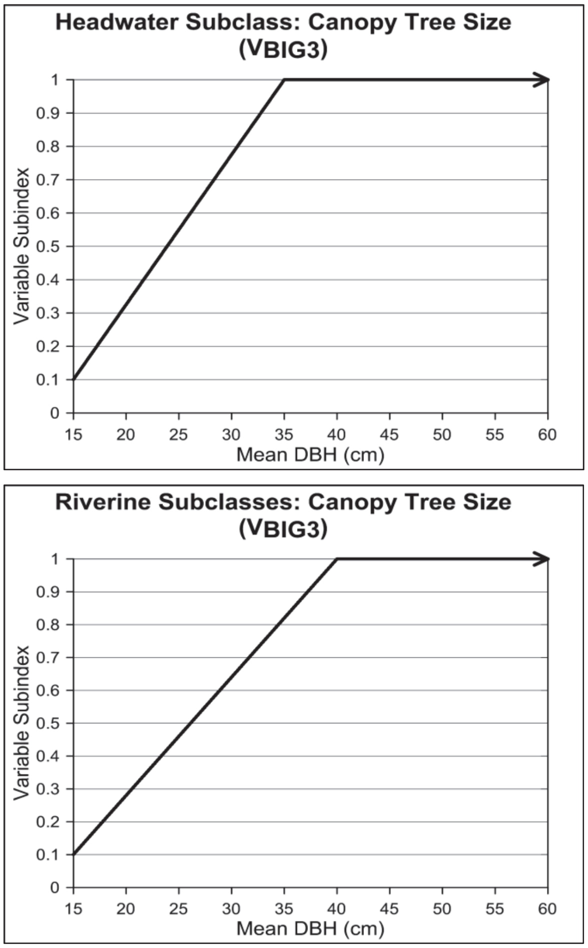


Figure 14. Relationship between mean Canopy Tree DBH and functional capacity.

Canopy Tree Density (V_{TDEN})

This variable is defined as the density of canopy trees in a forest stand and is expressed as the number of tree stems per hectare. Canopy trees are defined as woody plants ≥ 15 cm (6 in.) dbh whose crowns comprise the uppermost stratum of the vegetation (see V_{CTD} above). Canopy trees are only measured if percent tree cover is 20 percent or greater.

Tree density, when combined with a metric of tree size (V_{BIG3}), provides a more complete description of the structure of a forest stand than either metric would by itself. Examining either by itself could be misleading. For example, one would not know for certain whether a large mean diameter indicates that the stand was mature or one composed of many young pole-sized trees with a only a few very large individuals (sometimes referred to as "wolf trees"). Likewise, the density of a stand does not convey much information about the size of the trees, and therefore its stage of development.

In the alluvial valley reference wetlands, the density of trees $\geq$ 15 cm (6 in) DBH (canopy trees) ranged from 0 stems/ha to more than 1200 stems/ha. Sites that had been recently disturbed, such as from a timber harvest, typically had lower densities than reference standard sites, while those with forests in early stages of development generally had the highest density.

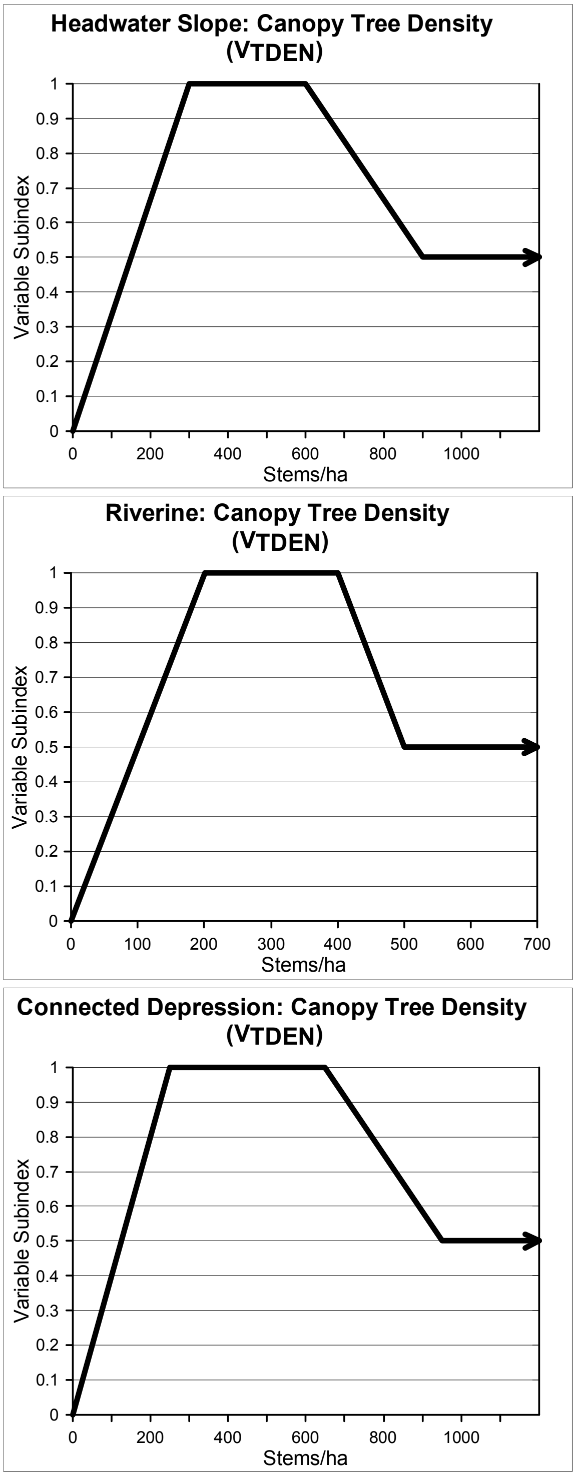


Figure 15. Relationship between mean Canopy Tree density and functional capacity.

The density of canopy trees at reference standard wetlands of the Headwater Slope subclass was between 300 and 600 stems/ha. A variable subindex of 1.0 is assigned at sites in this range (Figure 15). Density of canopy trees were similar in Mid-gradient and Low-gradient Riverine subclasses, each ranging from 200 to 400 stems/ha. The reference standard for the Connected Depression subclass was densest, ranging from 250 to 650 stems/ha (Figure 15). V_{TDEN} applies to all functions and always is used in combination with V_{BIG3}.

Sapling/Shrub Cover (V_{SSC})

This variable is defined as the average percent cover of woody vegetation >1 m (39 in.) in height and <10 cm (4 in.) dbh (e.g., shrubs, saplings, and understory trees). Shrubs contribute to the structure of the wetland plant community, particularly if trees are absent. They take up nutrients, produce biomass, and provide cover and breeding sites for wildlife. Shrubs may dominate the community in forested wetlands during early to mid-successional stages. V_{SSC} applies to the biogeochemistry, plant community, and wildlife habitat functions, and is only measured if tree canopy cover is <20 percent and sapling/shrub cover is $\geq$ 20 percent.

Sapling/shrub cover was highly variable in reference standard wetlands, ranging from 4 to 91 percent. However, V_{SSD} is not used to evaluate alluvial valley wetlands that have a well-developed tree canopy. Instead, V_{SSD} is measured only in areas with <20 percent tree cover due to recent natural or anthropogenic disturbance. In this context, V_{SSD} reflects the amount of woody regeneration on the site that contributes immediately to carbon cycling and provides habitat for wildlife, and will eventually reproduce a mature forest canopy. Therefore, higher values of sapling/shrub cover are assumed to contribute more to these functions. Sapling/shrub cover on reference wetland sites with <20 percent tree cover ranged from 0 to 100 percent. Based on reference data, a subindex of 1.0 is assigned when sapling/shrub cover is >70 percent (Figure 16).

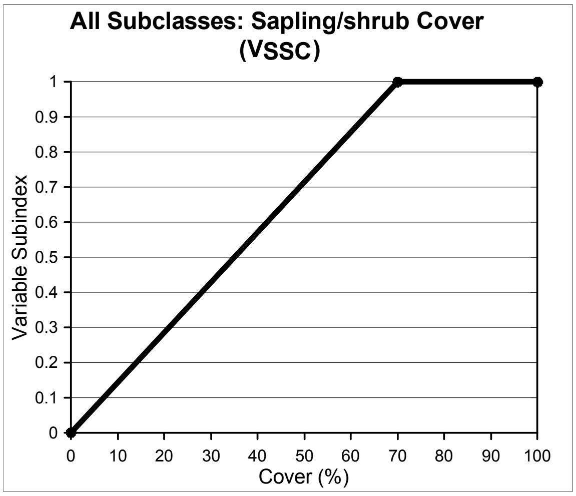


Figure 16. Relationship between percent cover of saplings and shrubs to functional capacity.

Ground Vegetation Cover (V_{GVC})

This variable is defined as the average percent cover of ground vegetation inside a 0.04-ha plot. Ground vegetation is defined as all herbaceous vegetation, regardless of height, and woody vegetation <1 m (39 in.) in height. Ground vegetation cover is an index to the abundance and biomass of low vegetation in the alluvial valley wetlands; these two characteristics affect the productivity and structure of these habitats. V_{GVC} only applies to the biogeochemistry, plant community, and wildlife habitat functions and only when canopy tree cover and shrub cover are each less than 20 percent.

On reference standard sites, coverage of ground-layer vegetation was highly variable, ranging from absent to 100 percent cover. The majority of the reference standard sites (+/- one standard deviation) were between 7 and 45 percent in the Mid-gradient and Low-gradient Riverine subclasses, and between 20 and 60 percent in the Headwater Slope subclass. However, V_{GVC} is not used to evaluate wetlands that have a well-developed tree or sapling/ shrub canopy. Instead, V_{GVC} is measured only in areas where tree and sapling/shrub cover are both <20 percent due to severe natural or anthropogenic disturbance. Even under these conditions, ground-layer vegetation contributes some organic material to the wetland's carbon cycle, provides some benefits for wildlife, and helps produce conditions favorable to the regeneration of trees. Ground vegetation cover on reference sites with <20 percent tree and sapling/shrub cover ranged from 20 to 100 percent. A subindex of 1.0 is assigned when ground vegetation cover is >70 percent (Figure 17).

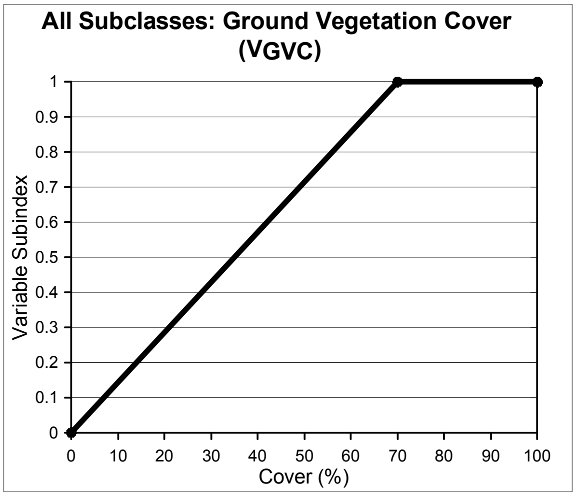


Figure 17. Relationship between percent cover of ground vegetation to functional capacity.

Vegetation Composition and Diversity (V_{COMP})

This variable reflects the "floristic quality" of the community based on concepts in Andreas and Lichvar (1995) and Smith and Klimas (2002). The focus is on the plants that dominate the tallest stratum present. In reference standard wetlands in alluvial valleys of the Coastal Plain, the tallest stratum is composed of native canopy trees. In wetlands that have undergone recent and severe natural or anthropogenic disturbance, the tallest stratum may be dominated by herbaceous species or shrubs and tree saplings. Implicit in this approach is the assumption that the "quality" of the tallest layer is a reliable indicator of overall community composition, both current and future (i.e., native tree species dominating the shrub/sapling layer indicate appropriate future canopy composition). Most reference standard wetlands within the reference domain are relatively diverse with several dominant species present. Dominant species are determined using the "50/20 rule" described in Figure 18. Note that the tree stratum includes trees ≥15 cm (6 in.) dbh.

Steps in the 50/20 Rule for determining dominant plant species

1. Apply this procedure only to the tallest stratum present. To count as present, the total cover of the tree and sapling/shrub strata must be ≥20 percent.
2. Estimate the absolute percent cover of each species in the tallest stratum.
3. Rank all species in the stratum from most to least abundant.
4. Calculate the total coverage for all species in the stratum (i.e., sum their individual percent cover estimates). Absolute cover estimates do not necessarily sum to 100%.
5. Select plant species from the ranked list, in decreasing order of coverage, until the cumulative coverage of selected species exceeds 50% of the total coverage for the stratum. The selected species are all considered to be dominants. All dominants must be identified to species.
6. In addition, select any other species that, by itself, is at least 20% of the total percent cover in the stratum. Any such species is also considered to be a dominant and must be identified accurately.

Figure 18. Description of the 50/20 Rule.

Dominant species are classified into three groups reflecting presumed floristic quality (Tables 9, 10, and 11). Group 1 consists of species that are typically dominants in undisturbed forested wetlands. These include the various species of "bays," numerous hardwoods and pines, as well as swamp tupelo and baldcypress that can dominate in the wetter areas. Group 2 consists of other native plant species that are not typical dominants of

Table 9. Quality scores for dominant plant species of the Headwater Slope subclass used to calculate V_{COMP}.

Scientific name	Common Name	Subindex
Group 1		
Acer rubrum	Red maple	1.0
Carya aquatica	Water hickory	
Carya tomentosa	Mockernut hickory	
Fraxinus caroliniana	Carolina ash	
Fraxinus pennsylvanica	Green ash	
Fraxinus profunda	Pumpkin ash	
Liriodendron tulipifera	Yellow poplar (tulip tree)	
Magnolia virginiana	Sweetbay	
Nyssa aquatica	Water tupelo	
Nyssa biflora	Swamp black gum	
Persea borbonia	Redbay	
Persea palustris	Swamp redbay	
Pinus glabra	Spruce pine	
Pinus taeda	Loblolly pine	
Quercus alba	White oak	
Quercus laurifolia	Laurel oak	
Quercus michauxii	Swamp chestnut oak	
Quercus nigra	Water oak	
Quercus pagoda	Cherrybark oak	
Quercus phellos	Willow oak	
Taxodium distichum	Bald cypress	
Ulmus americana	American elm	
Group 2		
Carpinus caroliniana	Ironwood	0.66
Carya myristiciformis	Nutmeg hickory	
Carya ovata	Shagbark hickory	
Celtis laevigata	Sugarberry	
Crataegus spp.	Hawthorn species	
Diospyros virginiana	Persimmon	
Ilex opaca	American holly	
Liquidambar styraciflua	Sweetgum	
Group 3		
Albizia julibrissin	Silktree	0
Alternanthera philoxeroides	Alligatorweed	

Scientific name	Common Name	Subindex
Cyperus iria	Ricefield flatsedge	
Echinochloa crus-galli	Barnyard grass	
Imperata cylindrica	Cogongrass	
Ligustrum japonicum	Japanese privet	
Ligustrum sinense	Chinese Privet	
Lonicera japonica	Japanese Honeysuckle	
Lygodium japonicum	Japanese Climbing Fern	
Microstegium vimineum	Nepalese Browntop	
Panicum repens	Torpedo grass	
Pueraria montana	Kudzu	
Sorghum halepense	Johnsongrass	
Triadica sebifera	Tallowtree	
Verbena brasiliensis	Brazilian Vervain	

Table 10. Quality scores for dominant plant species of the Low- and Mid-gradient subclasses used to calculate V_{COMP}.

Scientific name	Common Name	Subindex
Group 1		
Acer barbatum	Florida maple	1.0
Acer rubrum	Red maple	
Carya aquatica	Water hickory	
Carya cordiformis	Bitternut hickory	
Carya glabra	Pignut hickory	
Carya illinoensis	Pecan	
Carya laciniosa	Shellbark hickory	
Carya ovata	Shagbark hickory	
Celtis laevigata	Sugarberry	
Diospyros virginiana	Persimmon	
Fraxinus americana	White ash	
Fraxinus caroliniana	Carolina ash	
Fraxinus pennsylvanica	Green ash	
Ilex opaca	American holly	
Liquidambar styraciflua	Sweetgum	
Magnolia virginiana	Sweetbay	
Nyssa aquatica	Water tupelo	
Nyssa biflora	Swamp black gum	

Scientific name	Common Name	Subindex
Persea borbonia	Redbay	
Pinus taeda	Loblolly pine	
Quercus alba	White oak	
Quercus laurifolia	Laurel oak	
Quercus lyrata	Overcup oak	
Quercus michauxii	Swamp chestnut oak	
Quercus nigra	Water oak	
Quercus pagoda	Cherrybark oak	
Quercus palustris	Pin oak	
Quercus phellos	Willow oak	
Quercus shumardii	Shumard's oak	
Quercus texana	Nuttall oak	
Taxodium distichum	Bald cypress	
Tilia americana	Basswood	
Ulmus americana	American elm	
Ulmus rubra	Slippery elm	
Group 2		
Acer negundo	Box elder	0.66
Acer saccharinum	Silver maple	
Betula nigra	River birch	
Carpinus caroliniana	Ironwood	
Cephalanthus occidentalis	Buttonbush	
Cornus florida	Flowering dogwood	
Crataegus spp.	Hawthorne species	
Gleditsia triacanthos	Honey locust	
Liriodendron tulipifera	Yellow poplar	
Ostrya virginiana	Hophornbeam	
Planera aquatica	Water elm	
Platanus occidentalis	Sycamore	
Prunus serotina	Black cherry	
Quercus rubra	Northern red oak	
Salix nigra	Black willow	
Ulmus crassifolia	Cedar elm	
Group 3		
Albizia julibrissin	Silktree	0
Alternanthera philoxeroides	Alligatorweed	

Scientific name	Common Name	Subindex
Cyperus iria	Ricefield flatsedge	
Echinochloa crus-galli	Barnyard grass	
Imperata cylindrica	Cogongrass	
Ligustrum japonicum	Japanese privet	
Ligustrum sinense	Chinese Privet	
Lonicera japonica	Japanese Honeysuckle	
Lygodium japonicum	Japanese Climbing Fern	
Microstegium vimineum	Nepalese Browntop	
Panicum repens	Torpedo grass	
Pueraria montana	Kudzu	
Sapium sebiferum	Chinese tallow-tree	
Sorghum halepense	Johnsongrass	
Triadica sebifera	Tallowtree	
Verbena brasiliensis	Brazilian Vervain	

Table 11. Quality scores for dominant plant species of the Connected Depression subclass used to calculate V_{COMP}.

Scientific name	Common Name	Subindex
Group 1		
Carya aquatica	Water hickory	1.0
Fraxinus caroliniana	Carolina ash	
Fraxinus pennsylvanica	Green ash	
Fraxinus profunda	Pumpkin ash	
Nyssa aquatica	Water tupelo	
Nyssa biflora	Swamp black gum	
Planera aquatica	Water elm	
Quercus laurifolia	Laurel oak	
Quercus lyrata	Overcup oak	
Taxodium distichum	Bald cypress	
Ulmus americana	American elm	
Group 2		
Carpinus caroliniana	Ironwood	0.66
Carya myristiciformis	Nutmeg hickory	
Carya ovata	Shagbark hickory	
Celtis laevigata	Sugarberry	
Cephalanthus occidentalis	Buttonbush	

Scientific name	Common Name	Subindex
Crataegus spp.	Hawthorn species	
Diospyros virginiana	Persimmon	
Ilex opaca	American holly	
Liquidambar styraciflua	Sweetgum	
Quercus alba	White oak	
Salix nigra	Black willow	
Group 3		
Albizia julibrissin	Silktree	0
Alternanthera philoxeroides	Alligatorweed	
Cyperus iria	Ricefield flatsedge	
Echinochloa crus-galli	Barnyard grass	
Imperata cylindrica	Cogongrass	
Ligustrum japonicum	Japanese privet	
Ligustrum sinense	Chinese Privet	
Lonicera japonica	Japanese Honeysuckle	
Lygodium japonicum	Japanese Climbing Fern	
Microstegium vimineum	Nepalese Browntop	
Panicum repens	Torpedo grass	
Pueraria montana	Kudzu	
Sorghum halepense	Johnsongrass	
Triadica sebifera	Tallowtree	
Verbena brasiliensis	Brazilian Vervain	

mature, undisturbed forests, but are often dominant in wetlands that have been disturbed or altered or on newly deposited surfaces. Group 3 consists of nonnative (exotic) species or native invasive species that are usually found on highly degraded sites. In reference standard wetlands within the reference domain, dominant vegetation composition included species from Groups 1 and 2, and the number of dominants was 4 or greater in the Headwater Slope, Mid-gradient Riverine, and Low-gradient Riverine subclasses (there are some instances when fewer dominants in these subclasses are appropriate). Two dominants were present in the reference standard wetlands of the Depression subclass. As either composition or diversity deviates from those conditions, functional capacity is assumed to decline. The procedure used to calculate a subindex value for V_{COMP} is described in Chapter 5 and incorporates both diversity and quality of dominant species. V_{COMP} applies only to the plant community and wildlife habitat functions.

Woody Debris (V_{WD})

Woody debris is defined here as down and dead woody stems that are greater than 7.5 cm (3 in) in diameter that are no longer attached to living plants.

Dead wood is an important component of wildlife habitat and nutrient cycling of forests. Dead wood may be present in snags, small twigs, roots, stumps, and limbs or logs. Some important dead wood habitat features, such as snags, are low in density in a healthy forest. An adequate sample design necessary to accurately estimate low density features such as snags in a forest is often outside the scope of a rapid assessment. Woody debris as defined here matches that of "coarse woody debris" in the Forest Inventory Analysis (FIA). Its volume may be estimated within a rapid assessment using methods based on those of the FIA (US Department of Agriculture 2011; Waddell 2002; Woodall and Monleon 2008). FIA data from naturally regenerated stands in categories that closely match this guidebook's wetland subclasses, and data from previous guidebooks within the region were used to scale this variable. Figure 19 illustrates the increase in woody debris volume with time in naturally regenerated floodplain forests of the Coastal Plain, compared to naturally regenerated forests identified as having human disturbances.

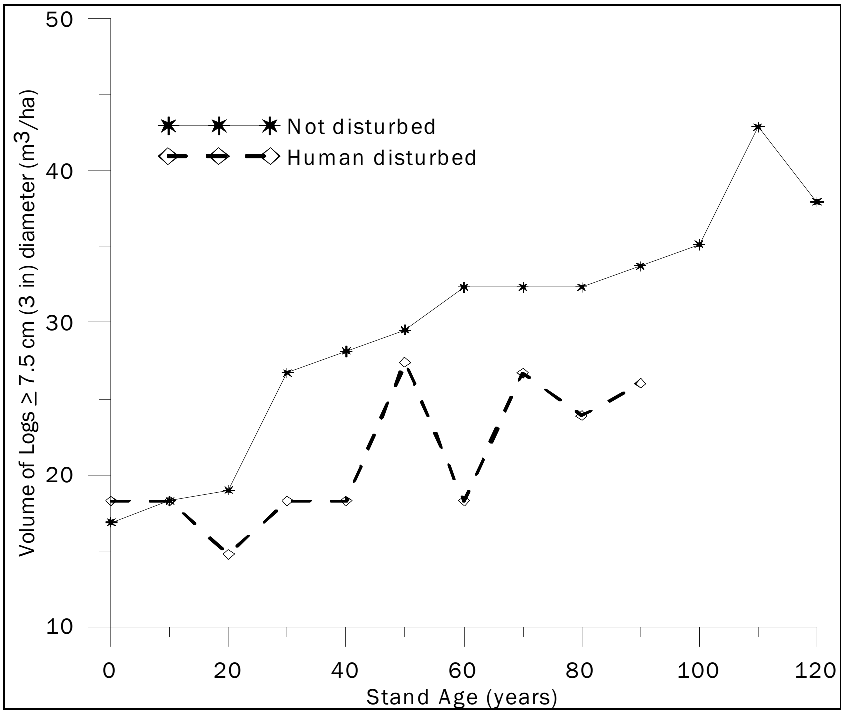


Figure 19. Mean log (≥7.5 cm (3 in) diameter) volumes by stand age in naturally regenerated stands of the Mid-gradient and Low-gradient Riverine subclasses in the Coastal Plain. Summary of data from the Forest Inventory Analysis Database (FIA) for stands identified with and without disturbance (summarized plots n = 907).

Despite its relatively slow turnover rate, woody debris is an important link in food webs and nutrient cycles of temperate terrestrial forests (Harmon et al. 1986). In this context, this variable serves as an indicator that the nutrients in vegetative organic matter are being recycled. Volume of woody debris per hectare is used to quantify this variable.

In reference wetlands across the Coastal Plain, the volume of woody debris ranged from 0 to 700 m3/ha. The amount of woody debris in reference standard wetlands varied by subclass and is scaled for each (Figure 20), and all subclasses were within the range of 20 to 60 m3/ha. The decrease in the variable subindex is based on the assumption that lower volumes of woody debris indicate an inadequate reservoir of nutrients (and a stand at an early stage of maturity) and the inability to maintain characteristic nutrient cycling over the long term. Above amounts characteristic of reference standard, the variable subindex decreases linearly to 0.5. This is based on the assumption that increasingly higher volumes of woody debris indicate that high levels of nutrients are tied up in long-term storage and are unavailable for primary production in the short term. This situation can occur in instances of catastrophic wind damage, such as hurricanes or following logging operations. It can also occur if a hydrologic obstruction increases inundation depth or duration to the point that trees experience tip dieback or death.

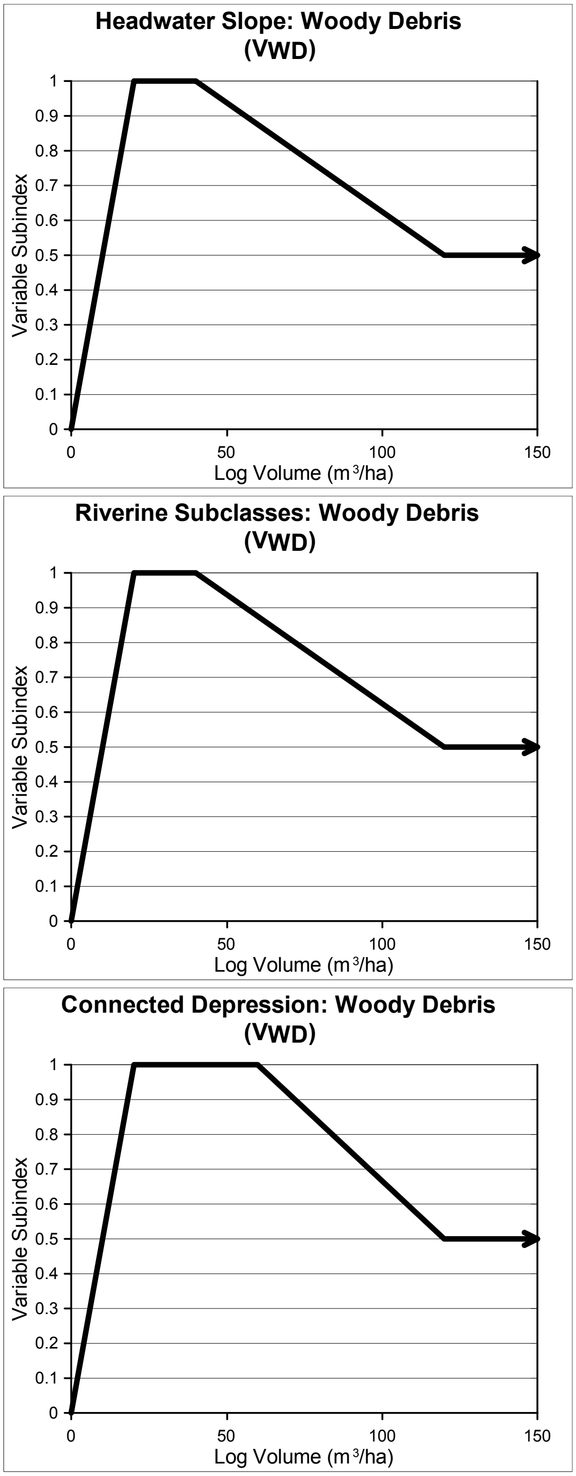


Figure 20. Relationship between log volume and functional capacity.

Functions and Assessment Models

The wetland subclasses and their functions that may be assessed using this guidebook, and the model structure and model variables used to conduct assessments, were selected by the consensus of the A-Team. The A-Team reviewed the functions, models and variables after collection of most reference data was complete. Reference data from existing HGM guidebooks for the Coastal Plain (Low-gradient Riverine wetlands of western Tennessee (Wilder and Roberts 2002), eastern Arkansas (Klimas et al. 2005), eastern Texas (Williams et al. 2010), and Headwater Slope wetlands in Mississippi and Alabama (Noble et al. 2007) and South Carolina (Noble et al. 2011) were added to the reference data collected in development of this Guidebook.

Based on the A-Team recommendations, this Regional Guidebook provides assessment models and methods for conducting assessments of the capacity of common forested wetlands of alluvial valleys of the Coastal Plain to perform the following functions:

- Maintain a Characteristic Hydrology
- Elemental Transformation and Cycling
- Maintain Characteristic Plant Community
- Maintain Characteristic Wildlife Habitat

Note that the form of the assessment model that is used to assess functions can vary from subclass to subclass.

Functional scores or indices represent a measure of ecosystem integrity, where the index drops as a wetland deviates from the reference standard condition for variables that contribute to the function. If there is no deviation, the score is 1.0; but as the deviation increases, the score becomes a fraction that approaches zero. This is true even if the actual function might be increasing, but in an unsustainable manner. For instance, a hydrologic change in a forested wetland could stress trees and lead to a large amount of crown dieback and a subsequent increase in woody debris, which would lead to an increase in the cycling of organic carbon within the wetland and nearby aquatic ecosystems. However, the functional score or index would actually decrease, because this woody-debris spike is a deviation from the amount that is sustainable in healthy mature forests of the subclass within the reference domain, hence a deviation from ecosystem integrity.

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

1. *Definition*. This section defines the function.

2. *Rationale for selecting the function*. This section discusses the reasons a function was selected for assessment, and the onsite and offsite effects that may occur as a result of lost functional capacity.
3. *Characteristics and processes that influence the function*. This section describes the characteristics and processes of the wetland and the surrounding landscape that influence the function, and lays the groundwork for the description of assessment variables.
4. *Form of the assessment model*. This section presents the structure of the assessment models and briefly describes the constituent variables.

The specific forms of the assessment models used to assess functions for each regional wetland subclass are presented here. Chapter 5 presents the methods used to measure or estimate the values of the individual variables.

Function 1: Maintain a Characteristic Hydrology

Definition

This function reflects the ability of wetlands to store, convey, and reduce the velocity and volume of water as it moves through a wetland. The potential effects of this reduction are the dampening of the downstream flood hydrograph, maintenance of post-flood base flow, and the deposition of suspended material from the water column to the wetland. Potential independent, quantitative measures for validating the functional index are direct measurements of wetlands' water budgets over multiple water years.

Rationale for selecting the function

The capacity of wetlands to store and convey precipitation, groundwater and floodwater temporarily has been extensively documented (Campbell and Johnson 1975; Demissie and Kahn 1993; Novitski 1978; Ogawa and Male 1983; Thomas and Hanson 1981). Generally, water interaction with wetlands influences downstream water quality and dampens and reduces peak discharge downstream. Wetlands can reduce the velocity of water from runoff and flooding events and, as a result, remove particulates from the water column and reduce 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 it 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 upon the redox capacity of the soil (Mausbach and Richardson 1994). This function also has important impacts on invertebrate and vertebrate populations. For example, some invertebrates, such as midges, have very rapid life cycles and are highly adapted to ephemeral wetlands. Certain amphibian species depend on the presence of predator-free ephemeral pools at particular times of the year to successfully complete reproduction.

This function deals specifically with the physical influences on flow and sediment dynamics. Groundwater and floodwater interaction with headwater and Riverine wetlands influences other wetland functions in the alluvial valleys of the Coastal Plain, including nutrient mobility and storage and the quality of habitat for plants and animals. The role of hydrology in maintaining these functions is considered separately in other sections of this chapter.

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 the wetland, the configuration and slope of the floodplain and channel, and the resistance to flow created by such things as vegetation, debris, and topographic relief (roughness) are factors 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 also on the hydrology of the wetland due to 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 slopes, size, shape, channel morphology, drainage pattern and density, and the presence of wetlands and lakes have pronounced effects on the stormflow response (Brooks et al. 1991; Dunne and Leopold 1978; Leopold 1994; Patton 1988; Ritter et al. 1995). In general, the interaction time of water with a wetland increases as roughness increases and slope decreases.

In addition to natural processes, human activities may have profound influence on the way a wetland interacts with water. Modifications to the uplands surrounding the wetland, the stream network of which the wetland is a component, or directly to the wetland itself may affect the receipt and retention of water. Channelization, impoundment, land-use conversion to agriculture or urban infrastructure, and changes in evapotranspiration after vegetation removal that result from grazing or logging are modifications that directly affect this function. Some modifications so significantly affect the natural delivery of water to, and its movement within the wetland, that many such wetlands lose their natural wetland characteristics, may change HGM wetland subclass or class, or no longer meet the definition of a wetland. For example, Headwater Slope wetlands may be impounded for a livestock pond, or a floodplain and its wetlands may be isolated from its stream by the construction of levees, flood control works, or the incision of channels after dredging or channelization.

Of the critical characteristics of alluvial valley wetland hydrology, only certain site characteristics such as vegetation (roughness and ET), presence of ditches and levees, and landscape characteristics, channel sinuosity, and incision, can reasonably be incorporated into a rapid assessment. Most stream channels in the region are not close enough to a stream gage to ascribe detailed hydrologic characteristics to any particular point on the floodplain. At best, hydrology can be estimated for some sites from evidence at the site, at least to the extent needed to classify a wetland. If available, quantitative hydrologic data or modeling may be used in the assessment of this function.

Form of the assessment model

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

- Change in Catchment Size (V_{CATCH})
- Upland Land Use (V_{UPUSE})
- Canopy Tree Diameter (V_{BIG3})
- Canopy Tree Density (V_{TDEN})
- Sapling/Shrub Cover (V_{SSC})
- Ground Vegetation Cover (V_{GVC})

- Site Hydrologic Alterations ($V_{HYDROALT}$)
- System Hydrologic Alterations ($V_{HYDROSYS}$)

The models for calculating the functional capacity index (FCI) for the Maintenance of a Characteristic Hydrology depend, in part, on the characteristics of the uppermost stratum of vegetation within the wetland. If the site supports a tree layer (>20% total tree cover), then Equation 4 or 7 is used. If dominated by saplings and shrubs (<20% canopy cover of trees but >20% cover of saplings and shrubs), then Equation 5 or 8 is used. If neither trees nor saplings/shrubs are common (<20% cover), then Equation 6 or 9 is used.

For the Headwater Slope subclass:

$$FCI = \left\{ V_{HYDROALT} \times \left[\frac{\left(\frac{V_{CATCH} + V_{UPUSE}}{2} \right) + \left(\frac{V_{BIG3} + V_{TDEN}}{2} \right)}{2} \right] \right\}^{1/2} \tag{4}$$

$$FCI = \left\{ V_{HYDROALT} \times \left[\frac{\left(\frac{V_{CATCH} + V_{UPUSE}}{2} \right) + \left(\frac{V_{SSC}}{3} \right)}{2} \right] \right\}^{1/2} \tag{5}$$

$$FCI = \left\{ V_{HYDROALT} \times \left[\frac{\left(\frac{V_{CATCH} + V_{UPUSE}}{2} \right) + \left(\frac{V_{GVC}}{5} \right)}{2} \right] \right\}^{1/2} \tag{6}$$

And for the Riverine subclasses:

$$FCI = \left\{ V_{HYDROSYS} \times \left[\frac{V_{HYDROALT} + \left(\frac{V_{BIG3} + V_{TDEN}}{2} \right)}{2} \right] \right\}^{1/2} \tag{7}$$

$$FCI = \left\{ V_{HYDROSYS} \times \left[\frac{V_{HYDROALT} + \left(\frac{V_{SSC}}{3} \right)}{2} \right] \right\}^{\frac{1}{2}} \tag{8}$$

$$FCI = \left\{ V_{HYDROSYS} \times \left[\frac{V_{HYDROALT} + \left(\frac{V_{GVC}}{5} \right)}{2} \right] \right\}^{\frac{1}{2}} \tag{9}$$

The assessment models express the wetland’s hydrologic connection to the watershed and the wetland’s capacity to modify water volume and velocity. In the case of Headwater Slope wetlands, inputs of water from surface and subsurface flow from the surrounding watershed are represented with V_{CATCH} and V_{UPUSE}. Water is removed from the system in surface and subsurface outflow, which is represented with $V_{HYDROALT}$, and evapotranspiration, which is represented with variable(s) expressing the structure of the site vegetation. The model assumes that if natural hydrologic inputs from the surrounding uplands are unaltered, and outflow is not increased by drainage ditches, soil compaction, or headcutting, or decreased with artificial obstructions, and woody vegetation is present to remove water through evapotranspiration at characteristic rates, then the wetland is functioning at the reference standard condition.

In the case of Riverine wetlands, the model uses $V_{HYDROSYS}$ instead of catchment characteristics. $V_{HYDROSYS}$ is similar, though, in that it represents external inputs of water to the wetland. In the Riverine subclasses, the dominant source of water is flooding from the adjacent stream. The characteristics of the wetland’s hydrology are determined, in part, by the condition of the stream. As with the Headwater Slope model, removal of water from the system is represented with $V_{HYDROALT}$ and the vegetation variable(s). Roughness, an important component of floodplain hydrology, is also represented by the vegetation. The model assumes that if natural hydrologic exchange with the stream is neither impeded nor accelerated and if the stream is unaltered and woody vegetation is present to remove water through evapotranspiration at characteristic rates, then the wetland is functioning at the reference standard condition.

Function 2: Elemental Transformation and Cycling

Definition

This function refers to the ability of the wetland to cycle elements, particularly nutrients, through a variety of biogeochemical processes such as photosynthesis and microbial decomposition. In the context of this assessment procedure, it also includes the capacity of the wetland to permanently remove or temporarily immobilize elements and compounds that are imported to the wetland. The elemental transformation and cycling function encompasses a complex web of chemical and biological activities that sustain the overall wetland ecosystem. Potential independent, quantitative measures for validating the functional index may include many direct measurements. Among them are net annual primary productivity (g/m^2), annual litter fall (g/m^2), standing stock of living and/or dead biomass (g/m^2), annual accumulation of organic matter (g/m^2), and annual decomposition of organic matter (g/m^2).

Rationale for selecting the function

In functional wetlands, elements are transferred among various components of the ecosystem such that materials stored in each component are sufficient to maintain ecosystem processes (Ovington 1965; Pomeroy 1970). For example, an adequate supply of nutrients in the soil profile supports primary production, which makes plant community development and maintenance possible (Bormann and Likens 1970; Perry 1994; Whittaker 1975). The plant community, in turn, provides a pool of nutrients and a source of energy for secondary production and also provides the habitat structure necessary to maintain the animal community (Fredrickson 1979b; Wharton et al. 1982). Plant and animal communities serve as the source of detritus, which provides nutrients and energy necessary to maintain a characteristic community of decomposers. These decomposers, in turn, break down organic material into simpler elements and compounds that can then reenter 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). 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 1980). Dissolved organic carbon is a significant source of energy for the microbes that form the base of the detrital food web in aquatic ecosystems (Dahm 1981; Edwards 1987; Schlosser 1991; Wohl 2000).

Characteristics and processes that influence the function

In wetlands, elements are stored within and cycled among four major compartments: (a) the soil, (b) primary producers such as vascular and nonvascular plants, (c) consumers such as animals, fungi, and bacteria, and (d) dead organic matter, such as logs, leaf litter, or other woody debris, referred to as detritus. The transformation of nutrients within each compartment and the flow of nutrients between compartments occur in a complex variety of biogeochemical processes and are mediated by the wetland's hydroperiod, or retention time of water that 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 take up nutrients from the soil and detritus and incorporate them into the organic matter in 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. Ultimately, all plant tissues are either consumed or die and fall to the ground where they are decomposed by fungi and microorganisms and mineralized to become available again for uptake by plants. The processes involved in nutrient cycling within wetlands of the southern United States 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).

Form of the assessment model

The model for assessing the Elemental Transformation and Cycling function includes nine variables:

- Soil Integrity ($V_{SOILINT}$)
- System Hydrologic Alterations ($V_{HYDROSYS}$)
- Site Hydrologic Alterations ($V_{HYDROALT}$)
- Canopy Tree Diameter (V_{BIG3})
- Canopy Tree Density (V_{TDEN})
- Sapling/Shrub Cover (V_{SSC})
- Ground Vegetation Cover (V_{GVC})
- Woody Debris (V_{WD})

The models for calculating the functional capacity index (FCI) for the Elemental Transformation and Cycling function depend, in part, on the characteristics of the uppermost stratum of vegetation within the wetland. If the site supports a tree layer (>20% total tree cover), then Equation 10 or 13 is used. If dominated by saplings and shrubs (<20% canopy cover of trees but >20% cover of saplings and shrubs), then Equation 11 or 14 is used. If neither trees nor saplings/shrubs are common (<20% cover), then Equation 12 or 15 is used.

For the Headwater Slope subclass:

$$FCI = \left\{ V_{HYDROALT} \times \left[\frac{\left(\frac{V_{BIG3} + V_{TDEN}}{2} \right) + V_{WD} + V_{SOILINT}}{3} \right] \right\}^{1/2} \tag{10}$$

$$FCI = \left\{ V_{HYDROALT} \times \left[\frac{\left(\frac{V_{SSC}}{3} \right) + V_{WD} + V_{SOILINT}}{3} \right] \right\}^{1/2} \tag{11}$$

$$FCI = \left\{ V_{HYDROALT} \times \left[\frac{\left(\frac{V_{GVC}}{5} \right) + V_{WD} + V_{SOILINT}}{3} \right] \right\}^{1/2} \tag{12}$$

And for the Riverine subclasses:

$$FCI = \left\{ \left(V_{HYDROALT} \times V_{HYDROSYS} \right)^{1/2} \times \left[\frac{\left(\frac{V_{BIG3} + V_{TDEN}}{2} \right) + V_{WD} + V_{SOILINT}}{3} \right] \right\}^{1/2} \tag{13}$$

$$FCI = \left\{ \left(V_{HYDROALT} \times V_{HYDROSYS} \right)^{1/2} \times \left[\frac{\left(\frac{V_{SSC}}{3} \right) + V_{WD} + V_{SOILINT}}{3} \right] \right\}^{1/2} \tag{14}$$

$$FCI = \left\{ \left(V_{HYDROALT} \times V_{HYDROSYS} \right)^{1/2} \times \left[\frac{\left(\frac{V_{GVC}}{5} \right) + V_{WD} + V_{SOILINT}}{3} \right] \right\}^{1/2} \tag{15}$$

The two constituent expressions within the model reflect the equal importance to the function of an intact hydrology ($V_{HYDROALT}$ and $V_{HYDROSYS}$) and intact production and storage compartments: living biomass, expressed as tree size (V_{BIG3}) and density (V_{TDEN}) (or V_{GVC} or V_{GVC}), dead biomass, expressed as volume of logs (V_{WD}), and the integrity of the soil at the site.

The first expression of the model 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 living components of the model reflecting varying levels of nutrient availability and turnover rates, as trees incorporate both short-term storage (leaves), as well as long-term storage (wood). The second expression also includes organic storage compartments that reflect various degrees of decay. Woody debris volume (V_{WD}) represents relatively long-term storage that gradually transfers nutrients into other components of the ecosystem through the activities of insects, fungi, bacteria, and higher plants. Soil integrity ($V_{SOILINT}$) incorporates both short-term storage of largely decomposed, but nutrient-rich organics on the soil surface and a longer-term storage compartment of deeper soil horizons, where 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.

The two expressions are integrated as a geometric mean in the model to reflect their interaction. The absence of either wetland hydrology or all production and storage components at a site would result in a severe degradation of function. The model output in either such circumstance reflects this degradation with an FCI of 0.0. The components within the production and storage expression are cumulative; the absence of one component will degrade the function, but not eliminate it entirely. Each component is assigned equal weight to reflect their cumulative contribution to the function. At sites with less than 20% cover of canopy trees, V_{SSC} or V_{GVC} is used in the vegetation term in the model, and the denominator of that term is increased, decreasing the model FCI to reflect the immature seral stage of the dominant vegetation.

Function 3: Maintain Characteristic Plant Community

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 and the physical factors that determine whether or not a characteristic plant community is likely to be maintained in the future. Potential independent, quantitative measures for validating the functional index are comprehensive floristic surveys.

Rationale for selecting the function

The ability to maintain a characteristic plant community is important because of the intrinsic value of the plant community. Many wetland attributes and processes are influenced by the 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 diversity of animals are directly influenced by the plant community (Harris and Gosselink 1990). In addition, the plant community of alluvial valley wetlands influences the quality of the physical habitat, nutrient status, and biological diversity of downstream systems.

Characteristics and processes that influence the function

Numerous studies describe the environmental factors that influence the occurrence and characteristics of plant communities in wetlands (Hodges 1997; Klimas et al. 2009; Robertson et al. 1984; Robertson et al. 1978; 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, system dynamics and disturbance history are important in determining the condition of a wetland plant community at any particular time. These include past land use, timber harvest history, hydrologic changes, sediment deposition, and 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 and the extent that the existing plant community structure, composition, and stage of maturity are appropriate to the subclass.

Form of the assessment model

The model for assessing the Maintain a Characteristic Plant Community function includes seven variables:

- System Hydrologic Alterations ($V_{HYDROSYS}$)
- Site Hydrologic Alterations ($V_{HYDROALT}$)
- Canopy Tree Diameter (V_{BIG3})
- Canopy Tree Density (V_{TDEN})
- Sapling/Shrub Cover (V_{SSC})
- Ground Vegetation Cover (V_{GVC})
- Vegetation Composition and Diversity (V_{COMP})

The models for calculating the functional capacity index (FCI) for the Maintain a Characteristic Plant Community function depend, in part, on the characteristics of the uppermost stratum of vegetation within the wetland. If the site supports a tree layer (>20% total tree cover), then Equation 16 or 19 is used. If dominated by saplings and shrubs (<20% canopy cover of trees but >20% cover of saplings and shrubs), then Equation 17 or 20 is used. If neither trees nor saplings/shrubs are common (<20% cover), then Equation 18 or 21 is used.

For the Headwater Slope subclass:

$$FCI = \left\{ V_{HYDROALT} \times \left[\frac{\left(\frac{V_{BIG3} + V_{TDEN}}{2} \right) + V_{COMP}}{2} \right] \right\}^{1/2} \tag{16}$$

$$FCI = \left\{ V_{HYDROALT} \times \left(\frac{V_{SSC} + V_{COMP}}{6} \right) \right\}^{1/2} \tag{17}$$

$$FCI = \left\{ V_{HYDROALT} \times \left(\frac{V_{GVC} + V_{COMP}}{10} \right) \right\}^{1/2} \tag{18}$$

And for the Riverine subclasses:

$$FCI = \left\{ \left(V_{HYDROALT} \times V_{HYDROSYS} \right)^{1/2} \times \left[\frac{\left(\frac{V_{BIG3} + V_{TDEN}}{2} \right) + V_{COMP}}{2} \right] \right\}^{1/2} \tag{19}$$

$$FCI = \left\{ \left(V_{HYDROALT} \times V_{HYDROSYS} \right)^{1/2} \times \left(\frac{V_{SSC} + V_{COMP}}{6} \right) \right\}^{1/2} \tag{20}$$

$$FCI = \left\{ \left(V_{HYDROALT} \times V_{HYDROSYS} \right)^{1/2} \times \left(\frac{V_{GVC} + V_{COMP}}{10} \right) \right\}^{1/2} \tag{21}$$

These models each contain two expressions; the first represents the existing hydrologic conditions ($V_{HYDROALT}$ and $V_{HYDROSYS}$) and the second combines variables expressing the structure and composition of the plant community in the wetland. The two expressions are integrated as a geometric mean in the model to reflect their interaction. The absence of a characteristic wetland hydrology would result in a severe degradation of the site's ability to maintain an appropriate plant community. In this circumstance, the model output reflects this degradation with an FCI of 0.0. The model includes variables that provide insight into the wetland plant community's seral stage, structure, species composition, diversity, and the wetland's ability to maintain it. In the context of this function, canopy tree diameter (V_{BIG3}) and density (V_{TDEN}) are structural indicators of seral stage and of disturbance. The vegetation composition and diversity variable (V_{COMP}) reflect floristic quality and diversity, as well as seral stage and disturbance. The variables V_{BIG3} and V_{CTDEN} are cumulative expressions of structure and stand age and are combined with V_{COMP}, which expresses the diversity and appropriateness of the species present. At sites with less than 20% cover of canopy trees, V_{SSC} or V_{GVC} is used in the vegetation term in the model, and the denominator is increased, decreasing the model FCI to reflect the immature seral stage of the dominant vegetation.

Function 4: Maintain Characteristic Wildlife Habitat

Definition

This function is defined as the ability of a wetland to support the fish and wildlife species that depend on wetlands during some part of their life cycles. Potential independent, quantitative measures for validating the functional index are comprehensive faunal surveys.

Rationale for selecting the function

Terrestrial, semi-aquatic, and aquatic animals use wetlands extensively. Maintenance of this function ensures habitat for a diversity of organisms, contributes to secondary production, and maintains complex trophic interactions. Habitat functions span a range of temporal and spatial scales, and include the provision of refugia and habitat for wide-ranging or migratory animals as well as highly specialized habitats for endemic species. Most wildlife and fish species found in wetlands of the alluvial valleys of the Coastal Plain depend on certain aspects of wetland dynamics and structure, such as periodic flooding or ponding of water, vegetation characteristics, and proximity to other habitats.

Characteristics and processes that influence the function

Hydrology is a major factor influencing wildlife habitat quality in Coastal Plain alluvial valley wetlands. Hydrologic alteration has the potential to impact a number of 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 inundation, or amphibians 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 the stream with levees, and/or stream-flow regulation. Such changes impact breeding activity because egg development and maturation of the young require certain lengths of time at particular times of the year. There is considerable variability in development time among species. Most anurans require the presence of water for 2-3 months (Duellman and Trueb 1986). Some species, however, require substantially shorter periods of time. The eastern spadefoot toad (*Scaphiopus holbrooki holbrooki*), for example, needs only 2-3 weeks to mature. Conversely, artificially increasing the amount of time 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. Bailey et al. (2004) noted that predatory fish prey on breeding amphibians, their eggs, and tadpoles.

Besides the direct effects of hydrologic change on animals, indirect effects can occur through changes in the plant community. Sites with unaltered hydrology that have not been subjected to significant disturbance for long periods support a characteristic vegetation composition and structure (i.e., tree size, density, and composition) as described in the plant community model. Wildlife species have evolved with and adapted to these conditions. Altering the plant community has the potential to change the composition and structure of the wildlife community. Other factors — including droughts and catastrophic storms, fire frequency and intensity, competition, disease, browsing pressure, shade tolerance, community succession, and natural and anthropogenic disturbances — also affect the wildlife community indirectly.

Habitat structure is a critical determinant of wildlife species composition and diversity (Anderson and Shugart 1974; Wiens 1969). This is especially well-documented with birds, which tend to show affinities for habitats based on physical characteristics, such as the size and density of overstory trees, density of shrub and ground cover, number of snags, and other factors. 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. For example, Ford's (1990) study of birds and their habitats in bottomland hardwood wetlands supported the importance of community structure to the majority of species that were common at his study sites during the breeding season. Many of these same species also occur in Headwater Slope wetlands within the reference domain. Hunter (1990) provided a good overview of the importance of plant community structure to wildlife. Structural complexity provides a myriad of habitat conditions for animals and allows numerous species to coexist in the same area (Schoener 1986). For example, some bird species utilize the forest canopy, whereas others are associated with the understory (Cody 1985; Wakeley and Roberts 1996). Structural characteristics of forested ecosystems (e.g., tree size, tree density, and understory cover) are easily measured and are reliable indicators of habitat quality for birds. Similar measures of vegetation structure have been used in Habitat Suitability Index (HSI) models (Allen 1987; Schroeder 1985) and in other HGM guidebooks (Ainslie et al. 1999; Klimas et al. 2005; Noble et al. 2011; Noble et al. 2007; Smith and Klimas 2002; Wilder and Roberts 2002; Williams et al. 2010). They are discussed briefly in the following paragraphs.

Tree size is an indicator of forest maturity (Brower and Zar 1984; DeGraaf et al. 1993) and, in most cases, structural complexity (Hunter 1990). Older, undisturbed wetlands dominated by large trees provide resources that areas dominated by smaller trees cannot. For example, large trees are more likely to develop natural cavities or be attacked by cavity excavators. Cavities provide shelter and nesting sites for gray squirrels, redbellied woodpeckers, and other species. In forests populated by oaks, age is an important factor in acorn production. Although there is considerable variation among species, most oaks do not begin producing acorns until they are at least 25 cm (10 in.) in diameter (U.S. Forest Service 1980). Older forests dominated by large trees also typically have distinct strata, including a tree canopy, a woody understory composed of saplings and shrubs, and an herbaceous or ground layer. Young forests composed of sapling to pole-sized trees tend to be less stratified.

Tree density also is an indicator of forest maturity. In most forested systems, the density of tree seedlings and saplings is very high following stand establishment and decreases as the forest matures (DeGraaf et al. 1993; Hunter 1990; Spurr and Barnes 1981). Stem densities often number in the tens of thousands per hectare in the early stages of succession and normally are reduced to a few hundred per hectare at maturity. In undisturbed mature forested wetlands within the reference domain, tree spacing is such that the crowns grow relatively close together. Reducing tree density, such as through timber harvesting, reduces crown volume and results in a direct loss of fruit production and foraging space for insectivorous birds.

Land use surrounding a wetland site also has a major impact on the wetland wildlife community. Historically, the reference domain was largely forested. The wildlife community evolved in a landscape with wetlands surrounded by vast tracts of open woods and savannas maintained by frequent fires. With fire suppression during recent times, many upland forests on the Coastal Plain have become crowded with undergrowth and increasingly dominated by hardwoods. Human activities have dramatically altered the reference domain in other ways as well. Currently much of it is devoted to commercial pine plantations, crop production and pasture, residential and commercial developments, and other “open” land uses. Adverse effects of the “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). Research into the adverse effects of fragmentation on mammals has been less common (Nilon 1986; Nilon and VanDruff 1987; VanDruff and Rowse 1986). Effects on the wildlife community may be indirect; for example, the size of fragments has been found to be positively correlated to tree species diversity in floodplain forests of the Coastal Plain (Rudis 1995), and proximity to fragmented areas can impact the ecological function of unaffected areas (Stein and Ambrose 2001).

Biological and genetic diversity are reduced as habitat fragmentation and urbanization occur in an area. Species have lower reproductive output in smaller habitat patches or avoid small patches altogether. Larger and more specialized animal species, especially those having large home ranges, are affected from the onset of fragmentation (VanDruff et al. 1996). Habitat specialists are often the first to be extirpated from an area or region. Eventually, even generalist species are impacted if fragmentation is extreme. Urbanization often accompanies habitat fragmentation. Urbanization reduces the number of native wildlife species in an area, while increasing the abundance of exotic species (McKinney 2002; VanDruff et al. 1996). Birds are also impacted adversely by habitat fragmentation due to increased predation, nest parasitism by the brown-headed cowbird (*Molothrus ater*), and other factors (Askins et al. 1987; Keller et al. 1993; Kilgo et al. 1997). Although tied to wetlands and other aquatic habitats for breeding, many southeastern frogs and some salamanders spend portions of the year in terrestrial habitats, often in hardwood forests (Bailey et al. 2004). 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 the terrestrial habitat be referred to as part of the “core habitat” used by the animals. This is different from the traditional concept of the “buffer zone” commonly recommended around wetlands to protect various wetland functions (Boyd 2001).

Semlitsch and Bodie (2003) reviewed the literature on terrestrial habitats used by amphibians. Habitat features such as leaf litter, coarse woody debris (i.e., logs), boulders, small mammal burrows, cracks in rocks, spring seeps, and rocky pools are important for foraging, refuge, or overwintering. A well-developed canopy (for shade) and coarse woody debris and litter (for refuge and food) were considered to be essential habitat features. The abundance of litter is related to the age of forest stands. The litter layer in an older forest is usually thicker than in a younger forest due to the amount of foliage produced. Young stands do not begin to contain large amounts of litter and coarse woody debris until natural thinning begins. Coffey (1998) reported that minimal woody debris were found in bottomland hardwood stands younger than 6 years of age. Such a pattern also exists in upland forests. Shade, which is critical to amphibian species in slowing or preventing dehydration (Rothermel and Semlitsch 2002; Spight 1968), is provided to some extent in all forest stands but likely is not effective until tree canopies begin to close (Rothermel and Semlitsch 2002). Managed pine forest is considered suitable amphibian habitat only if soils, litter, and ground-layer vegetation have not been disturbed extensively (e.g., by bedding) such that cover has been eliminated and animal movement impeded. Areas devoted to row crops and closely mowed or grazed pastures are not suitable (Boyd 2001).

The size of terrestrial areas immediately adjacent to wetlands is important to the integrity of the wetland ecosystem. This is especially critical for Headwater Slope and depression wetlands that typically occur as small patches within a matrix of drier sites, and where wetlands occur as narrow zones along Mid-gradient streams. Buffer zones (or adjacent, nonwetland habitats) are very important to amphibians and reptiles that spend parts of their life cycles outside the wetland (Boyd 2001; Burke and Gibbons 1995; Gibbons 2003; Gibbons and Buhlmann 2001; McWilliams and Bachmann 1988; Semlitsch and Bodie 1998).

The width of suitable contiguous habitat needed for any given wetland area depends upon a number of variables, including wetland size, topography, climate, surrounding land use, and the species of herpetofauna present (Semlitsch and Jensen 2001). Boyd (2001) compiled information regarding animal use of areas adjacent to wetlands. She concluded that 30-m (100-ft) buffer provided protection for 77% of the species known to be dependent on wetlands, but recommended that even larger areas be considered because numerous species sometimes travel much greater distances. Semlitsch and

Bodie (2003) synthesized the literature on terrestrial habitats used by amphibians and reptiles associated with wetlands and concluded that core terrestrial habitat extends 159-290 m (522-950 ft) from the wetland edge for most amphibians and 127-289 m (417-948 ft) for most reptiles, although some species may move much farther. For example, certain frogs sometimes move up to 1,600 m (5,250 ft) from the 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. Such areas also reduce the amounts of silt, contaminants, and pathogens that enter the wetland, 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).

The quality and availability of habitats for fish and wildlife species in wetlands of the alluvial valleys of the Coastal Plain are dependent on a variety of factors operating at different scales. For example, though landscape considerations are important for birds as well as amphibians, there is a substantial difference in scale, 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 birds (i.e., patch size) is impractical. Having sufficient core habitat for amphibians may not entirely eliminate adverse effects of fragmentation, but it should be useful in protecting birds from nest parasitism and predation by animals. Most impacts on birds are thought to occur relatively close to an edge (within 100-300 m (328-984 ft)) (Brittingham and Temple 1983; Strelke and Dickson 1980; Wilcove 1985).

Habitat components that can be considered in a rapid field assessment include vegetation structure and composition, detrital elements, availability of water, and landscape scale attributes such as connectivity. The dependence of animals on native plant communities and their characteristic detrital components, such as logs, is well documented (Allen 1987; Harmon et al. 1986; Howard and Allen 1989; Hunter 1990; Johnston et al. 1990; Loeb 1993; Schoener 1986; Stauffer and Best 1980; Wharton et al. 1982). The assessment procedure used here focuses on those attributes to a large extent, with maximum habitat functionality for the widest group of animal species assumed to be present in mature, complex systems.

Form of the assessment model

The models for assessing the Maintain Characteristic Wildlife Habitat function include ten variables:

- Change in Catchment Size (V_{CATCH})
- Upland Land Use (V_{UPUSE})
- Habitat Connections ($V_{CONNECT}$)
- System Hydrologic Alterations ($V_{HYDROSYS}$)
- Site Hydrologic Alterations ($V_{HYDROALT}$)
- Canopy Tree Diameter (V_{BIG3})
- Canopy Tree Density (V_{TDEN})
- Sapling/Shrub Cover (V_{SSC})
- Ground Vegetation Cover (V_{GVC})
- Vegetation Composition and Diversity (V_{COMP})

The models for calculating the functional capacity index (FCI) for the Maintain Characteristic Wildlife Habitat function depend, in part, on the characteristics of the uppermost stratum of vegetation within the wetland. If the site supports a tree layer (>20% total tree cover), then Equation 22 or 25 is used. If dominated by saplings and shrubs (<20% canopy cover of trees but >20% cover of saplings and shrubs), then Equation 23 or 26 is used. If neither trees nor saplings/shrubs are common (<20% cover), then Equation 24 or 27 is used.

For the Headwater Slope subclass:

$$FCI = \left\{ \left[V_{HYDROALT} \times \left(\frac{V_{CATCH} + V_{UPUSE}}{2} \right) \right]^{1/2} \times \left[\frac{\left(\frac{V_{BIG3} + V_{TDEN} + V_{COMP}}{3} \right) + V_{CONNECT}}{2} \right] \right\}^{1/2} \tag{22}$$

$$FCI = \left\{ \left[V_{HYDROALT} \times \left(\frac{V_{CATCH} + V_{UPUSE}}{2} \right) \right]^{1/2} \times \left[\frac{\left(\frac{V_{SSC} + V_{COMP}}{6} \right) + V_{CONNECT}}{2} \right] \right\}^{1/2} \tag{23}$$

$$FCI = \left\{ \left[V_{HYDROALT} \times \left(\frac{V_{CATCH} + V_{UPUSE}}{2} \right) \right]^{\frac{1}{2}} \times \left[\frac{\left(\frac{V_{GVC} + V_{COMP}}{10} \right) + V_{CONNECT}}{2} \right] \right\}^{\frac{1}{2}} \quad (24)$$

And for the Riverine subclasses:

$$FCI = \left\{ \left(V_{HYDROALT} \times V_{HYDROSYS} \right)^{\frac{1}{2}} \times \left[\frac{\left(\frac{V_{BIG3} + V_{TDEN} + V_{COMP}}{3} \right) + V_{CONNECT}}{2} \right] \right\}^{\frac{1}{2}} \quad (25)$$

$$FCI = \left\{ \left(V_{HYDROALT} \times V_{HYDROSYS} \right)^{\frac{1}{2}} \times \left[\frac{\left(\frac{V_{SSC} + V_{COMP}}{6} \right) + V_{CONNECT}}{2} \right] \right\}^{\frac{1}{2}} \quad (26)$$

$$FCI = \left\{ \left(V_{HYDROALT} \times V_{HYDROSYS} \right)^{\frac{1}{2}} \times \left[\frac{\left(\frac{V_{GVC} + V_{COMP}}{10} \right) + V_{CONNECT}}{2} \right] \right\}^{\frac{1}{2}} \quad (27)$$

These models each contain two expressions; the first includes variables expressing the hydrologic integrity of the system ($V_{HYDROSYS}$, $V_{HYDROALT}$, V_{CATCH}, and V_{UPUSE}). In the context of this function, a characteristic hydrologic regime is a source of water for breeding fish and amphibians and the main environmental gradient controlling plant distribution. The plant community is the primary source of food and cover for animal communities. The second part of the equations reflect seral stage, cover potential, food production potential, nest site potential, availability of dispersal habitat, and other factors that depend on stand structure, maturity, and connectivity ($V_{CONNECT}$). V_{BIG3} and V_{TDEN} are used when the wetland is dominated by trees; V_{SSC} is used in sapling/shrub-dominated wetlands; and V_{GVC} is used in wetlands lacking sufficient trees or shrubs. In the context of this function, canopy tree diameter (V_{BIG3}) and density (V_{TDEN}) are structural indicators of seral stage and of disturbance. The vegetation composition and diversity variable (V_{COMP}) reflect floristic quality and diversity, as well as seral stage and disturbance. The subindices for V_{BIG3}, V_{CTDEN}, and V_{COMP} are cumulative expressions of structure and stand age and are averaged, which expresses the age, structure, and appropriateness of the species present. Woody debris, snags and other features of forested wetlands are also important habitat requirements for various members of the wildlife community, but are not explicitly included in the model. It was assumed that if the structure and composition of the overstory are appropriate, then these additional features will be present in the appropriate numbers or amounts.

The final variable in each equation is $V_{CONNECT}$, which represents the availability of suitable habitat connected to the wetland site of interest. For the Headwater Slope subclass, the assessment of landscape characteristics focuses on the adequacy of buffer zones adjacent to the wetland, particularly as they influence reptiles and amphibians. In the Depression, Mid- and Low-gradient Riverine subclasses, $V_{CONNECT}$ is used to represent the importance of the diversity of habitat in southeastern floodplain systems where contiguous forest is the dominant vegetation type in the absence of anthropogenic disturbance (Wickham et al. 2007). This focus is adopted to reflect concerns about animals adversely affected by habitat fragmentation (De Jager and Rohweder 2011) as well as the progressive loss of floodplain habitats beginning with the highest areas, such as terraces, and proceeding to lower areas due to human disturbance (Rudis 1995). The expression incorporates consideration of the proportion of the floodplain with suitable habitat.

Hydrologic integrity is assumed to be critical to the maintenance of wetland wildlife habitat; therefore, the hydrology component is used as a multiplier in each equation. The other terms in the model, which reflect onsite and offsite habitat conditions, are assumed to be partially compensatory (i.e., a low value for one term will be partially compensated by a high value for the other(s)).

This model is assumed to reflect the ability of alluvial valley wetlands to provide critical life requisites for wildlife, with an emphasis on wetland dependent species. If the components of this model are similar to those found under reference standard conditions, then it is likely that the entire complement of amphibians and birds characteristic of alluvial wetlands within the reference domain will be present.

5 Assessment Protocol

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 Coastal Plain. 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. Both 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 actions.

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

- Document the project purpose and characteristics.
- Screen for red flags.
- 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.

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 impact 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 wetland management technique.

Screen for Red Flags

Red flags are features within or in the vicinity of the project area to which special recognition or protection has been assigned on the basis of objective criteria (Table 12). 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 preempt or postpone an assessment of wetland functions. An assessment of wetland functions may not be necessary if the project is unlikely to occur as a result of a red flag feature. For example, if a proposed project has the potential to impact a threatened or endangered species or habitat, an assessment of wetland functions may be unnecessary since the project may be denied or modified strictly on the basis of the impacts to threatened or endangered species or habitat.

Identify Regional Subclass(es) and Define the Wetland Assessment Area

Determining the correct subclass is essential to completing a meaningful HGM assessment. Current aerial photographs, 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 (Figure 4), the wetland subclass descriptions (Table 5) and the project area boundary. The WAA is an area of wetland within a project area that belongs

Table 12. 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 = U.S. Fish and Wildlife Service

D = National Park Service

E = State Coastal Zone Office

F = State Departments of Natural Resources, Fish and Game, etc.

G = State Historic Preservation Office

H = State Natural Heritage Offices

I = U.S. Environmental Protection Agency

J = Federal Emergency Management Agency

K = Natural Resources Conservation Service

L = Local Government Agencies

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, as illustrated in Figure 21A. However, as the size and heterogeneity of the project area increase, it may be necessary to define and assess multiple WAAs or Partial Wetland Assessment Areas (PWAAs) within the project area.

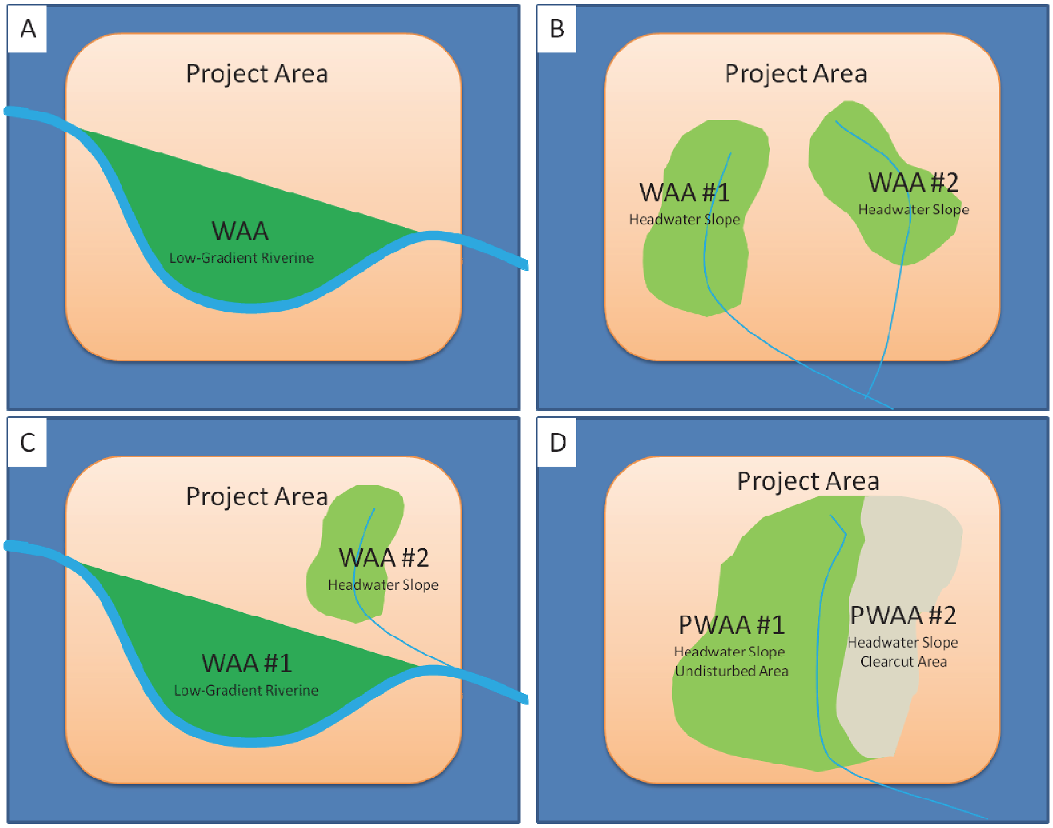


Figure 21. Wetland assessment area (WAA) scenarios within a project area. A.) A single WAA within a project area. B.) Spatially separated WAAs within the same regional subclass. C.) More than one regional subclass within a project area. D.) Multiple partial wetland assessment areas (PWAA) within a project area due to site-specific differences.

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 (Figure 21B). The second situation exists when more than one regional wetland subclass occurs within a project area (Figure 21C). 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 a significantly different value for one or more of the site-specific variable measures. These differences may be a result of natural variability (e.g., zonation on large river floodplains) or human disturbance (e.g., logging, surface mining, etc.) (Figure 21D). Designate each of these areas as a separate PWAA and conduct a separate assessment on each area.

In the Coastal Plain, the most common scenarios requiring designation of multiple Wetland Assessment Areas involve tracts of land with interspersed regional subclasses (such as depressions scattered within a matrix of Riverine wetlands) or tracts composed of a single regional subclass that includes areas with distinctly different land use influences that produce different land cover. 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 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. It will, however, greatly increase the sampling and analysis requirements.

Collect the Data

Information used to assess the functions of regional wetland subclasses in alluvial valleys of the Coastal Plain 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 proceeding in an organized fashion. As noted previously, the Project Information and Assessment Documentation form (Appendix B) is intended to be used as a cover sheet and for an overview of all documents and data forms 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 that 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 forms, because the assessment variables and their measurement protocol differ among subclasses (Table 7). Use the Data Sheets checklist in Appendix B2 to determine how many of each form are needed, then make copies of the required forms, which are provided in Appendix C. Data sheets may also be printed directly from the FCI/FCU calculator spreadsheet (see also Appendix D).

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, maps, and hydrologic information for each WAA and vicinity. Information on the second group of variables on Data Sheet 1 is collected during a walking reconnaissance of the WAA. Data collected for these two groups of variables are entered directly on the data forms, and do not require plot-based sampling. Information on the next group of variables is collected in sample plots placed in representative locations throughout the WAA. Data from a single plot are recorded on Data Sheet 2. Additional copies of Data Sheet 2 are completed for each plot sampled within the WAA. All summary data from each of the data forms are compiled on Data Sheet 3 prior to entry into the spreadsheet that calculates the functional capacity of the wetland being assessed.

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 metric units (although non-SI equivalents are indicated for most sampling criteria such as plot sizes).

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, although in no case should less than three plots be used to characterize a WAA.

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 0.04-ha plots, with associated transects in representative locations, are probably adequate to characterize the WAA. However, as the size and complexity of the WAA increase, more sample plots are required to represent the site accurately. Large forested wetland tracts usually include a mix of tree age classes, 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 as a whole. 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. 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, 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, tree size, and tree density has been accounted for. That is, as the number of plots sampled has increased, are new dominant species being encountered, and has the average diameter or density of 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 composition variability remain high, then return to the alternate, unsampled transects and continue sampling until the data set is representative of the site as a whole, as indicated by a leveling off of the dominant species list and dbh and density values. Other variables may level off more quickly or slowly than tree composition, mean dbh, and density; but these factors are generally good indicators, and correspond well to the overall suite of interest characteristics 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 a single tree species), it may be that relatively few samples are adequate to reasonably characterize the wetland.

The information on Site/WAA level and Plot level Data Sheets (Appendix C) may be entered in the FCI/FCU calculator spreadsheet and automatically tabulated. The overall assessment summary is presented on the FCI/FCU summary page of the spreadsheet. All of 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 B. Appendix D contains a listing of scientific names of tree and shrub species that are referenced on the field data forms. Detailed instructions on collecting the data for entry on Data Sheets follow. Where plot samples are required, refer to the plot layout diagram in Figure 22. Variables are listed in the order in which they appear on the field data forms to facilitate locating them. Not all variables are used to assess all subclasses, as described in Chapter 4 and Table 7, but the data forms in Appendix C 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 the more detailed descriptions in this Chapter and have them available in the field for reference as necessary.

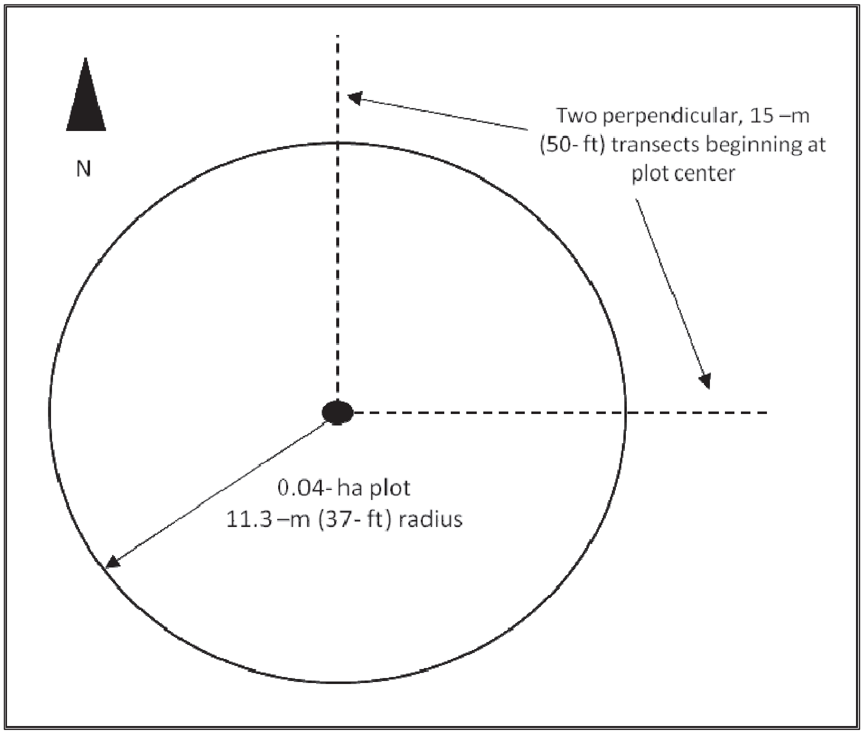


Figure 22. Layout of plot and transects for field sampling.

Change in Catchment Size (V_{CATCH})

Measure/Units: Percent change in the effective size of the wetland catchment or basin. 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 0 (subindex for V_{CATCH} = 1.0) and the following steps may be skipped. Otherwise, use aerial photographs, 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. In the case of water transfer into the wetland's catchment from an adjacent basin, determine the area of the basin (or portion of the basin) from which water is being transferred.
3. Use Equation 2 or 3 in Chapter 4, whichever is appropriate, to calculate the percent change in effective catchment size.
4. Use Figure 7 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.

Upland Land Use (V_{UPUSE})

Measure/Units: Weighted average runoff score for the catchment that provides water to the Headwater Slope wetland. Use the following procedure to measure V_{UPUSE}:

1. Use topographic maps or other sources to delineate the existing catchment or watershed of the Headwater Slope Wetland. Do not include areas from which water is being diverted away from the wetland; include any adjacent catchment area from which water is being imported into the wetland's catchment (see V_{CATCH} above).
2. Use recent aerial photographs, confirmed during field reconnaissance, to determine the land-use categories (Table 8) present in the catchment.
3. If the land-use of the catchment above the wetland is > 75 % in native plant communities, assign a subindex of 1.0 and skip the remaining steps. If not, proceed to step 4.
4. Use the Web Soil Survey (http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm), a local soil survey, or on-site soil sampling to determine the soil series that occur in the catchment. Based on information in the soil survey, determine the hydrologic group(s) (i.e., A, B, C, or D) for the soils present in the catchment.

5. Using GIS tools, aerial photos, or field reconnaissance, determine the percentage of the catchment represented by each combination of landuse category and soil hydrologic group shown in Table 8.
6. Determine the runoff score for each combination of land-use category and soil hydrologic group present in the catchment (Table 8).
7. Determine a weighted (by area) average runoff score for the catchment. An example can be found in Appendix B.
8. Use Figure 8 to determine the subindex score for V_{UPUSE}.

Habitat Connections ($V_{CONNECT}$)

Measure/Units: This variable is measured differently depending on the subclass. For the Headwater Slope subclass, the variable is expressed as the percentage of the wetland's perimeter that is connected to suitable habitat weighted by buffer width.

Use the following procedure in Headwater Slope wetlands to measure $V_{CONNECT}$:

1. Measure the total length of the wetland's perimeter within the WAA (the wetland may continue beyond the WAA).
2. Determine the length of wetland perimeter that is adjacent to a buffer of suitable habitat of at least 10-m (32.8 ft) in width. Perimeter may be measured during field reconnaissance, or from topographic maps, aerial photographs, or GIS techniques.
3. Divide the result from step 2 by the result from step 1 and multiply by 100 to obtain the percentage of wetland perimeter adjacent to suitable habitat. Record that percentage on Data Sheet 1.
4. Use the top series in Figure 10 to determine the variable subindex for $V_{CONNECT}$.
5. Multiply the variable subindex by 0.33 if the average perimeter width is >10 m and <30 m (32.8-98.4 ft) wide, 0.66 if the average perimeter width is > 30 m and < 150 m (98.4-492 ft), or 1.0 if the average perimeter width is > 150 m (492 ft) to determine the subindex score for $V_{CONNECT}$. Alternatively, these subindex scores can be read directly off the middle and lower series in Figure 10.

Use the following procedure (illustrated in Appendix D, Figure D3) in the Riverine subclasses (Connected Depressions, Mid-gradient, and Low-gradient) to measure $V_{CONNECT}$:

1. Determine the assessment area reach:
    a. Estimate the width of the alluvial valley using topographic maps, aerial photos, digital elevation models, etc., multiply by the estimate of valley width by 5.
    b. Measure ½ the distance obtained upstream and ½ downstream of the wetland assessment area. Measure along the central axis of the valley, not the stream. Make turns if necessary. These points will serve as the upstream and downstream limits of the $V_{CONNECT}$ assessment area.

2. Establish a buffer equal to ½ the width of the valley estimated in step a. on each side of the centerline of the valley (drawn in step 1b.) Using aerial photographs, determine the percentage within the assessment area reach that is in suitable habitat (See Chapter 4 for examples of suitable habitat types). If that percentage is $\geq$ 80%, report the result as 1.0. For percentages <80% use the subindex curve for $V_{CONNECT}$ (Figure 11).

Soil integrity ($V_{SOILINT}$)

Measure/Units: This variable is measured as the proportion of the assessment area with altered soils. Use the following procedure to measure $V_{SOILINT}$:

1. As part of the reconnaissance walkover of the entire WAA, determine whether any of the soils in the area being assessed have been altered. In particular, note roads, berms, ditches, parking areas and similar features, as well as other evidence of excavation, fill, or severe compaction. For the purposes of this assessment approach, the presence of a plow layer should not be considered a soil alteration.
2. If no altered soils exist, the percent of the assessment area with altered soils is zero. This indicates that all of the soils in the assessment area are soils in reference standard condition.
3. If altered soils exist, estimate the percentage of the assessment area that has soils that have been altered.
4. Report the percent of the assessment area with altered soils on Data Sheet 1, and use Figure 12 to determine the subindex score for $V_{SOILINT}$.

System Hydrologic Alterations ($V_{HYDROSYS}$)

Measure/Units: This variable applies to the Riverine subclasses, and represents the capacity of a stream network above a wetland to deliver floodwaters to it. The variable expresses departure from the system's natural capacity, which – due to alterations — may be either increased or decreased. The variable may be quantified by a number of approaches. Four methods are listed here, with the most direct approaches presented first.

The following procedures are listed in order of preference. Use one to assess $V_{HYDROSYS}$:

1. Use of stream gage data to compare existing state with pre-disturbance (See the example for a flow-regulated river in Appendix D)
2. Comparison of hydrologic modeling data of existing state to pre-disturbance (e.g., comparison of modeled hydrographs using cross-correlation, the cross-correlation coefficient is used as the $V_{HYDROSYS}$ subindex in all models)
3. Comparison of channel characteristics (regional dimensionless rating curves, channel width/watershed ratio, sinuosity, etc.) to natural conditions
4. Comparison to qualitative statements of departure. Refer to Table 13. Select the best description of the system from the "Indicators of condition" column and report the corresponding subindex.

Table 13. Description and subindex values for the System Hydrologic Alterations variable ($V_{HYDROSYS}$).

Subindex	Hydrologic condition	Indicators of condition
1.0	Natural stream hydrology	Clear evidence of overbank flooding such as drift lines, high-water marks, etc. and floodwater exchange with stream channel. Stream flow is natural (e.g., no large reservoirs regulating flow. No clear evidence of channel incision).
0.5	Altered stream hydrology	Stream flow is regulated or channel is deeply incised (both conditions may be present). Evidence of overbank flooding and floodwater exchange with stream channel is present but durations and frequencies of floodwater exchange have been reduced or increased from the natural condition.
0.1	Hydrologically isolated – floodwater exchange with floodplain rarely or never occurs	Anthropogenic changes have resulted in the elimination of all or nearly all overbank flooding. Examples of this condition include streams with deeply incised channels (channelized system) or streams with regulated flow.

Site Hydrologic Alterations ($V_{HYDROALT}$)

Measure/Units: This variable is defined as man-induced alterations to the natural hydrology of the wetland due to activities within the wetland assessment area. This variable is measured differently depending on the subclass. For the Headwater Slope subclass, the variable is quantified by the height of any dam, berm, or water-control structure or depth of any ditch located within the wetland, or by the maximum depth of water impounded in the wetland.

Use the following procedure in Headwater Slope wetlands to measure $V_{HYDROALT}$:

1. If wetland hydrology is unaltered and there are no obstructions to natural water storage or flow, and there are no ditches or excessive ponding within the wetland, then the height is 0, the subindex score for $V_{HYDROALT}$ is 1.0, and the following steps may be skipped.
2. If wetland hydrology has been altered, identify any permanent obstructions to surface water flow such as dams or road crossings, and any ditches that increase drainage. Natural microtopography or even wheel and tire ruts do not alter the natural hydrology of a Headwater Slope wetland appreciably.
3. Measure the height of the obstruction, depth of the ditch, or depth of ponded water in centimeters from the natural ground surface.
4. Use Figure 13 to determine the subindex score for $V_{HYDROALT}$.

Use the following table for the three Riverine subclasses of wetlands (Connected Depressions, Mid-gradient, and Low-gradient) to assign a subindex for $V_{HYDROALT}$:

Table 14. Description and subindex values for Site Hydrologic Alterations variable ($V_{HYDROALT}$). Use only for the Riverine subclasses.

Subindex	Hydrologic condition	Indicators of condition
1.0	Natural hydrology	Clear evidence of overbank flooding (such as drift lines, high-water marks, etc.) and floodwater exchange with stream channel. No evidence of effective ditches and levees.
0.5	Surface hydrology modified	Site has either drainage works or obstructions to floodwater exchange with the stream, or a combination of both are present. Evidence of overbank flooding and floodwater exchange with stream channel is present. Modifications may be those intended to either reduce or increase duration or frequency of inundation at the site (departure from natural conditions, either wetter or drier, is considered an adverse impact).

Subindex	Hydrologic condition	Indicators of condition
0.1	Hydrologically isolated – rarely inundated	Primary characteristic of this condition is that anthropogenic changes have resulted in the disconnection or isolation of the wetland from overbank flooding. An example of this condition includes areas behind maintained, integrated levee systems. Effectively, the hydrology of the area has been altered such that the wetland hydrology is no longer dominated by overbank flooding from the adjacent stream network (i.e., it is not functioning as a Riverine wetland), instead, hydrology may be precipitation driven (functioning like a hardwood-flat or a disconnected depression).
0.0	Hydrologically isolated – never inundated by stream flow	Assign a subindex of 0 when the site is isolated due to levee systems such that overbank flow never reaches the site.

Canopy Tree Size (V_{BIG3})

Measure/Units: Mean dbh of 3 largest diameter trees in each 0.04-ha (0.1-acre) plot. Use the following procedure to measure V_{BIG3}:

1. Measure this variable only if the total cover of trees >15 cm (6 in.) dbh in the wetland is $\geq$20 percent. If tree cover is <20 percent, the following steps may be skipped.
2. Measure the dbh (cm) of only the 3 largest trees in each 0.04-ha (0.1-acre) plot. (Record only the trees that are $\geq$15 cm (6 in.) dbh in the plot, even if there is only 1 or 2).
3. Calculate the mean canopy tree diameter by summing the dbh of the 3 largest trees within the plot, and dividing by 3 (or divide by 2, if there are only 2 that are $\geq$15 cm dbh).
4. Average the results from all plots.
5. Report the result in centimeters.
6. Use Figure 14 to determine the subindex score for V_{BIG3}.

Canopy Tree Density (V_{TDEN})

Measure/Units: Number of canopy trees (or stems) per hectare. Trees are defined as woody vegetation $\geq$ 15 cm dbh. Use the following procedure to measure V_{CTDEN}:

1. Measure this variable only if the total cover of trees $\geq$15 cm (6 in.) dbh in the wetland is >20 percent. If tree cover is <20 percent, the following steps may be skipped.
2. Count the number of trees $\geq$ 15cm dbh (6 in.) in a 0.04-ha (0.1-acre) plot.

3. Convert this result to a per hectare basis by multiplying by 25 (there are 25 0.04-ha plots in each hectare).
4. Average the results from all plots.
5. Report canopy tree density as the number of trees per hectare.
6. Use Figure 15 to determine the subindex score for V_{CTDEN}.

Sapling/Shrub Cover (V_{SSC})

Measure/Units: Average percentage cover of saplings and shrubs. The sapling/shrub stratum is defined as woody vegetation $\geq$1 m (39 in.) in height and <15 cm (6 in.) dbh (e.g., shrubs, saplings, and understory trees). Use the following procedure to measure V_{SSC}:

1. Measure this variable only if total tree cover is <20 percent and cover of sapling/shrubs is $\geq$20 percent.
2. Visually estimate the percentage cover of saplings/shrubs within a 0.04-ha (0.1-acre) plot or, alternatively, within each of the four 0.01-ha (0.025-acre) subplots. If necessary, average the results across subplots.
3. Average the percentage cover estimates if more than one 0.04-ha plot is sampled.
4. Report the average sapling/shrub cover as a percentage.
5. Use Figure 16 to determine the subindex score for V_{SSC}.

Ground Vegetation Cover (V_{GVC})

Measure/Units: Average percentage cover of ground-layer vegetation Ground vegetation is defined as all herbaceous vegetation, regardless of height, and woody vegetation <1 m (39 in.) in height. Use the following procedure to measure V_{GVC}:

1. Measure this variable only if tree and sapling/shrub cover are each <20 percent. See Chapter 4.
2. Visually estimate the percentage cover of ground-layer vegetation within a 0.04-ha (0.1-acre) plot or, alternatively, within each of the four 0.01-ha (0.025-acre) subplots. If necessary, average the results across subplots.
3. Average the percentage cover estimates if more than one 0.04-ha plot is sampled.
4. Report ground vegetation cover as a percent.
5. Use Figure 17 to determine the subindex score for V_{GVC}.

Vegetation Composition and Diversity (*V_{COMP}*)

Measure/Units: An index based on the species composition and number of dominant species in the uppermost stratum of the wetland's vegetation.

Use the following procedure to measure V_{COMP}:

1. If total tree cover is $\geq$20 percent, then V_{COMP} is determined for the tree stratum. If tree cover is <20 percent and sapling/shrub cover is $\geq$20 percent, then V_{COMP} is determined for the sapling/shrub stratum. If tree cover and sapling/shrub cover are both <20 percent, then V_{COMP} is determined for the ground layer, even if the ground layer has <20 percent vegetation cover.
2. Use the "50/20 rule" (see Figure 18) to identify the dominant species in the appropriate vegetation stratum. For sites containing a tree stratum, be sure to consider all trees $\geq$15 cm (6 in.) dbh
3. On the data form, place a check beside each dominant species that appears in either Group 1 or 2 for the appropriate subclass (Tables 9, 10, or 11). If a dominant species is not listed but is a species native to the reference domain, it can be added to Group 2 using the blanks provided. For exotic and invasive species in the reference domain (Group 3), check all species encountered on the plot without regard to dominance or stratum. Other exotic and invasive species can be added using the blanks provided and should be treated as Group 3 species. The data form does not list herbaceous plants due to the potentially very long list. Assign all native, non-invasive herbaceous species to Group 1. Invasive and exotic herb species that occur in wetlands in the reference domain should be listed in Group 3.
4. Using the checked dominants in Groups 1 and 2, and the checked exotic or invasive species in Group 3, calculate an initial quality index (Q) using the following formula:
5. Q = [(1.0 × *number of checked dominants in Group 1*) + (0.66 × *number of checked dominants in Group 2*) + (0.0 × *number of checked species in Group 3*)] / *total number of checked species in all groups*
6. Calculate an adjusted quality index (R) that takes species richness into consideration. Multiply Q by one of the following constants:
   a. If four or more species from Groups 1 or 2 occur as dominants, multiply by 1.0 (i.e., R = Q × 1.0).
   b. If three species from Groups 1 or 2 occur as dominants, multiply by 0.75 (i.e., R = Q × 0.75).

c. If two species from Groups 1 or 2 occur as dominants, multiply by 0.50 (i.e., $R = Q \times 0.50$).
d. If one species from Groups 1 or 2 occurs as a dominant, multiply by 0.25 (i.e., $R = Q \times 0.25$).
e. If no species from Groups 1 or 2 occur as dominants, multiply by 0.0 (i.e., $R = Q \times 0.0$).

(In a small assessment area (e.g., <0.25 ha), it is possible that fewer than four species may be dominant, even in a high-quality community. In such cases, at the discretion of the user, Q can be multiplied by 1.0, even if as few as two species are dominant.)

7. Calculate the square root of R. This is the subindex for vegetation composition and diversity (V_{COMP}).

Woody Debris (V_{WD})

Logs and other woody debris are an important of habitat and nutrient cycles of forests. Volume of woody debris per hectare is the metric used to quantify this variable. Measure woody debris with the procedure outlined in the following text, adapted from Woodall and Monleon (2008).

Log, or stem, diameter refers to the diameter at the point of intersection with the transect line. Leaning dead stems that intersect the sampling plane are sampled. Dead trees and shrubs still supported by their roots are not sampled. Rooted stumps are not sampled, but uprooted stumps are sampled. Down stems that are decomposed to the point where they no longer maintain their shape but spread out on the ground are not sampled.

Lay out two 50-ft (15.24-m) transects perpendicular to each other, one bearing north and one bearing east, originating at the 0.04-ha plot center point. (The transect bearings may also be established randomly. For the first transect, note the seconds on a watch and multiply by six. The product is the first transect's bearing. Add 90 degrees to the first transect bearing to obtain the second transect bearing. For example, if the seconds are 32, the bearing of the first transect is 182 (32 x 6) and the bearing of the second transect is 272 (182+90)).

1. Measure and record the diameter of nonliving stems greater than or equal to 7.5 cm (3 in) that intersect the plane above the entire length of the 50-ft

transect. Record the diameters of individual stems (in centimeters) from each transect in the spaces provided on the V_{WD} of the data sheet.
2. If not using the calculator spreadsheet, use the worksheet in Appendix D to hand calculate V_{WD} (m^3/ha) from the diameter measurements.
3. Woody debris is reported in m^3/ha. Use Figure 20 to determine the subindex score for V_{WD}.

Analyze Field Data

The data recorded on the field forms must be transferred to the spreadsheet. All calculations will be made automatically, and an overall summary report will be generated.

Document Assessment Results

Once data collection, summarization, and analysis have been completed, it is important to assemble all pertinent documentation. Appendix A1 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.

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 particular 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, as 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 on the basis of functions performed rather than the magnitude of functional performance. For example, Riverine subclasses have import and export functions that are not present in flats or isolated depressions. Conversely, isolated depressions are more likely to support endemic species than are river-connected systems. These types of comparisons may be particularly important where a proposed action will result in a change of subclass. When a levee, for example, will convert a Riverine wetland to a flat, it is helpful to be able to recognize that certain import and export functions will no longer occur.

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. In particular, 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 because of beaver activity or changes in channel courses, the buttonbush swamp should be recognized as a functional component of a larger wetland complex, and the V_{COMP} weighting system can be adjusted accordingly. Another potential way to deal with 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 affected by fire, sites damaged by ice storms, and similar occurrences. Fire, in particular, can cause dramatic short-term changes in many of the indicators measured to assess function, such as woody debris. Note, however, that normal, non-catastrophic disturbances to wetlands (i.e., tree mortality causing small openings) are accounted for in the reference data used in this guidebook.

The assessment models and procedures presented in this guidebook are applicable to the majority of the wetlands that exist within alluvial valleys of the Coastal Plain. However, the classification system presented in Chapter 3 includes a number of wetland subclasses that may occur within the reference domain, 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 Chapter 3 is provided specifically to assist users who encounter these uncommon or unique systems.

References

Ainslie, W. B., R. D. Smith, B. A. Pruitt, T. H. Roberts, E. J. Sparks, L. West, G. L. Godshalk, and M. V. Miller. 1999. *A regional guidebook for assessing the functions of Low Gradient, Riverine Wetlands in Western Kentucky*. Technical Report WRP-DE-17. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

Alexander, R. B., E. W. Boyer, R. A. Smith, G. E. Schwarz, and R. B. Moore. 2007. The role of headwater streams in downstream water quality. *Journal of the American Water Resources Association (JAWRA)* 43:41-59.

Alford, J. J., and J. C. Holmes. 1985. Meander scars as evidence of major climate changes in southeast Louisiana. *Annals of the Association of American Geographers* 75:395-405.

Allen, A. W. 1987. *Habitat suitability index models: Gray squirrel, revised*. Biological Report 10.135. Washington, DC: U.S. Fish and Wildlife Service.

Alpert, P., E. Bone, and C. Holzapfel. 2000. Invasiveness, invasibility and the role of environmental stress in the spread of non-native plants. *Perspectives in Plant Ecology, Evolution and Systematics* 3:52-66.

Anderson, S. H., and H. H. Shugart, Jr. 1974. Habitat selection of breeding birds in an East Tennessee deciduous forest. *Ecology* 55 (4):828-837.

Andreas, B. K., and R. W. Lichvar. 1995. *Floristic index for establishing assessment standards: A case study for northern Ohio*. Wetlands Research Program Technical Report WRP-DE-8. Vicksburg, MS: Waterways Experiment Station.

Angermeier, P. L., and J. R. Karr. 1984. Relationships between Woody Debris and Fish Habitat in a Small Warmwater Stream. *Transactions of the American Fisheries Society* 13:716-726.

Askins, R. A., M. J. Philbrick, and D. S. Sugeno. 1987. Relationship between the regional abundance of forest and the composition of forest bird communities. *Biological Conservation* 39 (2):129-152.

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

Baker, V. R., and M. M. Penteado-Orellana. 1977. Adjustment to Quaternary climatic change by the Colorado River in central Texas. *The Journal of Geology* 85:395-422.

Balco, G., and C. W. Rovey II. 2010. Absolute chronology for major Pleistocene advances of the Laurentide Ice Sheet. *Geology* 38:795-798.

Bales, J. D., and D. A. Walters. 2003. *Relations among floodplain sater levels, instream disolved-oxygen conditions, and streamflow in the Lower Roanoke River, North Carolina, 1997-2001*. Water-Resources Investigations Report 03-4295.

Beaulac, M. N., and K. H. Reckhow. 1982. An examination of land use - nutrient export relationships. *JAWRA Journal of the American Water Resources Association* 18 (6):1013-1024.

Bechtold, W. A., and P. L. Patterson. 2005. *The enhanced forest inventory and analysis program - national sampling design and estimation procedures*. Gen. Tech. Rep. SRS-80. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station.

Benke, A. C., R. L. Henry III, D. M. Gillespie, and R. J. Hunter. 1985. Importance of snag habitat for animal production in Southeastern streams. *Fisheries* 10:8-13.

Bilby, R. E., and G. E. Likens. 1980. Importance of organic debris dams in the structure and function of stream ecosystems. *Ecology* 61:1107-1113.

Bolton, S. M., and J. Shelberg. 2001. Ecological issues in floodplains and riparian corridors. Report WARD 524.1. Seattle, WA: Center for Streamside Studies.

Bonham, C. D. 1989. *Measurements for terrestrial vegetation*. New York: Wiley-Interscience.

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

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

Bridge, J. S. 2003. *Rivers and floodplains: Forms, processes, and sedimentary record*. Malden, MA: Wiley-Blackwell.

Brinson, M. M. 1990. Riverine forests. Chapter. In *Forested Wetlands*, ed. A. E. Lugo, M. M. Brinson and S. Brown. Amsterdam: Elsevier Scientific Publishers.

Brinson, M. M. 1993a. Changes in the functioning of wetlands along environmental gradients. *Wetlands* 13:65-74.

Brinson, M. M. 1993b. *A hydrogeomorphic classification for wetlands*. Technical Report RP-DE-4. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

Brinson, M. M., A. E. Lugo, and S. Brown. 1981. Primary productivity, decomposition and onsumer activity in freshwater wetlands. *Annual Review of Ecology and Systematics* 12 (ArticleType: research-article / Full publication date: 1981 / Copyright © 1981 Annual Reviews):123-161.

Brinson, M. M., R. D. Smith, D. F. Whigham, L. C. Lee, R. D. Rheinhardt, and W. L. Nutter. 1998. Progress in development of the hydrogeomorphic approach for assessing the functioning of wetlands. In *Wetlands for the Future*, ed. A. J. Mccomb and J. A. Davis. Adelaide, Australia: Gleneagles Publishing.

Brittingham, M. C., and S. A. Temple. 1983. Have cowbirds caused forest songbirds to decline? *BioScience* 33 (1):31-35.

Brooks, K. N., P. F. Folliott, H. M. Gregerson, and J. L. Thames. 1991. *Hydrology and the management of watersheds*. Ames, IA: Iowa State University Press.

Brower, J. H., and J. H. Zar. 1984. *Field and lab methods for general ecology*. Dubuque, IA: William C. Brown.

Brown, S., and D. L. Peterson. 1983. Structural Characteristics and Biomass Production of Two Illinois Bottomland Forests. *American Midland Naturalist* 110 (1):107-117.

Burke, V. J., and J. W. Gibbons. 1995. Terrestrial buffer Zones and wetland conservation: A case study of freshwater turtles in a Carolina Bay. *Conservation Biology* 9 (6):1365-1369.

Campbell, K. L., and H. P. Johnson. 1975. Hydrologic simulation of watersheds with artificial drainage. *Water Resour. Res.* 11 (1):120-126.

Cody, M. L. 1985. *Habitat selection in birds*. Orlando, FL: Academic Press, Inc.

Coffey, P. L. 1998. Evaluation of early successional bottomland hardwood forests. MS thesis, Tennessee Technological University.

Conner, W. H., and J. W. Day. 1976. Productivity and composition of a baldcypress-water Tupelo site and a bottomland hardwood site in a Louisiana swamp. *American Journal of Botany* 63 (10):1354-1364.

Cowardin, L. M., V. Carter, F. C. Golet, and E. T. LaRoe. 1979. *Classification of wetlands & deepwater habitats of the US*. FWS/OBS-79/31. Washington, DC: Office of Biological Services, U.S. Fish and Wildlife Service.

Dahm, C. M. 1981. Pathways and mechanisms for removal of dissolved organic carbon from leaf leachates in streams. *Canadian Journal of Fish and Aquatic Science* 38:68-76.

Dale, E. E., and S. Ware. 2004. Distribution of wetland tree species in relation to a flooding gradient and backwater versus streamside location in Arkansas, U.S.A. . *Journal of the Torrey Botanical Society* 131:177-186.

Daniels, R. B., and J. W. Gilliam. 1996. Sediment and chemical load reduction by grass and riparian filters. *Soil Sci. Soc. Am. J.* 60 (1):246-251.

Day, F. P. 1979. Litter accumulation in four plant communities in the Dismal Swamp, Virginia. *American Midland Naturalist* 102:281-89.

Day, R. H., T. M. Williams, and C. M. Swarsenski. 2007. Hydrology of tidal freshwater forested wetlands of the Southeast United States. Chapter 2. In *Ecology of tidal freshwater forested wetlands of the Southeast United States*, ed. W. H. Conner, Doyle, T.W., Krauss, K.W. The Netherlands: Springer.

De Jager, N., and J. Rohweder. 2011. Spatial scaling of core and dominant forest cover in the Upper Mississippi and Illinois River floodplains, USA. *Landscape Ecology* 26 (5):697-708.

DeGraaf, R. M., M. Yamasaki, and W. B. Leak. 1993. Management of New England northern hardwoods, spruce-fir, and eastern white pine for neotropical migratory birds. In *Status and management of neotropical migratory birds*, edited by D. M. Finch and P. W. Stangel. Gen. Tech. Rep. RM-229. Estes Park, Colorado: U.S. Forest Service.

Demissie, M., and A. Kahn. 1993. *Influence of wetlands on streamflow in Illinois*. Contract Report 561. Champaign, IL: Illinois State Water Survey.

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

Diggs, G. M., Jr., B. L. Lipscomb, M. D. Reed, and R. J. O'Kennon. 2006. *Illustrated flora of east Texas. Volume one: Introduction, Pteridophytes, Gymnosperms, and Monocotyledons*. Fort Worth, TX: Botanical Research Institute of Texas and Austin College Publishers.

Duberstein, J. A., and W. H. Conner. 2009. Use of hummocks and hollows by trees in tidal freshwater forested wetlands along the Savannah River. *Forest Ecology and Management* 258 (7):1613-1618.

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

Dunne, T., and L. B. Leopold. 1978. *Water in environmental planning*. San Francisco, CA: WH Freeman & Co.

Dury, G. H. 1977. Underfit streams: Retrospect, perspect and prospect. Chapter. In *River Channel Changes*, ed. K. J. Gregory. New York, NY: John Wiley and Sons.

Edwards, R. T. 1987. Sestonic bacteria as a food source for filtering invertebrates in two southeastern blackwater rivers. *Limnology and Oceanography* 32 (1):221-234.

Elliott, M., and V. N. de Jonge. 2002. The management of nutrients and potential eutrophication in estuaries and other restricted water bodies. *Hydrobiologia* 475/476:513-524.

Elwood, J. W., J. D. Newbold, R. V. O’Neill, and W. Van Winkle. 1983. Resource spiraling: An operational paradigm for analyzing lotic ecosystems. Chapter. In *Dynamics of lotic ecosystems* ed. T. D. Fontaine and S. M. Bartell. Ann Arbor, MI: Ann Arbor Science.

Federal Register. 1997. *The national action plan to implement the hydrogeomorphic approach to assessing wetland functions*. 62(119), June 20, 1997, 33607-33620.

Federico, A. D. 1977. *Investigations of the relationship between land use, rainfall, and runoff quality in the Taylor Creek watershed*. Technical Publication 77-3. West Palm Beach, FL: S. F. W. M. District.

Ford, R. P. 1990. Habitat relationships of breeding birds and winter birds in forested wetlands of west Tennessee. MS thesis, University of Tennessee.

Fredrickson, L. H. 1979a. *Floral and faunal changes in lowland hardwood forests in Missouri resulting from channelization, drainage and impoundment*. Office of Biological Services FWS/OBS-78/91.

———. 1979b. *Lowland hardwood wetlands current status and habitat values for wildlife*. ed. P. E. Greeson, J. R. Clark and J. E. Clark, *Wetland functions and values:Tthe state of our understanding*. Minneapolis, MN: American Water Resources Association.

Gibbons, J. 2003. Terrestrial habitat: A vital component for herpetofauna of isolated wetlands. *Wetlands* 23 (3):630-635.

Gibbons, J. W., and K. A. Buhlmann. 2001. Reptiles and amphibians. Chapter. In *Wildlife of Southern forests, habitat and management*, ed. J. G. Dickson. Blaine, WA: Hancock House Publishers.

Golet, F. C., and J. S. Larson. 1974. *Classification of freshwater wetlands in the glaciated Northeast*. Resource Publication 116. U.S. Fish and Wildlife Service.

Graf, W. L. 2006. Downstream hydrologic and geomorphic effects of large dams on American rivers. *Geomorphology* 79 (3-4):336-360.

Grubb, H. F., and P. D. Ryder. 1972. *Effects of coal mining on the water resources of the Tradewater River Basin, Kentucky, related information: Geological Survey Water-Supply Paper 1940*.

Gustafson, E. J. 1998. Quantifying landscape spatial pattern: What is the state of the art? *Ecosystems* 1 (2):143-156.

Hardison, E. C., M. A. O'Driscoll, J. P. DeLoatch, R. J. Howard, and M. M. Brinson. 2009. Urban land use, channel incision, and water table decline along coastal plain streams, North Carolina(1). *Journal of the American Water Resources Association* 45 (4):1032-1046.

Harmon, M. E., J. F. Franklin, and F. J. Swanson. 1986. Ecology of coarse woody debris in temperate ecosystems. *Notes* 15:133.

Harnsberger, D., and M. O'Driscoll. 2010. The influence of urban channel incision and water table decline on floodplain groundwater nitrogen dynamics, Greenville, NC *Journal of Environmental Hydrology* 18 (6):1-22.

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

Hauer, F. R., and R. D. Smith. 1998. The hydrogeomorphic approach to functional assessment of riparian wetlands: evaluating impacts and mitigation on river floodplains in the U.S.A. *Freshwater Biology* 40 (3):517-530.

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

Hidinger, L. L., and A. E. Morgan. 1912. Drainage Problems of Wolf, Hatchie and South Fork of Forked Deer Rivers, in West Tennessee. *The Resources of Tennessee* 2 (6):231-249.

Hodges, J. D. 1997. Development and ecology of bottomland hardwood sites. *Forest Ecology and Management* 90 (2-3):117-125.

Hodges, J. D. 1998. Minor alluvial floodplains. Chapter 13. In *Southern forested wetlands :Ecology and management*, ed. M. G. Messina and W. H. Conner. Boca Raton, Fla.: Lewis Publishers.

Howard, R. J., and J. A. Allen, eds. 1989. *Streamside habitats in southern forested wetlands: Their role and implications for management*. Edited by D. D. Hook and R. Lea. Vol. General Technical Report SE-50, *Proceedings of the Symposium: The forested wetlands of the southern United States*: U.S. Department of Agriculture Forest Service.

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

Hupp, C., M. Woodside, and T. Yanosky. 1993. Sediment and trace element trapping in a forested wetland, Chickahominy River, Virginia. *Wetlands* 13 (2):95-104.

Hupp, C. R. 2000. Hydrology, geomorphology and vegetation of Coastal Plain rivers in the south-eastern USA. *Hydrological Processes* 14 (16-17):2991-3010.

Hupp, C. R., A. R. Pierce, and G. B. Noe. 2009. Floodplain geomorphic processes and environmental impacts of uman alteration along coastal plain rivers, USA. *Wetlands* 29 (2):413-429.

Hutchinson, J. T., E. S. Menges, R. L. Pickert, and H. M. Swain. 2003. Fire management at Archbold Biological Station: Burning to promote heterogeneity, conservation, research, and education Paper read at Second International Wildland Fire Ecology and Fire Management Congress and Fifth Symposium on Fire and Forest Meteorology, 16-20 November 2003, at Orlando, FL.

Isendahl, C. 2010. The Anthropocene forces us to reconsider adaptationist models of human-environment interactions. *Environmental Science & Technology* 44 (16):6007-6007.

Johnston, C. A., N. E. Detenbeck, and G. J. Niemi. 1990. The cumulative effect of wetlands on stream water quality and quantity. A landscape approach. *Biogeochemistry* 10 (2):105-141.

Keller, C., C. Robbins, and J. Hatfield. 1993. Avian communities in riparian forests of different widths in Maryland and Delaware. *Wetlands* 13 (2):137-144.

Kellison, R. C., M. J. Young, R. R. Braham, and E. J. Jones. 1998. Major alluvial floodplains. Chapter 12. In *Southern forested wetlands:Ecology and management*, ed. M. G. Messina and W. H. Conner. Boca Raton, Fla.: Lewis Publishers.

Kilgo, J. C., R. A. Sargent, K. V. Miller, and B. R. Chapman. 1997. Landscape influences on breeding bird communities in hardwood fragments in South Carolina. *Wildlife Society Bulletin* 25 (4):878-885.

Klimas, C., E. Murray, T. Foti, J. Pagan, M. Williamson, and H. Langston. 2009. An ecosystem restoration model for the Mississippi Alluvial Valley based on geomorphology, soils, and hydrology. *Wetlands* 29 (2):430-450.

Klimas, C. V., E. O. Murray, J. Pagan, H. Langston, and T. Foti. 2005. *A regional guidebook for applying the hydrogeomorphic approach to assessing wetland functions of forested wetlands in the West Gulf Coastal Plain Region of Arkansas*. ERDC/EL TR-05-12, U.S. Army Engineer Research and Development Center, Ecosystem Management and Restoration Research Program, Vicksburg, MS.

Kuenzler, E. J., P. J. Mulholland, L. A. Ruley, and R. P. Sniffen. 1977. *Water Quality of North Carolina Coastal Plain Streams and Effects of Channelization*. UNC-WRRI-77-127 W78-04707 OWRT-B-084-NC(2).

Laan, R., and B. Verboom. 1990. Effects of pool size and isolation on amphibian communities. *Biological Conservation* 54 (3):251-262.

LaSage, D. M., J. L. Sexton, A. Mukherjee, A. E. Fryar, and S. F. Greb. 2008. Groundwater discharge along a channelized Coastal Plain stream. *Journal of Hydrology* 360 (1-4):252-264.

Leigh, D. S. 2006. Terminal Pleistocene braided to meandering transition in rivers of the Southeastern USA. *Catena* 66 (1-2):155-160.

_____. 2008. Late Quaternary climates and river channels of the Atlantic Coastal Plain, Southeastern USA. *Geomorphology* 101 (1-2):90-108.

Leigh, D. S., H. K. LaMoreaux, G. A. Brook, and J. A. Knox. 2009. Late Pleistocene and Holocene environments of the Southeastern United States from the stratigraphy and pollen content of a peat deposit on the Georgia Coastal Plain. *Palaeogeography, Palaeoclimatology, Palaeoecology* 280 300-312.

Leigh, D. S., P. Srivastava, and G. A. Brook. 2004. Late Pleistocene braided rivers of the Atlantic Coastal Plain, USA. *Quaternary Science Reviews* 23 (1-2):65-84.

Leopold, L. B. 1994. *A view of the river*. Cambridge, MA: Harvard University Press.

Leopold, L. B., M. G. Wolman, and J. P. Miller. 1964. *Fluvial processes in geomorphology*. San Francisco, CA, USA: W.H. Freeman and Co.

Light, H. M., K. R. Vincent, M. R. Darst, and F. D. Price. 2006. *Water level decline in the Apalachicola River, FL from 1954 to 2004, and effects on floodplain habitats*. Scientific Investigations Report 2006-5143. Reston, VA: U.S. Geological Survey.

Loeb, S. C. 1993. The role of coarse woody debris in the ecology of southeastern mammals. In *Biodiversity and coarse woody debris in southern forests*, ed. J. W. Mcminn and D. A. Crossley: U.S. Department of Agriculture, Forest Service, Southern Research Station.

MacArthur, R. H., and J. W. MacArthur. 1961. On Bird Species Diversity. *Ecology* 42 (3):594-598.

Magilligan, F. J., and K. H. Nislow. 2005. Changes in hydrologic regime by dams. *Geomorphology* 71:61-78.

Mausbach, M. J., and J. L. Richardson. 1994. Biogeochemical processes in hydric soil formation. *Current topics in wetland biogeochemistry* 1:68-127.

McKay, K. S., and J. C. Fischenich. 2011. *Robust prediction of hydraulic roughness*. CHETN-VII-11. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

McKinney, M. L. 2002. Urbanization, Biodiversity, and Conservation. *BioScience* 52 (10):883-890.

McWilliams, S. R., and M. D. Bachmann. 1988. Using life history and ecology as tools to manage a threatened salamander species. *Journal of the Iowa Academy of Science* 95 (2):66-71.

Miller, J. H. 2003. Nonnative invasive plants of southern forests: A field guide for identification and control. Gen. Tech. Rep. SRS-62. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station.

Mitch, P. P., and J. G. Gosselink. 1993. *Wetlands*. New York: Van Nostrand Reinhold.

Miwa, M., D. L. Gartner, C. S. Bunton, R. Humphreys, and C. C. Trettin. 2003. *Characterization of headwater stream hydrology in the southeastern lower coastal plain*. IAG#: DW12945840-01-0. Charleston, SC: USDA Forest Service.

Mulholland, P. J. 1981. Organic Carbon Flow in a Swamp-Stream Ecosystem. *Ecological Monographs* 51 (3):307-322.

Nilon, C. H. 1986. Quantifying small mammal habitats along a gradient of urbanization. Ph.D. dissertation, State University of New York.

Nilon, C. H., and L. W. VanDruff. 1987. Analysis of small mammal community data and applications to management of urban greenspaces. In *Integrating man and nature in the metropolitan environment*, ed. L. W. Adams and D. L. Leedy. Columbia, MD: National Institute for Urban Wildlife.

Noble, C. V., E. O. Murray, C. V. Klimas, and W. Ainslie. 2011. *Regional guidebook for applying the hydrogeomorphic approach to assessing the functions of headwater lope wetlands on the South Carolina Coastal Plain*. ERDC/EL TR-11-11. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Noble, C. V., J. S. Wakeley, T. H. Roberts, and C. Henderson. 2007. *Regional Guidebook for applying the hydrogeomorphic approach to assessing the functions of headwater slope wetlands on the Mississippi and Alabama Coastal Plains*. ERDC/EL TR-07-9. Vicksburg, MS: U.S. Army Engineer Research and Development Center,.

Novitski, R. P. 1978. Hydrogeological characteristics of Wisconsin's wetlands and their influences on floods, stream flow, and sediment. Chapter. In *Wetland functions and values: The state of our understanding*, ed. P. E. Greeson, J. R. C. Clark and J. E. Clark. Minneapolis, MN: American Water Resources Association.

O'Driscoll, M., J. Soban, and S. Lecce. 2009. Stream channel enlargement response to urban land cover in small coastal plain watersheds, North Carolina. *Physical Geography* 30 (6):528-555.

O'Driscoll, M., S. Clinton, A. Jefferson, A. Manda, and S. McMillan. 2010. The effects of urbanization on streams in the southern U.S.: A Review *Water* 2:605-648.

Ogawa, H., and J. W. Male. 1983. *The flood mitigation potential of inland wetlands*. Publication Number 138. Amherst, MA: Water Resources Center.

Ostry, R. C. 1982. Relationship of water quality and pollutant loads to land uses in adjoining watersheds. *JAWRA Journal of the American Water Resources Association* 18 (1):99-104.

Oswalt, S. N., and S. L. King. 2005. Channelization and floodplain forests: Impacts of accelerated sedimentation and valley plug formation on floodplain forests of the Middle Fork Forked Deer River, Tennessee, USA. *Forest Ecology and Management* 215 (1-3):69-83.

Ovington, J. D. 1965. Organic production, turnover and mineral cycling in woodlands. *Biological Review* 40:772-785.

Patton, P. C. 1988. Drainage basin morphometry and floods. Chapter. In *Flood geomorphology*, ed. V. R. Baker, R. C. Kochel and P. C. Patton. New York: John Wiley.

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

Phillips, J. 1997. Human Agency, Holocene Sea Level, and Floodplain Accretion in Coastal Plain Rivers. *Journal of Coastal Research* 13 (3):854-866.

Pinckney, J. L., H. W. Paerl, P. Tester, and T. L. Richardson. 2001. The Role of Nutrient Loading and Eutrophication in Estuarine Ecology. *Environmental Health Perspectives* 109 (Supplement 5: Pfiesteria: From Biology to Public Health):699-706.

Pomeroy, L. R. 1970. The strategy of mineral cycling. *Annual Review of Ecology and Systematics* 1:171-190.

Pugh, G., and C. H. Dickinson. 1974. *Biology of plant litter decomposition. Volume II* London: Academic Press.

Reiners, W. A. 1972. Terrestrial detritus and the carbon cycle. In *Carbon and the biosphere, Conference Proceedings 720510*, ed. by G. M. Woodwell and E. V. Pecan: U.S. Atomic Energy Commission.

Rheinhardt, R., and C. Hershner. 1992. The relationship of below-ground hydrology to canopy composition in five tidal freshwater swamps. *Wetlands* 12 (3):208-216.

Rheinhardt, R. D., M. M. Brinson, and P. M. Farley. 1997. Applying wetland reference data to functional assessment, mitigation, and restoration. *Wetlands* 17 (2):195-215.

Rheinhardt, R. D., M. C. Rheinhardt, M. M. Brinson, and K. Faser. 1998. Forested wetlands of low order streams in the inner coastal plain of North Carolina, USA. *Wetlands* 18 (3):365-378.

Rheinhardt, R. D., M. C. Rheinhardt, M. M. Brinson, and K. Faser. 1999. Application of Reference Data for Assessing and Restoring Headwater Ecosystems. *Restoration Ecology* 7:241-251.

Riitters, K. H., J. D. Wickham, R. V. O'Neill, K. B. Jones, E. R. Smith, J. W. Coulston, T. G. Wade, and J. H. Smith. 2002. Fragmentation of Continental United States Forests. *Ecosystems* 5 (8):0815-0822.

Ritter, D. F., R. C. Kochel, and J. R. Miller. 1995. *Process geomorphology*. Chicago, IL: William C. Brown.

Robertson, K. M. 2006. Distributions of tree species along point bars of 10 rivers in the southseastern U.S. Coastal Plain. *Journal of Biogeography* 33 (1):121-132.

Robertson, P. A., M. D. MacKenzie, and L. F. Elliott. 1984. Gradient analysis and classification of the woody vegetation for four sites in southern Illinois and adjacent Missouri. *Vegetation* 58:87-104.

Robertson, P. A., G. T. Weaver, and J. A. Cavanaugh. 1978. Vegetation and tree species patterns near the northern terminus of the southern floodplain forest. *Ecological monographs* 48:249-267.

Rothermel, B. B., and R. D. Semlitsch. 2002. An experimental investigation of landscape resistance of forest versus old-field habitats to emigrating juvenile amphibians. *Conservation Biology* 16 (5):1324-1332.

Rudis, V. A. 1995. Regional forest fragmentation effects on bottomland hardwood community types and resource values. *Landscape Ecology* 10 (5):291-307.

Saucier, R. T. 1994. *Geomorphology and quaternary geologic history of the Lower Mississippi Valley, Vol I (report), Vol II (map folio)*. Vicksburg MS: U.S. Army Engineer Waterways Experiment Station.

Schlesinger, W. H. 1977. Carbon balance in terrestrial detritus. *Annual Review of Ecology and Systematics* 8 (ArticleType: research-article / Full publication date: 1977 / Copyright © 1977 Annual Reviews):51-81.

Schlosser, I. J. 1991. Stream fish ecology: A landscape pPerspective. *BioScience* 41 (10):704-712.

Schoener, T. W. 1986. Resource partitioning. Chapter. In *Community ecology: Patterns and processes*, ed. J. Kikkawa and D. J. Anderson. Melbourne: Blackwell.

Schroeder, R. L. 1985. *Eastern wild turkey*. Biological Report 82(10.106). Washington, DC: U. S. Fish and Wildlife Service.

Sechnick, C. W., R. F. Carline, R. A. Stein, and E. T. Rankin. 1986. Habitat Selection by Smallmouth Bass in Response to Physical Characteristics of a Simulated Stream. *Transactions of the American Fisheries Society* 115:314-321.

Sedell, J. R., J. E. Richey, and F. J. Swanson. 1989. The river continuum concept: A basis for the expected ecosystem behavior of very large rivers. *Canadian Journal of Fisheries and Aquatic Sciences* (46):49-55.

Semlitsch, R. D. 1998. Biological delineation of terrestrial buffer zones for pond-breeding salamanders. *Conservation Biology* 12 (5):1113-1119.

Semlitsch, R. D., and J. R. Bodie. 1998. Are small, isolated wetlands expendable? *Conservation Biology* 12 (5):1129-1133.

———. 2003. Biological criteria for buffer zones around wetlands and riparian habitats for amphibians and reptiles. *Conservation Biology* 17 (5):1219-1228.

Semlitsch, R. D., and J. B. Jensen. 2001. Core habitat, not buffer zone. *National Wetlands Newsletter* 23 (4):5-6.

Shafer, D. J., and D. J. Yozzo. 1998. *National guidebook for application of hydrogeomorphic assessment to tidal fringe wetlands*. Technical Report WRPDE-16. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

Shahane, A. N. 1982. Estimation of pre- and post-development nonpoint water quality loadings. *JAWRA Journal of the American Water Resources Association* 18 (2):231-237.

Shankman, D. 1993. Channel migration and vegetation patterns in the Southeastern Coastal Plain. *Conservation Biology* 7 (1):176-183.

Shields, F. D., S. S. Knight, and C. M. Cooper. 1997. Rehabilitation of warmwater stream ecosystems following channel incision. *Ecological Engineering* 8 (2):93-116.

Singh, J., and S. Gupta. 1977. Plant decomposition and soil respiration in terrestrial ecosystems. *The Botanical Review* 43 (4):449-528.

Smith, D. R., A. Ammann, C. Bartoldus, and M. M. Brinson. 1995. *An approach for assessing wetland functions using hydrogeomorphic classification, reference wetlands, and functional indices*. Technical Report WRP-DE-9. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

Smith, R. D., and C. V. Klimas. 2002. *A regional guidebook for applying the hydrogeomorphic approach to assessing wetland functions of selected regional wetland subclasses, Yazoo Basin, Lower Mississippi River Alluvial Valley*. ERDC/EL TR-02-4. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Smith, R. D., and C. V. Noble. *Hydrogeomorphic (HGM) approach to assessing wetland functions: Guidelines for developing guidebooks (Version 2)*. In preparation. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Snyder, N. J., S. Mostaghimi, D. F. Berry, R. B. Reneau, and E. P. Smith. 1995. Evaluation of a riparian wetland as a naturally occurring decontamination zone. Paper read at Clean water, clean environment - 21st century : team agriculture, working to protect water resources March 5-8, 1995, at Kansas City, MO.

Spight, T. M. 1968. The water economy of salamanders: Evaporative water loss. *Physiological Zoology* 41 (2):195-203.

Spurr, S. H., and B. V. Barnes. 1981. *Forest ecology*. New York: John Wiley and Sons.

Stallins, J. A., M. N. Nesius, M. Smith, and K. Watson. 2010. Biogeomorphic characterization of floodplain forest change in response to reduced flows along the Apalachicola River, Florida *River Research and Applications* 26:242-260.

Stauffer, F., and L. B. Best. 1980. Habitat selection by birds of riparian communities: evaluating effects of habitat alterations. *The Journal of Wildlife Management* 44 (1):1-15.

Stein, E. D., and R. F. Ambrose. 2001. Landscape-scale analysis and management of cumulative impacts to riparian ecosystems: Past, present, and future. *Journal of the American Water Resources Association* 37 (6):1597-1614.

Stewart, R. E., and H. A. Kantrud. 1971. *Classification of natural ponds and lakes in the glaciated prairie region*. Resource Publication 92. Washington, DC: U.S. Fish and Wildlife Service.

Strahler, A. N. 1952. Dynamic basis of geomorphology. *Geological Society of America Bulletin* 63 (9):923.

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

Strelke, W. K., and J. G. Dickson. 1980. Effect of forest clear-cut edge on breeding birds in East Texas. *The Journal of Wildlife Management* 44 (3):559-567.

Suther, B., D. Leigh, and G. Brook. 2011. Fluvial terraces of the Little River Valley, Atlantic Coastal Plain, North Carolina. *Southeastern Geology* 48:73-93.

Sylvia, D. A., and W. E. Galloway. 2006. Morphology and stratigraphy of the late Quaternary lower Brazos valley: Implications for paleo-climate, discharge and sediment delivery. *Sedimentary Geology* 190:159-175.

Terry, J. E., R. L. Hosman, and C. T. Bryant. 1979. *Summary appraisals of the nation's ground-water resources - Lower Mississippi Region* U.S. Geological Survey Professional Paper 813-N.

Thomas, D. M., and M. A. Hanson. 1981. *Generalization of streamflow characteristics from drainage-basin characteristics*. Water Supply Paper 1-55. Washington, DC: U.S. Geological Survey.

Townsend, P. A. 2001. Relationships between vegetation patterns and hydroperiod on the Roanoke River floodplain, North Carolina. *Plant Ecology* 156 (1):43-58.

Tritton, L. M., and J. W. Hornbeck. 1982. *Biomass equations for major tree species the northeast*. General Technical Report NE-69. Northeast Forest Experiment Station: U.S. Forest Service.

U.S. Forest Service. 1980. *Wildlife habitat management handbook, southern region*. FSH-2609.23R. Washington, DC: U. S. Forest Service.

U.S. Department of Agriculture, Forest Service. 2010a. *The foreset inventory and analysis database: Database description and users manual version 4.0 for phase 2*. Draft, Revision 3. U.S. Forest Service.

———. 2011. *The forest inventory and analysis phase 3 indicators database 5.1: Description and users manual*. October, 2011. Department of Agriculture, U.S. Forest Service.

U.S. Department of Agriculture, Natural Resources Conservation Service. 1986. *Urban hydrology for small watersheds*. Technical Release 55 (TR-55). Washington, DC: U.S. Department of Agriculture.

———. 2010b. *Field indicators of hydric soil in the United States, Version 7.0*. L.M. Vasilas, G.W. Hurt, and C.V. Noble (eds.): USDA, NRCS, in cooperation with the National Technical Committee for Hydric Soils.

VanDruff, L. W., E. G. Bolen, and G. J. S. Julian. 1996. Management of urban wildlife. Chapter. In *Research and management techniques for wildlife and habitats, Fifth edition*, ed. T. A. Bookhout. Bethesda, MD: The Wildlife Society.

VanDruff, L. W., and R. N. Rowse. 1986. Habitat association of mammals in Syracuse, New York. *Urban Ecology* 9 (3–4):413-434.

Vannote, R. L. 1980. The river continuum concept. *Canadian Journal of Fisheries and Aquatic Sciences* 37 (1):130.

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

Waddell, K. L. 2002. Sampling coarse woody debris for multiple attributes in extensive resource inventories. *Ecological Indicators* 1 (3):139-153.

Wakeley, J. S., and T. H. Roberts. 1996. Bird distributions and forest zonation in a bottomland hardwood wetland. *Wetlands* 16 (3):296-308.

Wharton, C. H., W. M. Kitchens, E. C. Pendleton, and T. W. Sipe. 1982. *The ecology of bottomland hardwood swamps of the Southeast: A community profile*. FWS/OBS-81/37.

Wharton, C. H., H. Odum, K. Ewel, M. Duever, and A. Lugo. 1977. *Forested wetlands of Florida-their management and use*. Gainesville Report DSP-BCP-19-77. Gainesville, FL: Center for Wetlands, University of Floriday, Gainesville.

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

Whittaker, R. H., F. H. Bormann, G. E. Likens, and T. G. Siccama. 1974. The Hubbard Brook ecosystem study: Forest biomass and production. *Ecological Monographs* 44 (2):233-254.

Wickham, J. D., K. H. Riitters, T. G. Wade, and J. W. Coulston. 2007. Temporal change in forest fragmentation at multiple scales. *Landscape Ecology* 22 (4):481-489.

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

Wilcove, D. S. 1985. Nest predation in forest tracts and the decline of migratory songbirds. *Ecology* 66 (4):1211-1214.

Wilder, T. C., C. D. Piercy, and T. M. Swannack. 2012. *Review of flow regulation scenarios at John H. Kerr Reservoir and effects on the lower Roanoke River floodplain - Report to the U.S. Army Corps of Engineers - Wilmington District*. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Wilder, T. C., and T. H. Roberts. 2002. *A regional guidebook for applying the hydrogeomorphic approach to assessing wetland functions of Low-Gradient Riverine Wetlands in Western Tennessee*. ERDC/EL TR-02-6. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Wilder, T. C., and T. H. Roberts. 2005. A comparison of tree species composition in bottomland hardwoods adjacent to channelized and unchannelized rivers in western Tennessee. Chapter. In *Ecology and management of bottomland hardwood systems: the state of our understanding*. Puxico, MO: University of Missouri-Columbia, Gaylord Memorial, Laboratory. Original edition, Special Publication No. 10.

Williams, H. M., A. J. Miller, R. S. McNamee, and C. V. Klimas. 2010. *A regional guidebook for applying the hydrogeomorphic approach to the functional assessment of forested wetlands in Alluvial Valleys of East Texas*. ERDC/EL TR-10-17. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Wohl, E. E. 2000. *Mountain rivers*: American Geophysical Union Washington, DC.

Woodall, C. W., and V. J. Monleon. 2008. *Sampling protocol, estimation, and analysis procedures for the down woody materials indicator of the FIA program*. Gen. Tech. Rep. NRS-22. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station.

Young, R. A., T. Huntrods, and W. Anderson. 1980. Effectiveness of vegetated buffer strips in controlling pollution from feedlot runoff. *J. Environ. Qual.* 9 (3):483-487.

Zarbock, H., A., D. W. Janicki, D. Heimbuch, and H. Wilson. 1994. *Estimates of total nitrogen, total phosphorus, and total suspended solids loadings to Tampa Bay, Florida*. St. Petersburg, FL: T. B. N. E. Program.

Zedler, J. B., and S. Kercher. 2004. Causes and consequences of nvasive plants in wetlands: Opportunities, opportunists, and outcomes. *Critical Reviews in Plant Sciences* 23 (5):431-452.

Appendix A: 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 (Figure D3).

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).

Assessment Team (A-Team): 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.

Catchment: The geographic area where surface water would flow or run off into the headwater wetland.

Curve number: A dimensionless parameter that varies from 0 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): Tree diameter measured at 1.4 m (55 in.) above the ground.

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

Exotics: See Invasive species.

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

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

Functional Capacity Index (FCI): An index of the capacity of a wetland to perform a function comparable to other wetlands in a regional wetland subclass. Functional Capacity Indices are by definition scaled from 0.0 to 1.0. An index of 1.0 indicates the wetland is performing a function at the highest sustainable functional capacity, the level equivalent to a wetland under reference standard conditions in a 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 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 m (39 in.) tall.

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 highest sustainable functional capacity is achieved when a wetland ecosystem and the surrounding area are undisturbed.

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 Soil Group: Soils are classified by the Natural Resources Conservation Service into four groups based on the soil's runoff potential. The four groups are A, B, C, and D. Soils in group A have the least runoff potential and soils in group D have the highest runoff potential.

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

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 altered by direct impacts.

Indirect measure: A qualitative measure of an assessment model variable that corresponds to an identifiable variable condition.

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

Jurisdictional wetland: Areas that meet the soil, vegetation, and hydrologic criteria described in the "Corps of Engineers Wetlands Delineation Manual" (Environmental Laboratory 1987) or its successor. Not all wetlands are regulated under Section 404.

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 as a result of project impacts.

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

Model variable: A 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 of 18 percent or more with 60 percent or more clay, or 12 percent or more organic carbon with 0 percent clay. Soils with an intermediate amount of clay have an intermediate amount of organic carbon. If the soil is never saturated for more than a few days, it contains 20 percent or more organic carbon.

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 disturbance.

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

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

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

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

Reference domain: All 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 highest level of functioning (highest sustainable capacity) across the suite of functions of the regional wetland subclass. By definition, highest 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.

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

Sapling/shrub layer: For the purposes of this guidebook, the vegetation layer consisting of self-supporting woody plants greater than 1 m (39 in.) in height but less than 15 cm (6 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 disturbance history, land use, or other factors. Site capacity may be equal to or less than levels of functioning established by reference standards for the reference domain, and it may be equal to or less than the functional capacity of 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.

Value of wetland function: The relative importance of wetland function or functions to 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 404: "……. 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, or simply, the things that wetlands do. 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 function in a degraded wetland. Restoration is typically done as mitigation.

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):

Wetland Assessment Area (WAA) ID Number	HGM Subclass	WAA Size (ha)	Number of plots sampled	Attached Data Forms and Summary Forms			
				Data Forms (number attached)			FCI/FCU Calculator Output (from spreadsheet)
				WAA or Tract Data (1 per WAA)	Plot Data (sets of 2 sheets per plot)	WAA Plot Data Summary (from spreadsheet)	

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 (length of ≥ 20 m (50 ft))	Metric is preferred. More than one will be useful for measuring multiple variables simultaneously.
DBH tape, DBH calipers or Biltmore Stick™	Metric is preferred. For the measurement of tree diameter.
Folding Rule	A folding rule, small tape, or DBH tape or calipers is necessary for measuring the diameter of logs, or in the Headwater Slope Subclass, a folding rule is necessary for measuring the height of obstructions or depth of ditches.
Shovel	Although soils profile characteristics are not assessed in the protocol of this guidebook, information gained from the examination of soils may be helpful in determining subclass. For example, an assessment area may be in a portion of the watershed where Headwater Slope (groundwater dominated) wetlands grade into Mid-gradient Riverine (stream flooding dominated) wetlands. Evidence in the soil profile, such as the layering of organic material with fluvial sediments may indicate the dominance of one hydrology source over another. Examination of groundwater levels in areas that have been ditched may also serve in bounding PWAAs. Shovels are also useful in anchoring distance tapes at the plot center.
Spirit level and string	A small spirit level (such as a string level) and a length of string will be useful in determining depths of ditches or heights of obstructions.
Plant identification guides	The correct identification of woody species, invasive and exotic species is necessary.
Data forms	See data forms requirements table (bringing extra forms to the field are often a good idea).
Plot layout diagram	Appendix B3.
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 by the use of maps and aerial photos .
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.
Miscellaneous	Clipboards, pencils, notebooks, flagging, insect repellant, drinking water, etc

APPENDIX B2

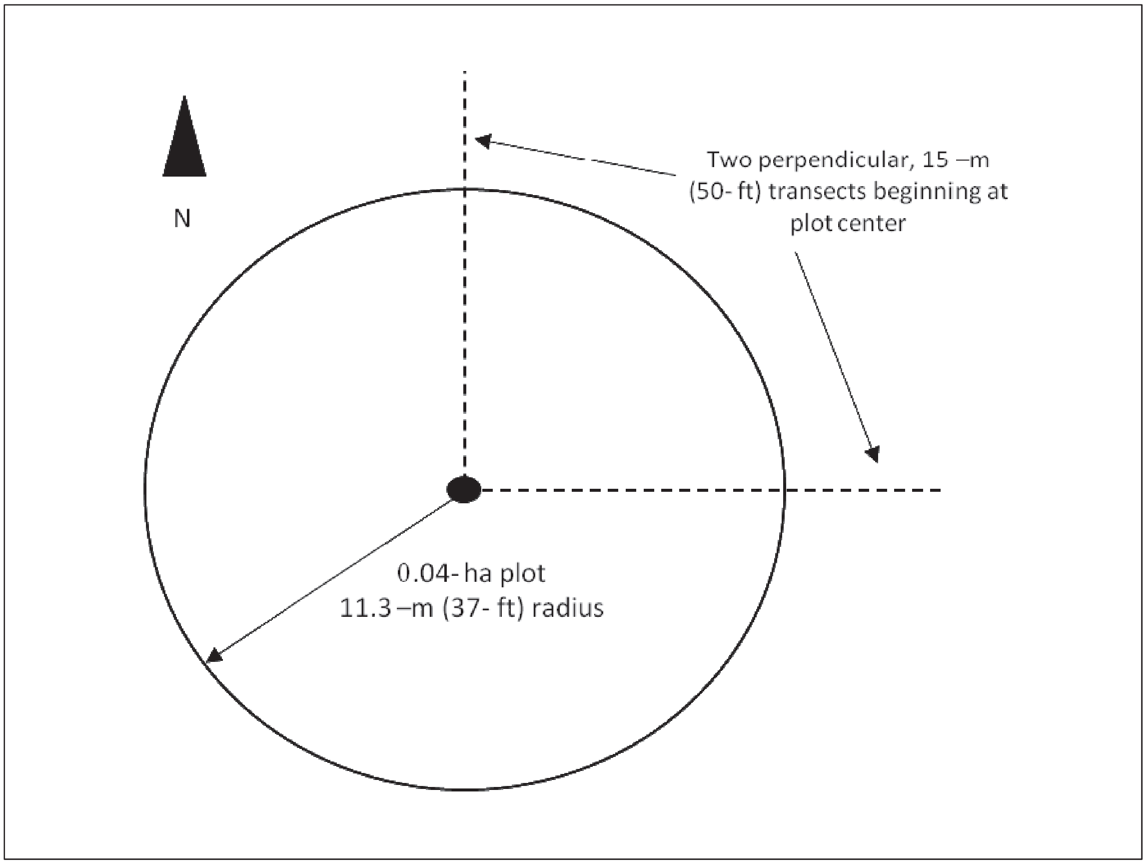
DATA FORM REQUIREMENTS

Print or copy the following data forms (Data Forms 1 and 2 are found in Appendix B). Minimum number of copies is indicated but extra copies are always a good idea. When printing the forms from the FCI/FCU calculating spreadsheet, be sure that the appropriate subclass is selected from the options on the spreadsheet.

Data Form	Minimum Number of Copies Required
Project or Site Description and Assessment Documentation (1 page)	1
Data Sheet 1 – Tract and WAA-Level Variables (1page)	1 per WAA
Data Sheet 2 – (2 pages per set)	Multiple sets. The number depends on the number of plots necessary to characterize the variability of each wetland assessment area (see Chapter 5)

APPENDIX B3

PLOT LAYOUT DIAGRAM



Appendix C: Field Data Forms

Headwater Slope

Mid-gradient and Low-gradient Riverine

Connected Depression

Headwater Slope Wetlands data sheets

Southeastern Coastal Plain HGM Field Data Sheet and Calculator
Site and WAA Data Form for Headwater Slope Wetlands, Page 1 of 2

Team: WAA Number:

Project Name:

Location: Sampling Date:

Top Strata in WAA (trees, sapling/shrub, herbs): Select Strata Project/Mitigation Site (circle one) Before/After Project (circle one)

Sample Variables 1-6 using aerial photography, topographic maps, soil survey maps, etc. or a walkover of the entire WAA, as appropriate.

1 V_{CATCH} Percent change in the size of the catchment (If there is no water diversion or augmentation in the catchment, percent change = 0). **Used in Headwater Slopes Only.**

Size of original Catchment

If diversion: Size of current catchment

If augmentation: Size of catchment from which water is being diverted.

2 V_{UPUSE} Weighted Average of Runoff Score for Catchment. **Used in Headwater Slopes Only.**

☐ **Check here if catchment is >75% in native vegetation. Other calculations are not necessary if this is the case.**

Land Use (Choose From Drop List)	Soil Group (Choose From Drop List)	Runoff Score	% in Catchment	Running Percent (not >100)

3a $V_{CONNECT}$ **For Headwater Slopes.** Percent of wetland perimeter connected to suitable habitat, adjusted for width of buffer (buffer must be at least 10 meters wide).

☐ **Check here if >90% of the perimeter is clearly buffered by at least 150m of suitable habitat; no further calculations are necessary.**

Total length of wetland perimeter (meters)

Length of wetland perimeter with suitable habitat at least 10m wide (meters)

Average width of suitable habitat buffer (meters)

3b $V_{CONNECT}$ **For Riverine Subclasses.** Percent of assessment area reach with suitable habitat. Not Used

Determine Assessment Area Reach:

Width of alluvial valley associated with WAA (meters) (three measurements)

Avg:

Enter valley width measurements

Enter valley width measurements

Enter valley width measurements

4 $V_{SOILINT}$ Soil integrity. Estimate the percentage of the site that has significantly altered soils. Normal farm tillage is not considered a significant alteration in this case, but fill, excavation, land leveling that removes surface horizons, and compacted areas such as roads are counted.

Southeastern Coastal Plain HGM Field Data Sheet and Calculator
Site and WAA Data Form for Headwater Slope Wetlands, Page 2 of 2

Project Name: ____________________ WAA Number: ________

5 **$V_{HYDROSYS}$** **Used in Riverine Subclasses Only.** System Hydrologic Alterations. It represents the capacity of a stream network above a wetland to deliver floodwaters to it. The variable expresses departure from the system's natural capacity. In the absence of other data, it can be estimated by the comparison to qualitative statements. If more precise data are available, check the box and enter an index between 0 and 1. The index represents the proportion of similarity to natural conditions. Attach supporting documentation to this form.

Not Used

☐ **Check here if using external data, and select type below:** Enter Index:

☐ Stream gage data ☐ Hydrologic modeling data

☐ Channel characteristics (e.g., regional dimensionless rating curves, channel width/watershed width, sinuosity)

If no external data are available, select one of the following (select top circle to print blank form):

●	**Hydrologic Condition**	**Indicators**
○	Natural stream hydrology	Clear evidence of overbank flooding such as drift lines, highwater marks, etc. and floodwater exchange with stream channel. Stream flow is natural (e.g. no large reservoirs regulating flow. No clear evidence of channel incision).
○	Altered stream hydrology	Stream flow is regulated or channel is deeply incised (both conditions may be present). Evidence of overbank flooding and floodwater exchange with stream channel is present but durations and frequencies of floodwater exchange have been reduced or increased from the natural condition.
○	Hydrologically isolated – floodwater exchange with floodplain rarely or never occurs	Anthropogenic changes have resulted in the elimination of all or nearly all overbank flooding. Examples of this condition include streams with deeply incised channels (channelized system) or streams with regulated flow.

6a **$V_{HYDROALT}$** **Used in Headwater Slopes Only.** Hydrologic Alteration within the WAA. Height of obstruction, depth of ditch, or depth of impounded water. (cm)

Enter height of obstruction or depth of ditch (cm):

6b **$V_{HYDROALT}$** **Used in Riverine Subclasses Only.** Hydrologic Alteration within the WAA. This variable is defined as man-induced alterations to the natural hydrology of the wetland due to activities within the wetland assessment area.

Not Used

Select one of the following (select top circle to print blank form):

●	**Hydrologic Condition**	**Indicators**
○	Natural hydrology	Clear evidence of overbank flooding (such as drift lines, highwater marks, etc.) and floodwater exchange with stream channel. No evidence of effective ditches and levees.
○	Surface hydrology modified	Site has either drainage works or obstructions to floodwater exchange with the stream, or a combination of both are present. Evidence of overbank flooding and floodwater exchange with stream channel is present. Modifications may be those intended to either reduce or increase duration or frequency of inundation at the site (departure from natural conditions, either wetter or drier, is considered an adverse impact).
○	Hydrologically isolated –rarely inundated	Primary characteristic of this condition is that anthropogenic changes have resulted in the disconnection or isolation of the wetland from overbank flooding.
○	Hydrologically isolated – never inundated by stream flow	The site is isolated due to levee systems such that overbank flow never reaches the site.

Southeastern Coastal Plain HGM Field Data Sheet and Calculator
Plot Data Form for Headwater Slope Wetlands, Page 1 of 2

Team:

UTM Easting:

Project Name:

UTM Northing:

Location:

Sampling Date:

WAA Number: Plot Number: of

Plot Area (0.04 ha is standard): 0.04

Top Strata in WAA (trees, sapling/shrub, herbs): Select Stratum

Project/Mitigation Site (circle one)

Before/After Project (circle one)

Sample Variables 7-12 within one or more representative 0.04-ha (0.1-acre) plot(s) within the WAA (use a separate data sheet for each)

7	V_{BIG3}	Average dbh of three largest-diameter canopy trees(defined as live trees >15 cm dbh) in plot. Measure only if total tree cover is at least 20%. List the dbh measurements of three largest canopy trees (at least 15cm): Tree 1: Tree 2: Tree 3:	
8	V_{CTDEN}	Average number of canopy trees per ha (=canopy trees in 0.04 ha plot x 25) Enter number of canopy trees located in the plot:	
9	V_{SSC}	Average percentage cover of saplings/shrubs (measure only if site tree cover is <20% and site sapling/shrub cover >20%). Subplot 1: Subplot 2: Subplot 3: Subplot 4:	
10	V_{GVC}	Average percentage cover of ground-layer vegetation (measure only if tree and sapling/shrub cover are each <20%) Subplot 1: Subplot 2: Subplot 3: Subplot 4:	
11	V_{WD}	Large Woody Debris biomass. Volume per hectare of non-living large woody stems (m^3/ha).	

	Transect 1	Transect 2
Enter diameters (cm) of each fallen woody stem 7.6 cm (3 inches) or greater in diameter in each 50-foot transect. Leaning dead stems that intersect the sampling plane are sampled. Dead trees and shrubs still supported by their roots are not sampled. Rooted stumps are not sampled, but uprooted stumps are sampled. Down stems that are decomposed to the point where they no longer maintain their shape but spread out on the ground are not sampled. ☐ Check here if there are no logs.		

Southeastern Coastal Plain HGM Field Data Sheet and Calculator
Plot Data Form for Headwater Slope Wetlands, Page 2 of 2

Project Name: WAA Number: Plot Number: 0

12 V_{COMP} Vegetation Composition. Check all dominant species (using the 50/20 rule) in the tallest stratum. Check all exotics and invasives, including non-dominants, in all strata on plot. Spaces are available for write-ins, and justification can be added in the Notes.

☐ **This checkbox is not used for the Headwater Slope subclass.**

Group 1 = 1.0		Group 2 = 0.66	Groups 3 = 0.00
☐ *Acer rubrum*	☐ *Quercus pagoda*	☐ *Carpinus caroliniana*	☐ *Albizia julibrissin*
☐ *Carya aquatica*	☐ *Quercus phellos*	☐ *Carya myristiciformis*	☐ *Alternanthera philoxeroides*
☐ *Carya tomentosa*	☐ *Taxodium distichum*	☐ *Carya ovata*	☐ *Cyperus iria*
☐ *Fraxinus caroliniana*	☐ *Ulmus americana*	☐ *Celtis laevigata*	☐ *Echinochloa crus-galli*
☐ *Fraxinus pennsylvanica*	☐	☐ *Crataegus spp.*	☐ *Imperata cylindrica*
☐ *Fraxinus profunda*	☐	☐ *Diospyros virginiana*	☐ *Ligustrum japonicum*
☐ *Liriodendron tulipifera*	☐	☐ *Ilex opaca*	☐ *Ligustrum sinense*
☐ *Magnolia virginiana*	☐	☐ *Liquidambar styraciflua*	☐ *Lonicera japonica*
☐ *Nyssa aquatica*	☐	☐	☐ *Lygodium japonicum*
☐ *Nyssa biflora*	☐	☐	☐ *Microstegium vimineum*
☐ *Persea borbonia*	☐	☐	☐ *Panicum repens*
☐ *Persea palustris*	☐	☐	☐ *Pueraria montana*
☐ *Pinus glabra*	☐	☐	☐ *Sorghum halepense*
☐ *Pinus taeda*	☐	☐	☐ *Triadica sebifera*
☐ *Quercus alba*	☐	☐	☐ *Verbena brasiliensis*
☐ *Quercus laurifolia*	☐	☐	☐
☐ *Quercus michauxii*	☐	☐	☐
☐ *Quercus nigra*	☐	☐	☐
0 Species in Group 1		0 Species in Group 2	0 Species in Group 3

Initial Quality Index: Adjusted Quality Index:

Summary: Plot Number 0

Variable	Value	VSI
V_{CATCH}	NA	NA
V_{UPUSE}		
$V_{CONNECT}$		
Avg. width		
$V_{SOILINT}$		
$V_{HYDROSYS}$		
$V_{HYDROALT}$		
V_{BIG3}		
V_{CTDEN}		
V_{SSC}		
V_{GVC}		
V_{WD}		
V_{COMP}		

Notes:

Mid- and Low-gradient Riverine Wetlands data sheets

Southeastern Coastal Plain HGM Field Data Sheet and Calculator

Site and WAA Data Form for Mid- or Low-Gradient Riverine Wetlands, Page 1 of 2

Team: ______ WAA Number: ______

Project Name: ______

Location: ______ Sampling Date: ______

Top Strata in WAA (trees, sapling/shrub, herbs): Select Strata Project/Mitigation Site (circle one) Before/After Project (circle one)

Sample Variables 1-6 using aerial photography, topographic maps, soil survey maps, etc. or a walkover of the entire WAA, as appropriate.

1 V_{CATCH} Percent change in the size of the catchment (If there is no water diversion or augmentation in the catchment, percent change = 0). **Used in Headwater Slopes Only.** Not Used

Size of original Catchment

If diversion: Size of current catchment

If augmentation: Size of catchment from which water is being diverted.

2 V_{UPUSE} Weighted Average of Runoff Score for Catchment. **Used in Headwater Slopes Only.** Not Used

☐ **Check here if catchment is >75% in native vegetation. Other calculations are not necessary if this is the case.**

Land Use (Choose From Drop List)	Soil Group (Choose From Drop List)	Runoff Score	% in Catchment	Running Percent (not >100)

3a $V_{CONNECT}$ **For Headwater Slopes.** Percent of wetland perimeter connected to suitable habitat, adjusted for width of buffer (buffer must be at least 10 meters wide). Not Used

☐ **Check here if >90% of the perimeter is clearly buffered by at least 150m of suitable habitat; no further calculations are necessary.**

Total length of wetland perimeter (meters)

Length of wetland perimeter with suitable habitat at least 10m wide (meters)

Average width of suitable habitat buffer (meters)

3b $V_{CONNECT}$ **For Riverine Subclasses.** Percent of assessment area reach with suitable habitat.

Determine Assessment Area Reach:

Width of alluvial valley associated with WAA (meters) (three measurements)

Avg:

Enter valley width measurements

Enter valley width measurements

Enter valley width measurements

4 $V_{SOILINT}$ Soil integrity. Estimate the percentage of the site that has significantly altered soils. Normal farm tillage is not considered a significant alteration in this case, but fill, excavation, land leveling that removes surface horizons, and compacted areas such as roads are counted.

Southeastern Coastal Plain HGM Field Data Sheet and Calculator

Site and WAA Data Form for Mid- or Low-Gradient Riverine Wetlands, Page 2 of 2

Project Name: ____________________ WAA Number: ________

5 $V_{HYDROSYS}$ **Used in Riverine Subclasses Only.** System Hydrologic Alterations. It represents the capacity of a stream network above a wetland to deliver floodwaters to it. The variable expresses departure from the system's natural capacity. In the absence of other data, it can be estimated by the comparison to qualitative statements. If more precise data are available, check the box and enter an index between 0 and 1. The index represents the proportion of similarity to natural conditions. Attach supporting documentation to this form.

☐ **Check here if using external data, and select type below:** Enter Index: ________

☐ Stream gage data ☐ Hydrologic modeling data

☐ Channel characteristics (e.g., regional dimensionless rating curves, channel width/watershed width, sinuosity)

If no external data are available, select one of the following (select top circle to print blank form):

●	**Hydrologic Condition**	**Indicators**
○	Natural stream hydrology	Clear evidence of overbank flooding such as drift lines, highwater marks, etc. and floodwater exchange with stream channel. Stream flow is natural (e.g. no large reservoirs regulating flow. No clear evidence of channel incision).
○	Altered stream hydrology	Stream flow is regulated or channel is deeply incised (both conditions may be present). Evidence of overbank flooding and floodwater exchange with stream channel is present but durations and frequencies of floodwater exchange have been reduced or increased from the natural condition.
○	Hydrologically isolated – floodwater exchange with floodplain rarely or never occurs	Anthropogenic changes have resulted in the elimination of all or nearly all overbank flooding. Examples of this condition include streams with deeply incised channels (channelized system) or streams with regulated flow.

6a $V_{HYDROALT}$ **Used in Headwater Slopes Only.** Hydrologic Alteration within the WAA. Height of obstruction, depth of ditch, or depth of impounded water. (cm) Not Used

Enter height of obstruction or depth of ditch (cm): ________

6b $V_{HYDROALT}$ **Used in Riverine Subclasses Only.** Hydrologic Alteration within the WAA. This variable is defined as man-induced alterations to the natural hydrology of the wetland due to activities within the wetland assessment area.

Select one of the following (select top circle to print blank form):

●	**Hydrologic Condition**	**Indicators**
○	Natural hydrology	Clear evidence of overbank flooding (such as drift lines, highwater marks, etc.) and floodwater exchange with stream channel. No evidence of effective ditches and levees.
○	Surface hydrology modified	Site has either drainage works or obstructions to floodwater exchange with the stream, or a combination of both are present. Evidence of overbank flooding and floodwater exchange with stream channel is present. Modifications may be those intended to either reduce or increase duration or frequency of inundation at the site (departure from natural conditions, either wetter or drier, is considered an adverse impact).
○	Hydrologically isolated –rarely inundated	Primary characteristic of this condition is that anthropogenic changes have resulted in the disconnection or isolation of the wetland from overbank flooding.
○	Hydrologically isolated – never inundated by stream flow	The site is isolated due to levee systems such that overbank flow never reaches the site.

Southeastern Coastal Plain HGM Field Data Sheet and Calculator

Plot Data Form for Mid- or Low-Gradient Riverine Wetlands, Page 1 of 2

Team: ____________ UTM Easting: ____________

Project Name: ____________ UTM Northing: ____________

Location: ____________ Sampling Date: ____________

WAA Number: ______ Plot Number: ______ of ______ Plot Area (0.04 ha is standard): 0.04

Top Strata in WAA (trees, sapling/shrub, herbs): Select Stratum Project/Mitigation Site (circle one) Before/After Project (circle one)

Sample Variables 7-12 within one or more representative 0.04-ha (0.1-acre) plot(s) within the WAA (use a separate data sheet for each)

7 V_{BIG3} Average dbh of three largest-diameter canopy trees(defined as live trees >15 cm dbh) in plot. Measure only if total tree cover is at least 20%.

List the dbh measurements of three largest canopy trees (at least 15cm):

Tree 1: ______ Tree 2: ______ Tree 3: ______

8 V_{CTDEN} Average number of canopy trees per ha (=canopy trees in 0.04 ha plot x 25)

Enter number of canopy trees located in the plot: ______

9 V_{SSC} Average percentage cover of saplings/shrubs (measure only if site tree cover is <20% and site sapling/shrub cover >20%).

Subplot 1: ______ Subplot 2: ______ Subplot 3: ______ Subplot 4: ______

10 V_{GVC} Average percentage cover of ground-layer vegetation (measure only if tree and sapling/shrub cover are each <20%)

Subplot 1: ______ Subplot 2: ______ Subplot 3: ______ Subplot 4: ______

11 V_{WD} Large Woody Debris biomass. Volume per hectare of non-living large woody stems (m^3/ha).

	Transect 1	Transect 2
Enter diameters (cm) of each fallen woody stem 7.6 cm (3 inches) or greater in diameter in each 50-foot transect. Leaning dead stems that intersect the sampling plane are sampled. Dead trees and shrubs still supported by their roots are not sampled. Rooted stumps are not sampled, but uprooted stumps are sampled. Down stems that are decomposed to the point where they no longer maintain their shape but spread out on the ground are not sampled.		
☐ Check here if there are no logs.		

Southeastern Coastal Plain HGM Field Data Sheet and Calculator

Plot Data Form for Mid- or Low-Gradient Riverine Wetlands, Page 2 of 2

Project Name: ________ WAA Number: ________ Plot Number: 0

12 V_{COMP} Vegetation Composition. Check all dominant species (using the 50/20 rule) in the tallest stratum. Check all exotics and invasives, including non-dominants, in all strata on plot. Spaces are available for write-ins, and justification can be added in the Notes.

☐ **For Mid- or Low-Gradient Riverine wetands, check here if this is a Cypress/Tupelo stand.**

Group 1 = 1.0		Group 2 = 0.66	Groups 3 = 0.00
☐ *Acer barbatum*	☐ *Persea borbonia*	☐ *Acer negundo*	☐ *Albizia julibrissin*
☐ *Acer rubrum*	☐ *Pinus taeda*	☐ *Acer saccharinum*	☐ *Alternanthera philoxeroides*
☐ *Carya aquatica*	☐ *Quercus alba*	☐ *Betula nigra*	☐ *Cyperus iria*
☐ *Carya cordiformis*	☐ *Quercus laurifolia*	☐ *Carpinus caroliniana*	☐ *Echinochloa crus-galli*
☐ *Carya glabra*	☐ *Quercus lyrata*	☐ *Cephalanthus occidentalis*	☐ *Imperata cylindrica*
☐ *Carya illinoensis*	☐ *Quercus michauxii*	☐ *Cornus florida*	☐ *Ligustrum japonicum*
☐ *Carya laciniosa*	☐ *Quercus nigra*	☐ *Crataegus spp.*	☐ *Ligustrum sinense*
☐ *Carya ovata*	☐ *Quercus pagoda*	☐ *Gleditsia triacanthos*	☐ *Lonicera japonica*
☐ *Celtis laevigata*	☐ *Quercus palustris*	☐ *Liriodendron tulipifera*	☐ *Lygodium japonicum*
☐ *Diospyros virginiana*	☐ *Quercus phellos*	☐ *Ostrya virginiana*	☐ *Microstegium vimineum*
☐ *Fraxinus americana*	☐ *Quercus shumardii*	☐ *Planera aquatica*	☐ *Panicum repens*
☐ *Fraxinus caroliniana*	☐ *Quercus texana*	☐ *Platanus occidentalis*	☐ *Pueraria montana*
☐ *Fraxinus pennsylvanica*	☐ *Taxodium distichum*	☐ *Prunus serotina*	☐ *Sapium sebiferum*
☐ *Ilex opaca*	☐ *Tilia americana*	☐ *Quercus rubra*	☐ *Sorghum halepense*
☐ *Liquidambar styraciflua*	☐ *Ulmus americana*	☐ *Salix nigra*	☐ *Triadica sebifera*
☐ *Magnolia virginiana*	☐ *Ulmus rubra*	☐ *Ulmus crassifolia*	☐ *Verbena brasiliensis*
☐ *Nyssa aquatica*	☐	☐	☐
☐ *Nyssa biflora*	☐	☐	☐
0 Species in Group 1		0 Species in Group 2	0 Species in Group 3

Initial Quality Index: Adjusted Quality Index:

Summary: Plot Number 0

Notes:

Variable	Value	VSI
V_{CATCH}	NA	NA
V_{UPUSE}	NA	NA
$V_{CONNECT}$		
Avg. width	NA	
$V_{SOILINT}$		
$V_{HYDROSYS}$		
$V_{HYDROALT}$		
V_{BIG3}		
V_{CTDEN}		
V_{SSC}		
V_{GVC}		
V_{WD}		
V_{COMP}		

Connected Depression Wetlands data sheets

Southeastern Coastal Plain HGM Field Data Sheet and Calculator

Site and WAA Data Form for Connected Depression Wetlands, Page 1 of 2

Team: ______________________ WAA Number: __________

Project Name: ______________________

Location: ______________________ Sampling Date: __________

Top Strata in WAA (trees, sapling/shrub, herbs): Select Strata | Project/Mitigation Site (circle one) | Before/After Project (circle one)

Sample Variables 1-6 using aerial photography, topographic maps, soil survey maps, etc. or a walkover of the entire WAA, as appropriate.

1 V_{CATCH} Percent change in the size of the catchment (If there is no water diversion or augmentation in the catchment, percent change = 0). **Used in Headwater Slopes Only.** — Not Used

Size of original Catchment

If diversion: Size of current catchment

If augmentation: Size of catchment from which water is being diverted.

2 V_{UPUSE} Weighted Average of Runoff Score for Catchment. **Used in Headwater Slopes Only.** — Not Used

☐ **Check here if catchment is >75% in native vegetation. Other calculations are not necessary if this is the case.**

Land Use (Choose From Drop List)	Soil Group (Choose From Drop List)	Runoff Score	% in Catchment	Running Percent (not >100)

3a $V_{CONNECT}$ **For Headwater Slopes.** Percent of wetland perimeter connected to suitable habitat, adjusted for width of buffer (buffer must be at least 10 meters wide). — Not Used

☐ **Check here if >90% of the perimeter is clearly buffered by at least 150m of suitable habitat; no further calculations are necessary.**

Total length of wetland perimeter (meters)

Length of wetland perimeter with suitable habitat at least 10m wide (meters)

Average width of suitable habitat buffer (meters)

3b $V_{CONNECT}$ **For Riverine Subclasses.** Percent of assessment area reach with suitable habitat.

Determine Assessment Area Reach:

Width of alluvial valley associated with WAA (meters) (three measurements)

Avg:

Enter valley width measurements

Enter valley width measurements

Enter valley width measurements

4 $V_{SOILINT}$ Soil integrity. Estimate the percentage of the site that has significantly altered soils. Normal farm tillage is not considered a significant alteration in this case, but fill, excavation, land leveling that removes surface horizons, and compacted areas such as roads are counted.

Southeastern Coastal Plain HGM Field Data Sheet and Calculator
Site and WAA Data Form for Connected Depression Wetlands, Page 2 of 2

Project Name: ______ WAA Number: ______

5 **$V_{HYDROSYS}$** **Used in Riverine Subclasses Only.** System Hydrologic Alterations. It represents the capacity of a stream network above a wetland to deliver floodwaters to it. The variable expresses departure from the system's natural capacity. In the absence of other data, it can be estimated by the comparison to qualitative statements. If more precise data are available, check the box and enter an index between 0 and 1. The index represents the proportion of similarity to natural conditions. Attach supporting documentation to this form.

☐ **Check here if using external data, and select type below:** Enter Index: ______

☐ Stream gage data ☐ Hydrologic modeling data

☐ Channel characteristics (e.g., regional dimensionless rating curves, channel width/watershed width, sinuosity)

If no external data are available, select one of the following (select top circle to print blank form):

●	**Hydrologic Condition**	**Indicators**
○	Natural stream hydrology	Clear evidence of overbank flooding such as drift lines, highwater marks, etc. and floodwater exchange with stream channel. Stream flow is natural (e.g. no large reservoirs regulating flow. No clear evidence of channel incision).
○	Altered stream hydrology	Stream flow is regulated or channel is deeply incised (both conditions may be present). Evidence of overbank flooding and floodwater exchange with stream channel is present but durations and frequencies of floodwater exchange have been reduced or increased from the natural condition.
○	Hydrologically isolated – floodwater exchange with floodplain rarely or never occurs	Anthropogenic changes have resulted in the elimination of all or nearly all overbank flooding. Examples of this condition include streams with deeply incised channels (channelized system) or streams with regulated flow.

6a **$V_{HYDROALT}$** **Used in Headwater Slopes Only.** Hydrologic Alteration within the WAA. Height of obstruction, depth of ditch, or depth of impounded water. (cm)

Not Used

Enter height of obstruction or depth of ditch (cm): ______

6b **$V_{HYDROALT}$** **Used in Riverine Subclasses Only.** Hydrologic Alteration within the WAA. This variable is defined as man-induced alterations to the natural hydrology of the wetland due to activities within the wetland assessment area.

Select one of the following (select top circle to print blank form):

●	**Hydrologic Condition**	**Indicators**
○	Natural hydrology	Clear evidence of overbank flooding (such as drift lines, highwater marks, etc.) and floodwater exchange with stream channel. No evidence of effective ditches and levees.
○	Surface hydrology modified	Site has either drainage works or obstructions to floodwater exchange with the stream, or a combination of both are present. Evidence of overbank flooding and floodwater exchange with stream channel is present. Modifications may be those intended to either reduce or increase duration or frequency of inundation at the site (departure from natural conditions, either wetter or drier, is considered an adverse impact).
○	Hydrologically isolated –rarely inundated	Primary characteristic of this condition is that anthropogenic changes have resulted in the disconnection or isolation of the wetland from overbank flooding.
○	Hydrologically isolated – never inundated by stream flow	The site is isolated due to levee systems such that overbank flow never reaches the site.

Southeastern Coastal Plain HGM Field Data Sheet and Calculator
Plot Data Form for Connected Depression Wetlands, Page 1 of 2

Team: ____________ UTM Easting: ____________
Project Name: ____________ UTM Northing: ____________
Location: ____________ Sampling Date: ____________
WAA Number: ______ Plot Number: ______ of ______ Plot Area (0.04 ha is standard): 0.04
Top Strata in WAA (trees, sapling/shrub, herbs): Select Stratum Project/Mitigation Site (circle one) Before/After Project (circle one)

Sample Variables 7-12 within one or more representative 0.04-ha (0.1-acre) plot(s) within the WAA (use a separate data sheet for each)

7	V_{BIG3}	Average dbh of three largest-diameter canopy trees(defined as live trees >15 cm dbh) in plot. Measure only if total tree cover is at least 20%. List the dbh measurements of three largest canopy trees (at least 15cm): Tree 1: ______ Tree 2: ______ Tree 3: ______	
8	V_{CTDEN}	Average number of canopy trees per ha (=canopy trees in 0.04 ha plot x 25) Enter number of canopy trees located in the plot: ______	
9	V_{SSC}	Average percentage cover of saplings/shrubs (measure only if site tree cover is <20% and site sapling/shrub cover >20%). Subplot 1: ______ Subplot 2: ______ Subplot 3: ______ Subplot 4: ______	
10	V_{GVC}	Average percentage cover of ground-layer vegetation (measure only if tree and sapling/shrub cover are each <20%) Subplot 1: ______ Subplot 2: ______ Subplot 3: ______ Subplot 4: ______	
11	V_{WD}	Large Woody Debris biomass. Volume per hectare of non-living large woody stems (m^3/ha).	

	Transect 1	Transect 2
Enter diameters (cm) of each fallen woody stem 7.6 cm (3 inches) or greater in diameter in each 50-foot transect. Leaning dead stems that intersect the sampling plane are sampled. Dead trees and shrubs still supported by their roots are not sampled. Rooted stumps are not sampled, but uprooted stumps are sampled. Down stems that are decomposed to the point where they no longer maintain their shape but spread out on the ground are not sampled.		
☐ Check here if there are no logs.		

Southeastern Coastal Plain HGM Field Data Sheet and Calculator
Plot Data Form for Connected Depression Wetlands, Page 2 of 2

Project Name: ______ WAA Number: ______ Plot Number: 0

12 V_{COMP} Vegetation Composition. Check all dominant species (using the 50/20 rule) in the tallest stratum. Check all exotics and invasives, including non-dominants, in all strata on plot. Spaces are available for write-ins, and justification can be added in the Notes.

☐ **This checkbox is not used for the Connected Depression subclass.**

Group 1 = 1.0		Group 2 = 0.66	Groups 3 = 0.00
☐ *Carya aquatica*	☐	☐ *Carpinus caroliniana*	☐ *Albizia julibrissin*
☐ *Fraxinus carolinana*	☐	☐ *Carya myristiciformis*	☐ *Alternanthera philoxeroides*
☐ *Fraxinus pennsylvanica*	☐	☐ *Carya ovata*	☐ *Cyperus iria*
☐ *Fraxinus profunda*	☐	☐ *Celtis laevigata*	☐ *Echinochloa crus-galli*
☐ *Nyssa aquatica*	☐	☐ *Cephalanthus occidentalis*	☐ *Imperata cylindrica*
☐ *Nyssa biflora*	☐	☐ *Crataegus spp.*	☐ *Ligustrum japonicum*
☐ *Planera aquatica*	☐	☐ *Diospyros virginiana*	☐ *Ligustrum sinense*
☐ *Quercus laurifolia*	☐	☐ *Ilex opaca*	☐ *Lonicera japonica*
☐ *Quercus lyrata*	☐	☐ *Liquidambar styraciflua*	☐ *Lygodium japonicum*
☐ *Taxodium distichum*	☐	☐ *Quercus alba*	☐ *Microstegium vimineum*
☐ *Ulmus americana*	☐	☐ *Salix nigra*	☐ *Panicum repens*
☐	☐	☐	☐ *Pueraria montana*
☐	☐	☐	☐ *Sorghum halepense*
☐	☐	☐	☐ *Triadica sebifera*
☐	☐	☐	☐ *Verbena brasiliensis*
☐	☐	☐	☐
☐	☐	☐	☐
☐	☐	☐	☐
0 Species in Group 1		0 Species in Group 2	0 Species in Group 3

Initial Quality Index: Adjusted Quality Index:

Summary: Plot Number 0

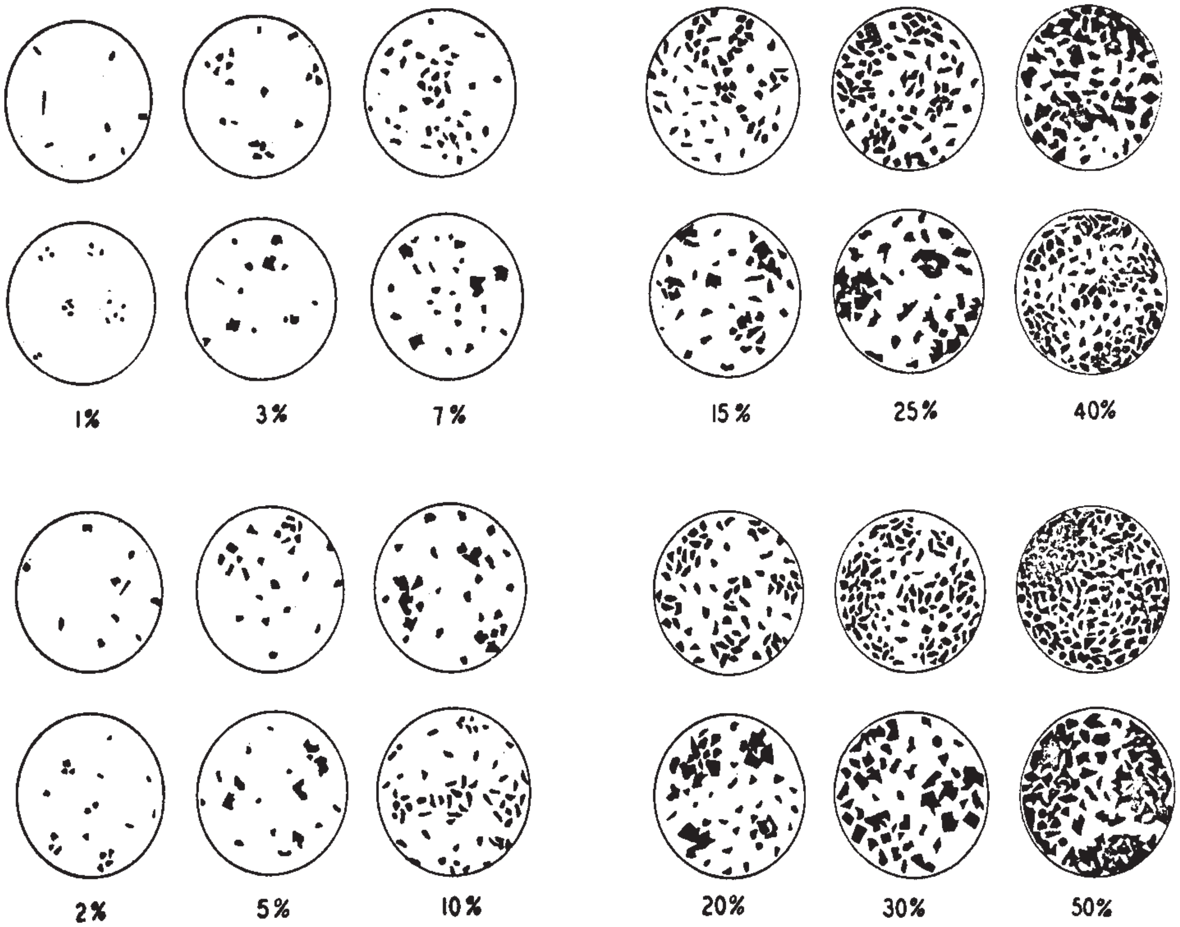
Variable	Value	VSI
V_{CATCH}	NA	NA
V_{UPUSE}	NA	NA
$V_{CONNECT}$		
Avg. width	NA	
$V_{SOILINT}$		
$V_{HYDROSYS}$		
$V_{HYDROALT}$		
V_{BIG3}		
V_{CTDEN}		
V_{SSC}		
V_{GVC}		
V_{WD}		
V_{COMP}		

Notes:

Appendix D: Supplementary Information on Model Variables

Contents

COMPARISON CHARTS FOR VISUAL ESTIMATION OF FOLIAGE COVER[1]



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

Table D1. Woody Species Observed on Reference Wetlands

Subclass			
Depression	Low-gradient Riverine	Mid-gradient Riverine	Headwater Slope
*Scientific Name**	*Scientific Name**	*Scientific Name**	*Scientific Name**
Acer rubrum	*Acer rubrum*	*Acer barbatum*	*Acer rubrum*
Carpinus caroliniana	*Asimina triloba*	*Acer negundo*	*Alnus rugosa*
Clethra alnifolia	*Carpinus caroliniana*	*Acer rubrum*	*Alnus serrulata*
Cornus foemina	*Carya aquatica*	*Aesculus pavia*	*Aronia arbutifolia*
Diospyros virginiana	*Carya cordiformis*	*Alnus rugosa*	*Arundinaria gigantea*
Forestiera acuminata	*Diospyros virginiana*	*Arundinaria gigantea*	*Asimina triloba*
Fraxinus pennsylvanica	*Fraxinus pennsylvanica*	*Asimina triloba*	*Betula nigra*
Ilex opaca	*Ilex opaca*	*Carex spp.*	*Callicarpa americana*
Itea virginica	*Itea virginica*	*Carpinus caroliniana*	*Carpinus caroliniana*
Liquidambar styraciflua	*Lindera benzoin*	*Carya aquatica*	*Carya cordiformis*
Lyonia lucida	*Liquidambar styraciflua*	*Carya glabra*	*Carya myristiciformis*
Nyssa aquatica	*Liriodendron tulipifera*	*Carya laciniosa*	*Carya species*
Nyssa sylvatica var. biflora	*Lyonia lucida*	*Carya ovata*	*Carya tomentosa*
Ostrya virginiana	*Magnolia virginiana*	*Celtis laevigata*	*Cephalanthus occidentalis*
Persea borbonia	*Myrica cerifera*	*Cornus drummondii*	*Clethra alnifolia*
Planera aquatica	*Nyssa aquatica*	*Cornus foemina*	*Cornus foemina*
Populus heterophylla	*Nyssa sylvatica*	*Crataegus speices*	*Crataegus speices*
Quercus lyrata	*Nyssa sylvatica var. biflora*	*Diospyros virginiana*	*Crataegus viridis*
Rhododendron viscosum	*Ostrya virginiana*	*Forestiera acuminata*	*Diospyros virginiana*
Taxodium distichum	*Persea borbonia*	*Fraxinus americana*	*Fraxinus caroliniana*
	Platanus occidentalis	*Fraxinus caroliniana*	*Fraxinus profunda*
	Quercus falcata	*Fraxinus pennsylvanica*	*Ilex coriacea*
	Quercus laurifolia	*Ilex decidua*	*Ilex decidua*
	Quercus lyrata	*Ilex opaca*	*Ilex opaca*
	Quercus michauxii	*Ilex vomitorla*	*Ilex vomitorla*
	Quercus nigra	*Itea virginica*	*Itea virginica*
	Salix nigra	*Ligustrum sinense*	*Juniperus virginiana*
	Styrax americana	*Lindera benzoin*	*Leucothoe axillaris*
	Taxodium distichum	*Lindera melissifolia*	*Ligustrum sinense*
	Ulmus alata	*Liquidambar styraciflua*	*Lindera benzoin*

Subclass			
Depression	Low-gradient Riverine	Mid-gradient Riverine	Headwater Slope
	Ulmus americana	*Liriodendron tulipifera*	*Liquidambar styraciflua*
	Ulmus rubra	*Magnolia virginiana*	*Liriodendron tulipifera*
	Vaccinium elliottii	*Morus rubra*	*Lyonia ligustrina*
		Nyssa aquatica	*Lyonia lucida*
		Nyssa sylvatica	*Magnolia virginiana*
		Nyssa sylvatica var. biflora	*Myrica cerifera*
		Ostrya virginiana	*Myrica heterophylla*
		Persea borbonia	*Nyssa aquatica*
		Pinus taeda	*Nyssa sylvatica*
		Planera aquatica	*Nyssa sylvatica var. biflora*
		Platanus occidentalis	*Osmanthus americanus*
		Populus heterophylla	*Persea borbonia*
		Prunus serotina	*Persea palustris*
		Quercus laurifolia	*Pinus taeda*
		Quercus lyrata	*Quercus laurifolia*
		Quercus michauxii	*Quercus michauxii*
		Quercus nigra	*Quercus nigra*
		Quercus nuttallii	*Quercus phellos*
		Quercus pagoda	*Quercus similis*
		Quercus phellos	*Rhododendron canescens*
		Quercus texana	*Rhododendron viscosum*
		Sabal minor	*Rubus spp.*
		Salix nigra	*Sabal minor*
		Sambucus canadensis	*Sambucus canadensis*
		Styrax americana	*Symplocos tinctoria*
		Taxodium distichum	*Taxodium distichum*
		Ulmus alata	*Ulmus americana*
		Ulmus americana	*Ulmus rubra*
		Ulmus crassifolia	*Vaccinium elliottii*
		Ulmus rubra	*Viburnum dentatum*
		Vaccinium elliottii	*Viburnum nudum*
		Viburnum dentatum	

Determination of Weighted Average for V_{UPUSE}

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

Identify the different land-use types within the catchment of the WAA using recent aerial photography (Figure D1). Estimate the percentage of the catchment in each land-use type. Verify during onsite reconnaissance.

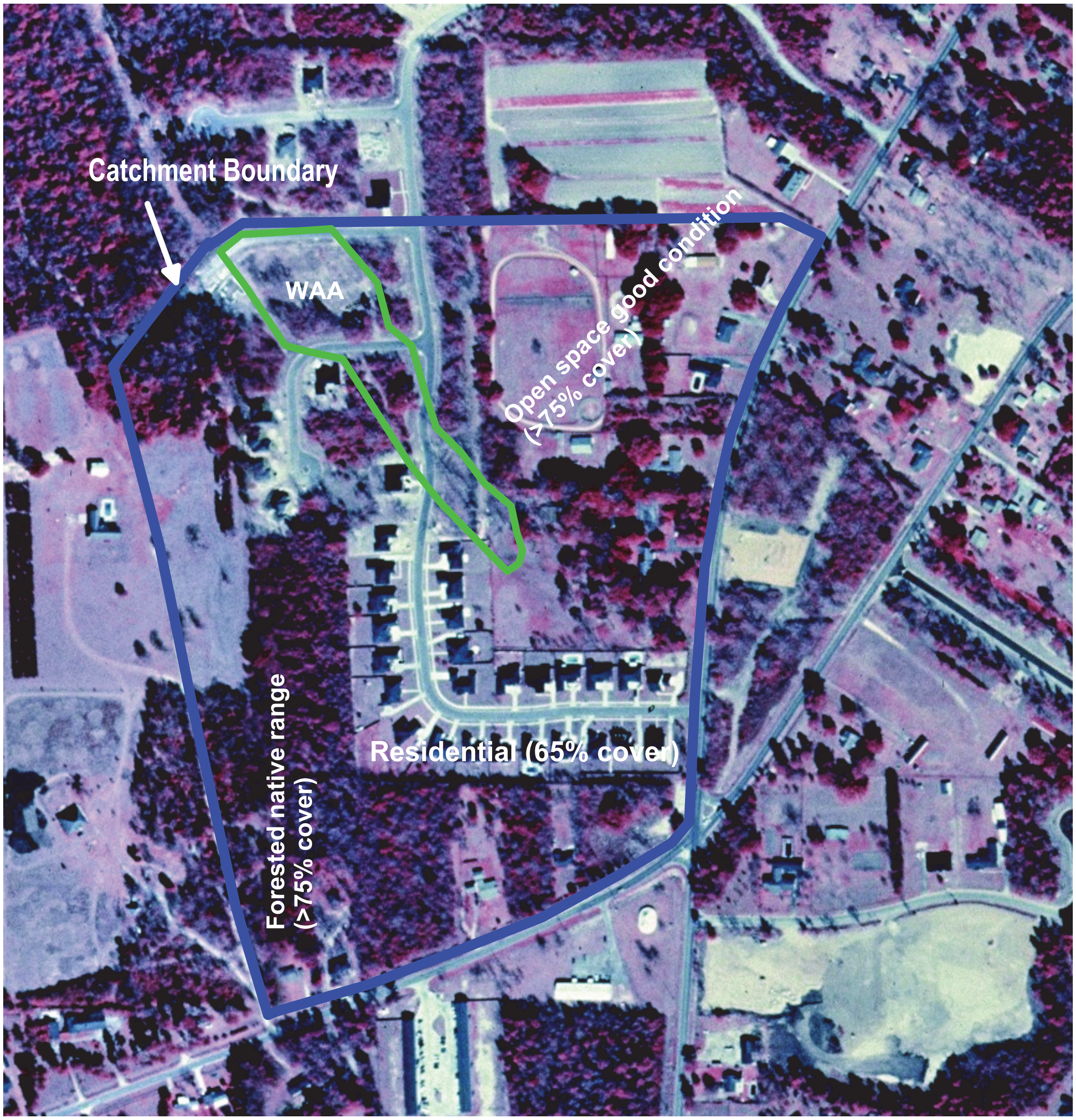


Figure D1. Aerial photograph illustrating the cover types found within the catchment of a wetland.

Identify the soils within the catchment and determine the hydrologic soil group (A, B, C, or D) based on the soil series identified for the area in the appropriate soil survey. In this example, all of the soils are within the hydrologic soil group D.

Table D2. Example runoff curve numbers by land use.

Cover Type	Percent of Catchment	Runoff Curve Numbers
Forest and native range (>75% ground cover)	75	77
Residential (65% cover)	10	92
Open space good condition (>75% cover)	15	80
Total	100	

Determine the runoff curve number for each combination of land-use and soil hydrologic group present using Table 8.

Multiply the runoff curve number by the percentage of the catchment, sum these products across the entire catchment and divide by 100.

For this example (Figure D1, Table D2), the weighted average runoff score is:

$$\left[\frac{(77\times 75)+(92\times 10)+(80\times 15)}{100}\right]=78.95$$

Using the graph for V_{UPUSE}, determine the variable subindex score that corresponds with a runoff score of 78.95 (Figure 8). The variable subindex score for this example is approximately 0.4.

Hand Calculations for Determining V_{WD} at Each Sample Plot

If you do not wish to use the spreadsheet calculator to calculate woody debris volume (V_{WD}), you can calculate the data manually. Transfer the transect data recorded on the plot data sheets to the worksheet below, and make the indicated calculations.

Table D3. Worksheet for the manual calculation of V_{WD}.

From the plot data sheet, transfer the diameter (cm) of each log or limb (> 7.6 cm, or >3 inches) measured along Transect 1 and Transect 2 into the table below. Multiply each diameter measurement by 0.3937, and then square the result. Sum all results, then multiply that sum by 0.2657 to get large woody debris volume (m^3/ha).					
Transect 1			Transect 2		
1	2	3	1	2	3
Stem Diameter(cm)	Multiply Stem Diameter by 0.3937	Square the Result in Column 2	Stem Diameter(cm)	Multiply Stem Diameter by 0.3937	Square the Result in Column 2
SUM =			SUM=		
Sum of (column 3) Transect 1 + Sum of Transect 2 = ______ · 0.2657 =__________ m^3/ha,					

Suggested Approach for Determination of Hydrologic Departure for $V_{HYDROSYS}$ on a Regulated Stream

Where sufficient gage data is available, a succinct means of expressing the departure of a regulated hydrology from the natural hydrology could be comparing the standard deviation (SD) of the means. Since SD is a description of variation in a sample, a comparison of the SD for daily mean flows pre- and post- regulation is an appropriate metric to express departure. Figure D2 is a plot of daily mean discharge for a gage on the Roanoke River for the period of record, before and after flow was regulated.

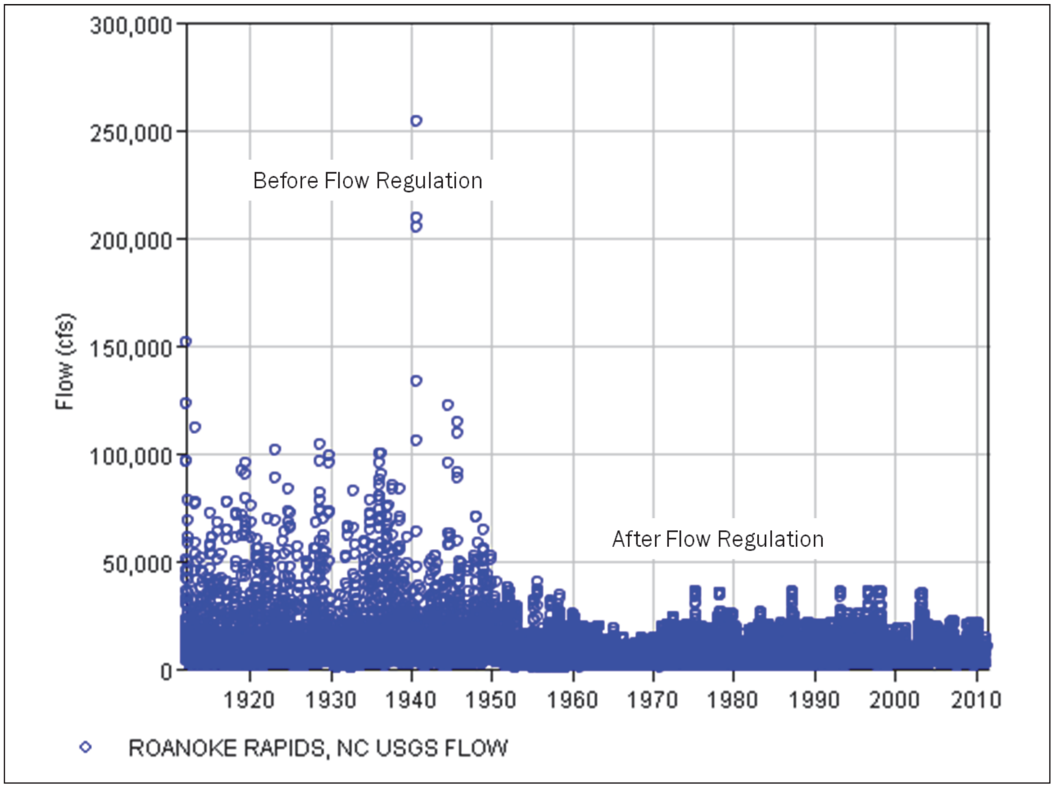


Figure D2. Plot of daily mean discharge before and after flow-regulation on the Roanoke River, NC, USA.

Table D4 is a summary of selected descriptive statistics for the data illustrated in Figure D2, with SD highlighted. Review of the “similarity index” in the table, which is simply calculated as a proportion, reveals that SD best expresses the departure from natural hydrology. The similarity index for SD may be used in place of the subindex value for $V_{HYDROSYS}$ in all of the assessment models. A similar approach may be taken with stage data in cases where the stream has been channelized, or is deeply incised, where such data is available.

Table D4. Descriptive statistics of daily mean discharge vaules for the period of record, pre- and post-impoundment.

Mean Daily Discharge Descriptive Statistic	Pre-impoundment	Post-impoundment	Similarity index (Post/Pre)
Mean	8493.9	7846.9	0.92
Median	5600.0	5980.0	1.07
Mode	3740.0	19000.0	5.08
Standard Deviation	10594.4	6384.5	0.60
Range	253528.0	39599.0	0.16
Minimum	472.0	501.0	1.06
Maximum	254000.0	40100.0	0.15
Count	13880.0	21182.0	
Largest(1)	254000.0	40100.0	0.16
Smallest(1)	472.0	501.0	1.06

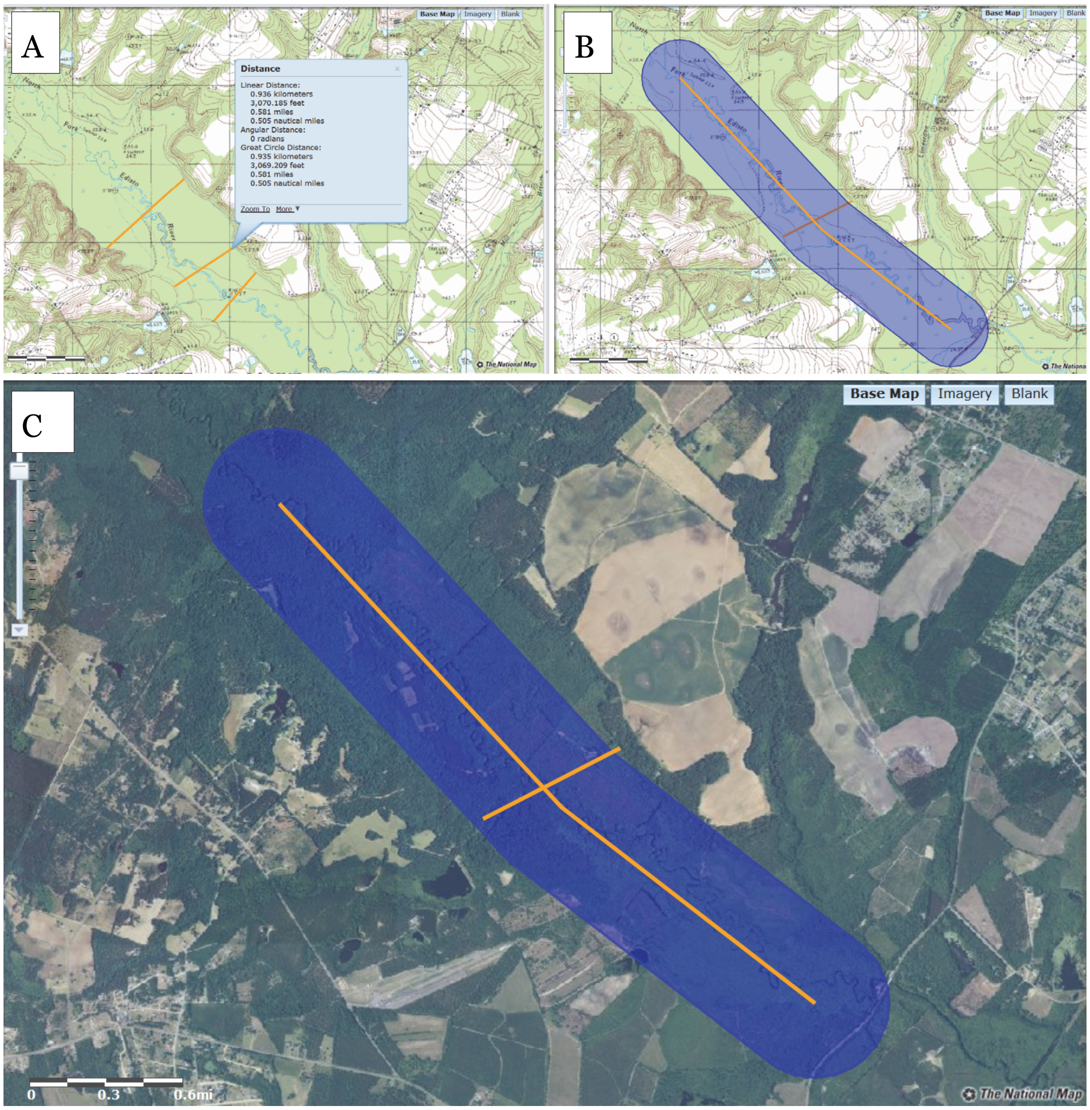
Determination of the assessment area reach for $V_{CONNECT}$ for the Riverine Subclasses

A number of websites serving GIS data now have basic analysis tools within the data browsing utilities. The example shown here is from the National Map Viewer (http://viewer.nationalmap.gov/viewer) maintained by USGS.

The width of alluvial valleys in the southeast can often be estimated using 7.5 minute topographic maps and aerial photographs. In cases where topographic maps and aerial photos are insufficient for an estimate of valley width, then digital elevation data may be downloaded from the GIS data server and used in a GIS system.

The following procedure is illustrated in Figure D3:

1. Determine the assessment area reach:
    a. Estimate the width of the alluvial valley, at a minimum of three locations at the WAA, using topographic maps, aerial photos, digital elevation models, or some other data. Average the estimates and multiply the result by 5.
    b. Measure ½ the distance obtained upstream and ½ downstream of the wetland assessment area. Measure along the central axis of the floodplain, not the stream. Make turns if necessary. These points will serve as the upstream and downstream limits of the $V_{CONNECT}$ assessment area.



Distance

Linear Distance:
0.936 kilometers
3,070.185 feet
0.581 miles
0.505 nautical miles
Angular Distance:
0 radians
Great Circle Distance:
0.935 kilometers
3,069.209 feet
0.581 miles
0.505 nautical miles

Figure D3. A.) Estimation of mean valley width from three measurements on a topographic map using The National Map Viewer (http://viewer.nationalmap.gov/viewer). B.) Establishment of assessment area reach using valley centerline buffered on each side by ½ the mean valley width. C.) Aerial photograph with buffer superimposed. Aerial extent of suitable habitat within the buffer envelope may be estimated visually, or calculated precisely using the polygon tool.

2. Establish a buffer equal to ½ the width of the valley estimated in step a. on each side of the centerline of the valley (drawn in step 1b.)
3. Using aerial photographs, determine the percentage within the assessment area reach that is in suitable habitat (See Chapter 4 for examples of suitable habitat types). If that percentage is ≥ 80%, report the result as 1.0.

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14. ABSTRACT

The Hydrogeomorphic (HGM) Approach is a method for developing and applying indices for the site-specific assessment of wetland functions. The HGM Approach was initially designed to be used 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, and management of wetlands. This Regional Guidebook presents the HGM Approach for assessing the functions of most of the wetlands that occur in alluvial valleys of the Coastal Plain of the Southeast United States. The report begins with an overview of the HGM Approach and then classifies and characterizes the principal wetlands that have been identified within the region. Detailed HGM assessment models and protocols are presented for four of those wetland types, or subclasses: Headwater Slope, Low-gradient Riverine, Mid-gradient Riverine, and Connected Depression. 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 (d) the functional index calibration curves developed from reference wetlands that are used in the assessment models. The guidebook outlines an assessment protocol for using the model variables and functional indices to assess each of the wetland subclasses. The appendices provide field data collection forms and spreadsheets for making calculations.

15. SUBJECT TERMS

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Mitigation
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