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Wetlands Regulatory Assistance Program

Regional Guidebook for Applying the Hydrogeomorphic Approach to Assessing the Functions of Flat and Seasonally Inundated Depression Wetlands on the Highland Rim

Chris V. Noble, Thomas H. Roberts, Kenneth L. Morgan, A. Jason Hill, Vincent S. Neary, and Reed W. Cripps

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Abstract

The Hydrogeomorphic (HGM) Approach is a collection of concepts and methods for developing functional indices and subsequently using them to assess the capacity of a wetland to perform functions relative to similar wetlands in a region. The approach was initially designed to be used in the context of the Clean Water Act Section 404 Regulatory Program permit review sequence. This Regional Guidebook (a) characterizes the Depression and Flat wetlands within the Highland Rim and Pennyroyal Major Land Resource Area, (b) describes and provides the rationale used to select functions for the Depression and Flat wetland subclass, (c) describes model variables and metrics, (d) describes the development of assessment models, (e) provides data from reference wetlands and documents their use in calibrating model variables and assessment models, and (f) outlines protocols for applying the functional indices to the assessment of wetland functions.

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Preface

This report was prepared by Chris V. Noble, Environmental Laboratory (EL), ERDC; Dr. Thomas H. Roberts, Kenneth L. Morgan, A. Jason Hill, and Dr. Vincent S. Neary, Tennessee Technological University, Cookeville; and Dr. Reed Cripps, USDA Natural Resources Conservation Service, Little Rock, Arkansas.

This guidebook was developed in cooperation with an Assessment Team (A-Team) of experts familiar with depressional and flats wetlands in Tennessee. The following A-Team members made major contributions to the development of this guidebook: Bill Ainslie, U. S. Environmental Protection Agency; Mark Bailey, Conservation Southeast Inc.; Bob Bay, Geoff Call, Mary Peterson, and Doug Winford, U.S. Fish and Wildlife Service; Dave Buehler, University of Tennessee; Karina Bynum, Tennessee Department of Environment and Conservation; Gordon Godshalk, Alfred University; Dr. Chuck Klimas, Dr. Jim Wakeley, and Wade Whittinghill, ERDC; Mike Lee and Jeff Patton, Tennessee Department of Environment and Conservation; Eric Somerville and Dr. Kim Stearman, Tennessee Technological University; Rob Todd, Tennessee Wildlife Resources Agency; Mike Williams, Tennessee Department of Transportation; and Mike Zeman, Natural Resources Conservation Service.

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This work was performed under the general supervision of Patrick O'Brien, Chief, Wetlands and Coastal Ecology Branch, EL; Dr. Edmond Russo, Chief, Ecosystem Evaluation and Engineering Division, EL; Sally Yost, Program Manager, WRAP; and Dr. Elizabeth C. Fleming, Director, EL.

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

Unit Conversion Factors

Multiply	By	To Obtain
inches	2.54	centimeters
acres	0.4047	hectares
feet	0.3048	meters

1 Introduction

Background

The Hydrogeomorphic (HGM) Approach is a collection of concepts and methods used to develop functional indices that can be used to assess the capacity of a wetland to perform functions relative 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.

On 16 August 1996, a National Action Plan (NAP) to Implement the Hydrogeomorphic Approach was adopted (Federal Register 1997). The NAP was developed cooperatively by a National Interagency Implementation Team consisting of the U.S. Army Corps of Engineers (USACE), U.S. Environmental Protection Agency (USEPA), Natural Resources Conservation Service (NRCS), Federal Highways Administration (FHWA), and U.S. Fish and Wildlife Service (USFWS). The NAP outlines a strategy to promote the development of Regional Guidebooks for assessing the functions of regional wetland subclasses using the HGM Approach; provides guidelines and a set of tasks required to develop Regional Guidebooks; and solicits the cooperation and participation of Federal, State, and local agencies, academia, and the private sector in this effort. Other regional guidebooks were used as a template for development of a guidebook for Depression and Flat wetlands of the Highland Rim (HR) in Tennessee. These include Wetland Functions of Flat Wetlands in the Everglades (Noble et al. 2002), Wetland Functions of North Carolina Flat (Rheinhardt et al. 2002), Wetland Functions of Selected Wetland Subclasses, Yazoo Basin, Lower Mississippi River Alluvial Valley (Smith and Klimas 2002), and Functions of Low-Gradient Riverine Wetlands for Western Kentucky (Ainslie et al. 1999). A series of meetings were held to begin development of a guidebook for Depression, Flat, and Slope wetlands of Tennessee's HR. These meetings were attended by hydrologists, soil scientists, plant and landscape ecologists, and wildlife biologists representing academic, private, and public sectors. During the meetings regional wetland subclasses were defined and characterized, a reference domain was identified, and potential model functions and variables were chosen. Once these tasks had been accomplished, assessment teams specializing in hydrology, soils, and habitat relationships developed rough drafts of guidebook chapters in each specialty. These chapters were conceptual only (based on literature) and were not based on actual data. Each chapter outlined tentative methods for assessing Depression, Flat, and Slope wetlands of the HR. Collection of field data from reference wetlands was then initiated. These data were then used to revise and calibrate the proposed conceptual models. Draft versions of these chapters were then submitted for peer review and revised.

Objectives

The objectives of this regional guidebook include the following: characterize Depression and Flat wetlands of the HR of Tennessee reference domain; quantitatively and/or qualitatively assess the performance level of these wetlands in such a way as to be scientifically valid and cost effective; provide the rationale behind selection of functions, variables, and metrics; and be user friendly.

Scope

This guidebook is organized in the following manner. Chapter 1 provides a brief discussion of background and objectives of the project, and organization of the guidebook. Chapter 2 provides a brief overview of the HGM approach and the development and application phases required to use this assessment method. Chapter 3 provides a characterization of Depression and Flat wetlands of the HR. This chapter includes information regarding geographic extent, climate, geomorphic setting, hydrology, vegetation, and soils. Chapter 4 discusses definitions and quantitative, independent measures of wetland functions and variables, calculation of functional indices, description of the ecosystem and landscape features that affect the function, assessment models used to derive the functional index, and explains the rationale used to calibrate the index with reference wetland data. Chapter 5 outlines steps in the assessment protocol for conducting functional assessments of Depression and Flat wetlands within the HR.

While it is possible to assess the functions of Depression and Flat wetlands within the HR using only the information contained in Chapter 5, users are encouraged to familiarize themselves with the information in Chapters 2-4 prior to conducting an assessment.

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

2 Overview of the Hydrogeomorphic Approach

As indicated in Chapter 1, the HGM Approach is a collection of concepts and methods used in developing functional indices to assess the capacity of a wetland to perform functions relative to similar wetlands in a region. The HGM Approach includes four integral components: (a) the HGM classification, (b) reference wetlands, (c) assessment models/functional indices, and (d) assessment protocols. During the development phase of the HGM Approach, these four components are integrated into a Regional Guidebook for assessing the functions of a regional wetland subclass. Subsequently, during the application phase, end users, following the assessment protocols outlined in the Regional Guidebook, assess the functional capacity of selected wetlands. Each of the components of the HGM Approach and the development and application phases are discussed in this chapter. More extensive discussions can be found in Brinson (1993; 1995a, 1995b); Brinson et al. (1995, 1996, 1998); Smith et al. (1995); Hauer and Smith (1998); Smith (2001); Smith and Wakeley (2001); and Wakeley and Smith (2001).

Hydrogeomorphic classification

Wetland ecosystems share a number of features including relatively long periods of inundation or saturation, hydrophytic vegetation, and hydric soils. In spite of these common attributes, wetlands occur under a wide range of climatic, geologic, and physiographic situations and exhibit a wide variety of physical, chemical, and biological characteristics and processes (Cowardin et al. 1979; Semeniuk 1987; Ferren et al. 1996a,1996b,1996c; Mitsch and Gosselink 2000). 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 relative 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. However, 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 1993). It identifies groups of wetlands that function similarly 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 source of water in the wetland (e.g., precipitation, overbank floodwater, or groundwater). Hydrodynamics refers to the level of energy and the direction that water moves in the wetland. 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 (1993) identified five hydrogeomorphic wetland classes. These were later expanded to the seven classes described in Table 1 (Smith et al. 1995). In many cases, the level of variability in wetlands encompassed by a continental-scale HGM class is still too great to allow development of assessment models that can be rapidly applied while being sensitive enough to detect changes in function at a level of resolution appropriate to the Section 404 review process. For example, at a continental geographic scale, the depression class includes wetland ecosystems in different regions as diverse as California vernal pools (Zedler 1987), prairie potholes in North and South Dakota (Hubbard 1988; Kantrud et al. 1989), playa lakes in the high plains of Texas (Bolen et al. 1989), kettles in New England, and cypress domes in Florida (Ewel 1984; Kurz and Wagner 1953).

To reduce both inter- and intra-regional variability, the three classification criteria are applied at a smaller, regional geographic scale to identify regional wetland subclasses. In many parts of the country, existing wetland classifications can serve as a starting point for identifying these regional subclasses (Stewart and Kantrud 1971; Golet and Larson 1974; Wharton et al. 1982; Ferren et al. 1996a, 1996b, 1996c). Regional subclasses, like the continental classes, are distinguished on the basis of geomorphic setting, water source, and hydrodynamics. In addition, certain ecosystem or landscape characteristics may also be useful for distinguishing regional subclasses in certain regions. For example, Depression subclasses might be based on water source (i.e., groundwater versus surface water), 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, landscape position, the source of water (i.e., throughflow versus groundwater), or other factors. Riverine subclasses might be based on water

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 center 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 recharge 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. Because 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. 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, and by evapotranspiration. Slope wetlands may develop channels, but the channels serve only to convey water away from the slope wetland. 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 seepage to underlying groundwater. They are distinguished from flat upland areas by their poor vertical drainage due to 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.

HGM Wetland Class	Definition
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 dominated by overland flow and seepage to underlying groundwater. Organic soil flats 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 been subjected to long periods of saturation from groundwater sources. Bottomland hardwoods on floodplains are an example of riverine wetlands.

source, position in the watershed, stream order, watershed size, channel gradient, or floodplain width. Examples of potential regional subclasses are shown in Table 2, Smith et al. (1995), and Rheinhardt et al. (1997).

Regional Guidebooks include a thorough characterization of the regional wetland subclass in terms of its geomorphic setting, water sources, hydrodynamics, vegetation, soil, and other features that were taken into consideration during the classification process.

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.

Table 2. Potential Regional Wetland Subclasses in Relation to Geomorphic Setting, Dominant Water Source, and Hydrodynamics

Geomorphic Setting	Dominant Water Source	Dominant Hydrodynamics	Potential Regional Wetland Subclasses	
			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

Note: Adapted from Smith et al. (1995) and Rheinhardt et al. (1997).

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 provide 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.

Assessment models and functional indices

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

Model variables represent the characteristics of the wetland ecosystem and surrounding landscape that influence the capacity of a wetland ecosystem to perform a function. Model variables are ecological quantities that consist of five components (Schneider 1994): (a) a name, (b) a symbol, (c) a measure of the variable and procedural statements for quantifying or qualifying the measure directly or calculating it from other measures, (d) a set of variables (i.e., numbers, categories, or numerical estimates (Leibowitz and Hyman 1997)) that are generated by applying the procedural statement, and (e) units on the appropriate measurement scale. Table 4 provides several examples of model variable components.

Model variables occur in a variety of states or conditions in reference wetlands. The state or condition of the variable is denoted by the value of the measure of the variable. For example, percent ground cover vegetation, the measure of the percent cover of ground cover vegetation, could be large or small. Based on its condition (i.e., value of the metric), model variables are assigned a variable subindex. When the condition of a variable is within the range of conditions exhibited by reference standard wetlands, a variable

Table 4. Components of a Model Variable

Name (Symbol)	Measure / Procedural Statement	Resulting Values	Units (Scale)
Canopy tree diameter (V_{CTD})	Average diameter at breast height (dbh) of canopy trees	0 to ≥39.4	Centimeters
O horizon thickness	Average thickness of the O horizon	0 to ≥8.0	Centimeters
Surrounding Land use ($V_{LANDUSE}$)	Percent cover of ground cover	0 to >100	Unitless

subindex of 1.0 is assigned. As the condition deflects from the reference standard condition (i.e., the range of conditions within which the variable occurs in reference standard wetlands), the variable subindex is assigned based on the defined relationship between model variable condition and functional capacity. As the condition of a variable deviates from the conditions exhibited in reference standard wetlands, it receives a progressively lower subindex reflecting its decreasing contribution to functional capacity. In some cases, the variable subindex drops to zero. For example, when the percent cover of ground cover vegetation is between 50 and 84% in Flat wetlands, the subindex for percent Ground Vegetation Cover (V_{GVC}) is 1.0. As the percent cover decreases below 50%, the variable subindex score decreases linearly to zero if no ground vegetation is present.

Model variables are combined in an assessment model to produce a Functional Capacity Index (FCI) that ranges from 0.0 to 1.0. The FCI is a measure of the functional capacity of a wetland relative to reference standard wetlands in the reference domain. Wetlands with an FCI of 1.0 perform the function at a level characteristic of reference standard wetlands. As the FCI decreases, it indicates that the capacity of the wetland to perform the function is less than that characteristic of reference standard wetlands.

Assessment protocol

The final component of the HGM Approach is the assessment protocol. The assessment protocol is a series of tasks, along with specific instructions, that allow the end user to assess the functions of a particular wetland area using the functional indices in the Regional Guidebook. The first task is characterization, which involves describing 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 model variables. The final task is analysis, which involves calculation of functional indices.

Development Phase

The Development Phase of the HGM Approach is ideally carried out by an interdisciplinary team of experts known as the “Assessment Team,” or “A-Team.” The product of the Development Phase is a Regional Guidebook for assessing the functions of a specific regional wetland subclass (Figure 1). In developing a Regional Guidebook, the A-Team will complete the following major tasks. After organization and training, the first task of the A-Team is to classify the wetlands within the region of interest into regional wetland subclasses using the principles and criteria of the HGM Classification (Brinson 1993, Smith et al. 1995). Next, focusing on the specific regional wetland subclasses selected, the A-Team develops an ecological characterization or functional profile of the subclass. The A-Team then identifies the important wetland functions, conceptualizes assessment models, identifies model variables to represent the characteristics and processes that influence each function, and defines metrics for quantifying model variables. Next, reference wetlands are identified to represent the range of variability exhibited by the regional subclass. Field data are then collected from the reference wetlands and used to calibrate model variables and verify the conceptual assessment models. Finally, the A-Team develops the assessment protocols necessary for regulators, managers, consultants, and other end users to apply the indices to the assessment of wetland functions. The following list provides the detailed steps involved in this general sequence:

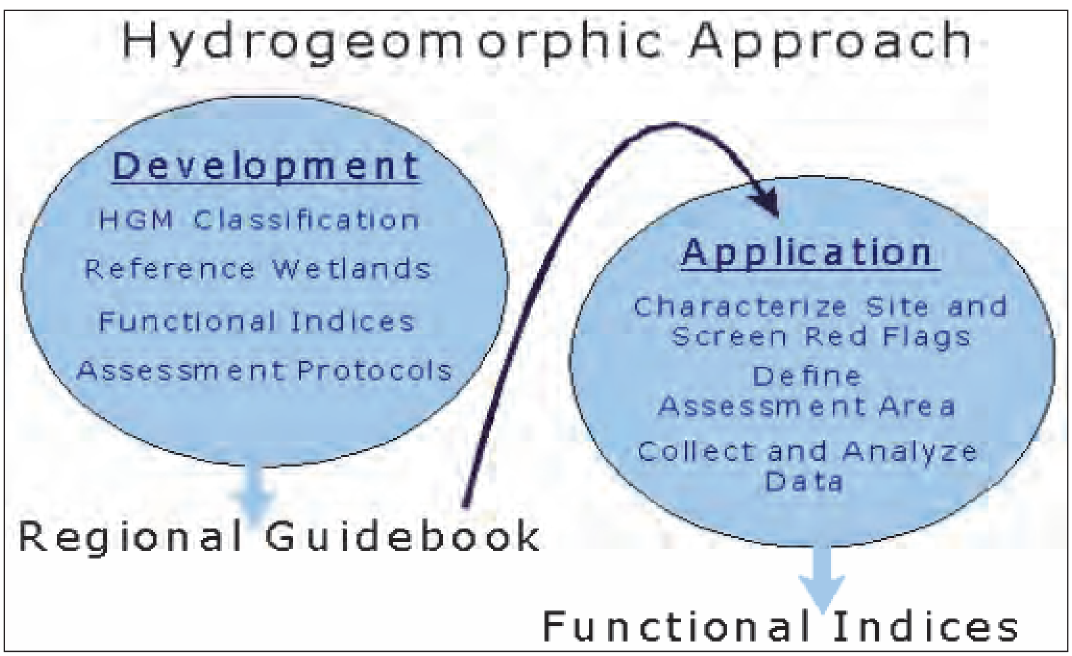

Figure 1. Development and application phases of the HGM Approach.

Task 1: Organize the A-Team.

1. Identify A-Team members.
2. Train A-Team in the HGM Approach.

Task 2: Select and Characterize Regional Wetland Subclasses.

1. Identify/prioritize wetland subclasses.
2. Select regional wetland subclass and define reference domain.
3. Initiate literature review.
4. Develop preliminary characterization of regional wetland subclasses.
5. Identify and define wetland functions.

Task 3: Select Model Variables and Metrics and Construct Conceptual Assessment Models.

1. Review existing assessment models.
2. Identify model variables and metrics.
3. Define initial relationship between model variables and functional capacity.
4. Construct conceptual assessment models for deriving FCIs.
5. Complete Precalibrated Draft Regional Guidebook (PDRG).

Task 4: Conduct Peer Review of PDRG.

1. Distribute PDRG to peer reviewers.
2. Conduct interdisciplinary, interagency workshop of PDRG.
3. Revise PDRG to reflect peer review recommendations.
4. Distribute revised PDRG to peer reviewers for comment.
5. Incorporate final comments from peer reviewers on revisions into PDRG.

Task 5: Identify and Collect Data from Reference Wetlands.

1. Identify reference wetland field sites.
2. Collect data from reference wetland field sites.
3. Analyze reference wetland data.

Task 6: Calibrate and Field Test Assessment Models.

1. Calibrate model variables using reference wetland data.

2. Verify and validate (optional) assessment models.
3. Field test assessment models for repeatability and accuracy.
4. Revise PDRG based on calibration, verification, validation (optional), and field testing results into a Calibrated Draft Regional Guidebook (CDRG).

Task 7: Conduct Peer Review and Field Test of CDRG.

1. Distribute CDRG to peer reviewers.
2. Field test CDRG.
3. Revise CDRG to reflect peer review and field test recommendations.
4. Distribute CDRG to peer reviewers for final comment on revisions.
5. Incorporate peer reviewers' final comments on revisions.
6. Publish Operational Draft Regional Guidebook (ODRG).

Task 8: Technology Transfer.

1. Train end users in the use of the ODRG.
2. Provide continuing technical assistance to end users of the ODRG.

Application Phase

The Application Phase involves two steps. The first is using the assessment protocols outlined in the Regional Guidebook to carry out the following tasks (Figure 1).

1. Define assessment objectives.
2. Characterize the project site.
3. Screen for red flags.
4. Define the Wetland Assessment Area.
5. Collect field data.
6. Analyze field data.

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

3 Characterization of Depression and Flat Wetlands of the Highland Rim

Regional Wetland Subclass and Reference Domain

This Regional Guidebook was developed to assess the functions of Depression and Flat wetlands within the Highland Rim and Pennyroyal Major Land Resource Area (MLRA 122) within the East and Central Farming and Forest Region (LRR-N) (U.S. Department of Agriculture (USDA) Natural Resources Conservation Service 2006). This area closely corresponds to the Highland Rim (HR) of the Interior Low Plateau physiographic province. This area, especially the northwestern and eastern portions, is well known for having extensive karst landforms in which wetlands readily form. Depressions occur most frequently within the central and southern portions of the eastern HR and the northwestern portion of the western HR. Flat wetlands most commonly occur within drainage divides of the central and southern portions of the HR, with the greatest concentration within the southern portion referred to as the "Barrens" region.

The significance of wetlands within the HR has been well documented by several authors including Ellis and Chester (1989), Jones (1989). Water storage, biogeochemical cycling, and plant and animal community support are among the important functions these wetlands perform cumulatively. Individual wetlands in both classes have been shown to be important habitat for a variety of species, several of which are considered to be disjunct populations (Bailey and Bailey 2000).

The reference domain for which this guidebook is applicable is the HR as defined by MLRA 122, including parts of Alabama, Indiana, Kentucky, and Tennessee (Figure 2). Although the data were collected in Tennessee, the models in this guidebook should be applicable for use in Depression and Flat wetlands throughout the reference domain. Time and resource constraints made it impossible to collect reference data throughout the entire area. The field sites were located throughout the HR in Tennessee, and persons applying the models in other areas should verify that existing reference standard data adequately describe local conditions. If not, additional data should be collected and used to revise the plant lists or rescale the Variable Subindex graphs. Soil properties and plant species composition vary somewhat throughout the reference domain, but differences are relatively minor.

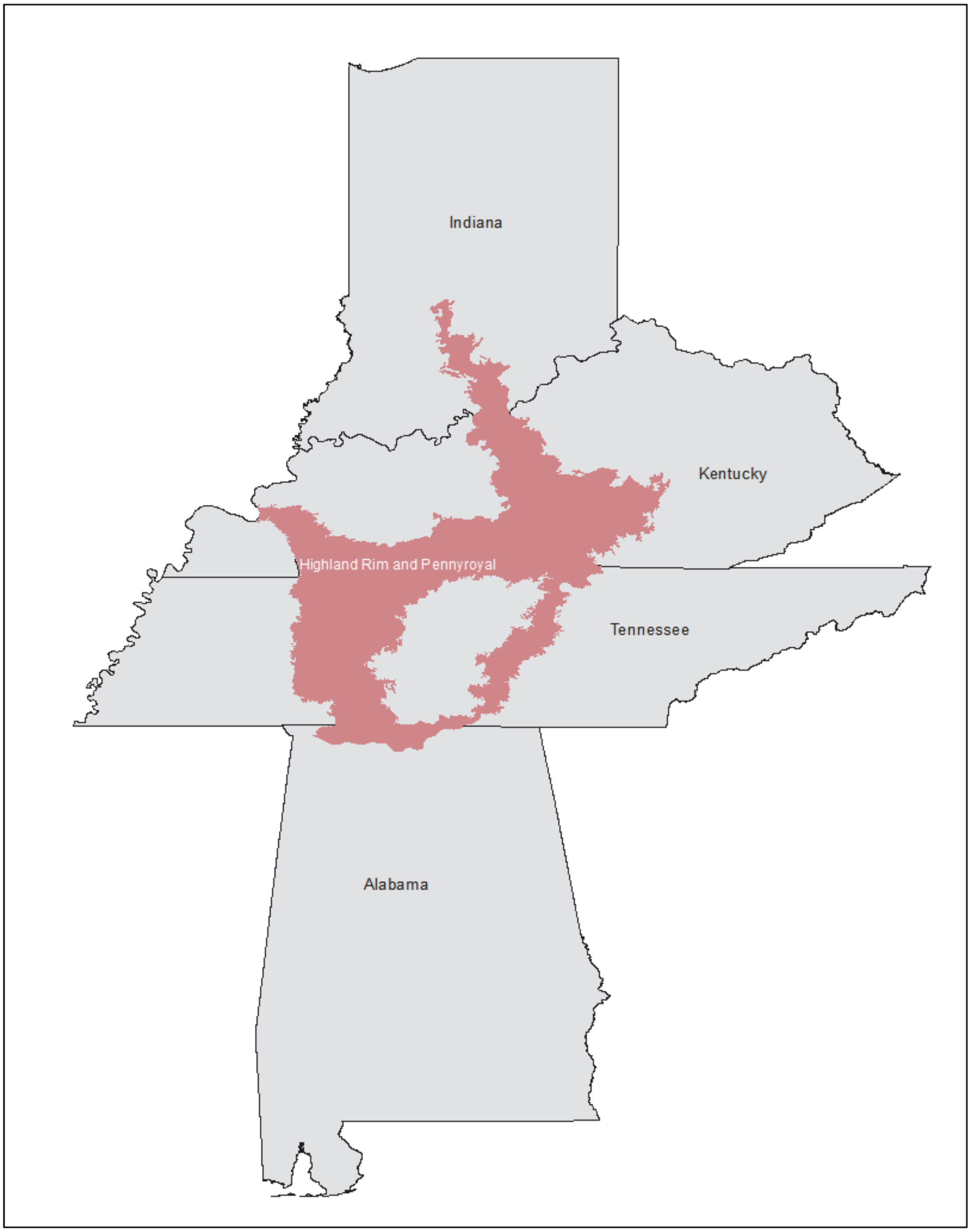

Figure 2. Map of the reference domain for Flat and Seasonally Inundated Depression wetlands on the Highland Rim.

Characterization of the regional subclass

Physiography and geology

The following information regarding physiography and geology of the Depression and Flat Wetlands area is quoted from USDA Natural Resources Conservation Service (2006).

This area is in the Highland Rim Section of the Interior Low Plateaus Province of the Interior Plains. It is a plateau consisting of low, rolling hills, upland flats, and narrow valleys. Steep slopes occur where the encircled Nashville Basin cuts into the area and along the western edge bordering the Coastal Plain. Elsewhere, except for steep walls and hillsides along deeply cut stream channels, the topography generally is gently rolling to strongly rolling and is interrupted in a few areas by broad upland flats and shallow basins. In many areas the land surface is pitted by limestone sinks. Elevation generally is 660 to 980 ft (200 to 300 m). It ranges from about 330 ft (100 m) along the deepest valley floors to about 1,310 ft (400 m) on the crest of isolated hills.

Most of this area is underlain by Ordovician- to Mississippian-age limestone and dolomite that has been exposed through erosion of the Cincinnati Arch. Parts of these rocks are covered by a layer of clay as much as 80 ft thick. Karst areas are common where the layer of clay does not occur. In the northernmost part of the MLRA, in Indiana, a sizable area is underlain by shale, sandstone, and limestone. Much of the bedrock on uplands and ridges is covered by a loess cap. Significant sand and gravel deposits occur.

The formation of Depressional wetlands is tied closely to the geology of the area. In general, this subclass of wetlands forms when the underlying carbonate rock is subjected to surface drainage or groundwater that results in dissolution, weakening, and eventual collapse of the rock. Such a collapse may result in the formation of a “sinkhole” of varying diameter and depth that often has a direct connection to groundwater (Jennings 1986). Once the sinkhole collapses, the depression begins to fill with sediment from the surrounding area. As a result, the downward movement of water may be reduced or occluded, resulting in the sinkhole holding water for long periods and eventually forming a wetland if vegetation becomes established.

The formation of Flat wetlands is not as well understood. Likely, most Flats within the HR formed because of the geologic interaction between level bedrock, the soils that form on or are deposited on the bedrock, and the eventual formation of a hardpan that is slowly permeable or relatively impermeable to water movement. The result is a level landscape that perches water near the surface long enough to produce hydric soils and a hydrophytic plant community (Baskin et al. 1999).

Climate

The climate within the reference domain is characterized by moderately hot summers and mild winters, typical of humid, mesothermal areas (Smalley 1983). Weather patterns are influenced primarily by air masses from either Canada or the Gulf of Mexico (Smalley 1983). Average overall temperature is approximately 58 °F (14 °C), with a growing season of approximately 190-200 days in length, extending from mid-April to mid-October (Chester and Ellis 1989). The last freeze of the year occurs in early to mid-April, while the first freeze is in mid- to late October. It is common for the ground to freeze to a depth of 2-6 in. (5-15 cm) several times during the year. Yearly rainfall averages 43-63 in. (109-160 cm), with most occurring during the spring and the least during the fall. Severe weather in the form of thunderstorms with intense rain occurs on approximately 55 days of the year, most during late spring and summer.

Hydrologic regime

Directly or indirectly, a wetland's hydrologic regime, or hydroperiod, affects all aspects of its structure and function (Mitsch and Gosselink 2000). The hydrologic regime of all wetlands, including Depressions and Flats within the reference domain, is determined by numerous interrelated and interacting factors including climate, timing and amounts of precipitation, the physical characteristics of the wetland and its watershed, soil characteristics, groundwater influences, and evapotranspiration. Some of these factors differ among subclasses of wetlands; consequently, there are differences in their hydrologic regimes and the concomitant plant community structure and the functions that the wetland performs. Depression and Flat wetlands have fundamentally different hydrologic regimes due primarily to their different physical characteristics (i.e., concave versus flat configuration) and the effects of those characteristics on hydrologic inputs and hydrodynamics.

Flat wetlands (Figure 3) are unique among other types within the reference domain in that direct precipitation is the primary source of hydrology. Runoff from the adjacent landscape is not significant because of the lack of topographic relief. The soils of wetlands in the Flat class commonly have a relatively impermeable layer near the surface and saturation occurs in the upper part for at least a portion of the growing season. Flat wetlands are not inundated for extended periods and, in fact, surface water normally is present only after heavy rainfall events. Ponding occurs primarily in micro-depressions; seldom over the entire wetland. Flat wetlands are saturated periodically during winter and spring, but normally are dry from May until the following winter. To date no criteria have been identified that would suggest Flat wetlands within the HR vary enough topographically or hydrologically to be classified into more than one subclass.

Figure 3. Typical Flat wetland within the HR.

The Depression wetlands within the reference domain all have a similar physical structure, but depending on depth and groundwater influence, can have distinctly different vegetation communities. These differences led to the designation of two Depression subclasses, namely Seasonally Inundated Depressions (SIDs) (Figure 4) and Semi-Permanently Inundated Depressions (SPIDs) (Figure 5). SIDs, the most common type, receive the majority of their annual hydrologic input from precipitation and runoff from the

Figure 4. Typical Seasonally Inundated Depression (SID) within the HR.

Figure 5. Typical Semi-Permanently Inundated Depression (SPID) within the HR.

adjacent landscape. Typically, wetlands in this subclass have a relatively impermeable soil layer near the surface that slows downward movement of water and results in a perched water table. Most SID wetlands pond water or are saturated in the upper portion of the soil profile from December through late spring (May-June). The wetlands typically are dry from this period until early winter (December) when they begin to accumulate water once again. In addition to precipitation and surface runoff, the SPID wetlands also receive groundwater inputs and commonly have much longer hydroperiods. They are relatively uncommon within the reference domain and are less likely to be impacted by human activities. Consequently, SPIDs are not included in this guidebook.

Soils

Hydric soils present in Depression and Flat wetlands within the HR generally are from 91-152 cm (36-60 in.) in depth and vary from nearly level to gently sloped (i.e., ≤ 2%). Drainage classes range from somewhat poorly drained to very poorly drained. Most soils are silt loams or silty clay loams and many have a fragipan within the upper 50 cm (20 in.) of the surface. Soil permeability varies but generally is moderate above the fragipan and slow within the fragipan. The hydric series that occur in Depression and Flat wetlands within the HR are listed in Table 5. Although some series tend to occur in specific landscape positions (e.g., the Prader series occurs primarily in Depression wetlands), other series are found in more than one setting (e.g., the Guthrie series occurs commonly in both Depressions and Flats (USDA Soil Conservation Service 1981).

Plant communities

The plant communities of the HR of Tennessee were classified by Braun (1950) as Western Mesophytic Forest (WMF) of the Mississippian Plateau. This region is transitional between the more mesic Mixed Mesophytic Forest Region to the east and the more xeric Oak-Hickory Forest Region to the west. In Tennessee, the Eastern Highland Rim (EHR) is the eastern limit of the WMF (McKinney 1989). Within the WMF, no single climax type occurs; instead a mosaic of types is determined by local climatic and edaphic factors and topography (i.e., exposure, slope, etc.) (Chester and Ellis 1989). McKinney (1989) identified six distinct forest communities within the EHR. These included xeric and sub-xeric forests, mesic upland forests, mixed mesophytic forests, swamp forests, bottomland forests, and hemlock (*Tsuga canadensis*) forests. Chester and Ellis (1989) developed a similar, but more detailed description of forests on the Western Highland Rim (WHR). In both the EHR and WHR, upland habitats constitute a very high percentage of the landscape.

Table 5. Landscape Settings and Characteristics of Common Hydric Soils in Depression and Flat Wetlands Within the Highland Rim of Tennessee

Map Unit Name and Symbol	Landscape Setting	Depth (cm)	% Slope	Drainage Class
Bonair silt loam (Bn)	Depression	157	<1	Poorly Drained
Dekoven silt loam (De)	Depression	122	<1	Poorly Drained
Elkins silt loam (Ek)	Depression	91	0 - 2	Poorly Drained
Forestdale silt loam (Fo)	Flat	152	<1	Poorly Drained
Guthrie silt loam (Gs/Gu)	Depression and Flat	152	0 - 2	Poorly Drained
Lee silt loam (Lb)	Depression	107	0 - 2	Poorly Drained
Newark silt loam (Ne)	Depression	107	0 - 2	Somewhat Poorly Drained
Prader (Atkins) (Pf)	Depression	107	<1	Poorly Drained
Purdy silt loam (Pd/Ph)	Depression and Flat	91	0 - 2	Poorly Drained
Robertsville silt loam (Ra/Rb)	Depression and Flat	152	<1	Poorly Drained

The primary forest type of much of the WHR is classified as oak and oak-hickory (Eyre 1980) with more mesophytic communities found in ravines and other areas. Besides oaks such as scarlet oak (*Quercus coccinea*), southern red oak (*Q. falcata*), and black oak (*Q. velutina*), common species in upland settings include pignut hickory (*Carya glabra*), blackgum (*Nyssa sylvatica*), and black cherry (*Prunus serotina*). More mesic sites commonly are dominated by sugar maple (*Acer saccharum*), American beech (*Fagus grandifolia*), and tulip poplar (*Liriodendron tulipifera*) (Chester and Ellis 1989). Descriptions from the EHR (McKinney 1989) indicate that plant communities in upland settings generally are quite similar.

As with upland landscapes, most of the wetlands within the HR are forested, but the composition of communities in both Depressions and Flats differ from either xeric or mesic sites (Ellis and Chester 1989). Wetlands within the HR have not been well studied, and the following description is from a few high quality sites that were intensively studied by Ellis and Chester (1989). Oaks occupied a substantial portion of the canopy in the wetlands, but the dominant species were different than in upland settings. Common species included willow oak (*Q. phellos*) and water oak (*Q. nigra*) with overcup oak (*Q. lyrata*) and pin oak (*Q. palustris*) sometimes present. Other species that were abundant at one or more sites include sweetgum (*Liquidambar styraciflua)*, red maple (*A. rubrum*), blackgum, sycamore

(*Platanus occidentalis*), and eastern cottonwood (*Populus deltoides*). This difference in species composition between upland and wetland forest communities is due largely to differential tolerance for anoxic soil conditions produced by prolonged ponding or soil saturation (Mitsch and Gosselink 2000). Plants that lack such tolerance are excluded from wetlands and while wetland plants can grow and reproduce in upland settings, they often are out-competed by better-adapted species.

The primary wetland forest type recognized by the Society of American Foresters (Burns and Honkala 1990) within the reference domain is the sweetgum and willow oak association, referred to as "Type 92." The authors noted that there often is considerable variation among stands, and an individual stand may include either of these species or other associates (Burns and Honkala 1990). Descriptions from both the WHR and EHR (Ellis and Chester 1989, Chester and Ellis 1989) confirm that variability does exist among sites. Scott et al. (1980) and Ellis and Chester (1989) suggested that the composition of an individual wetland within the WHR is dependent on degree of standing water, soil saturation, and water table level.

Few studies have examined plant community composition of Depression and Flat wetlands, but they do support the conclusion that some differences exist. Call (2003) quantified and compared the community composition between the two HGM classes. He found differences in species composition in all strata between forested Depressions and Flats at Arnold Air Force Base (AAFB). Most of the other work within the reference domain has been descriptive and has been conducted at sites that would be assigned to the Depression class. Dominants in these Depression wetlands included willow oak, overcup oak, and many of the other species mentioned above. Only a portion of Cedar Hill Swamp, referred to by Chester and Ellis (1989) as an "upland flat" likely would be assigned to the Flat class. The site was described in detail by Ellis and Chester (1989) and supported white oak (*Q. alba*), southern red oak, black oak, and chestnut oak (*Q. prinus*). These species have less tolerance for wetness than those found in Depression wetlands. A more detailed description of the plant communities of both HGM classes can be found in the plant community model.

Anthropogenic alterations

Although it is difficult to determine the conditions that existed within the reference domain prior to its current altered state, it is likely that the majority of the area was forested. This supposition is supported by descriptions written by early settlers traveling through the HR (Luther 1977) and by Braun (1950). This was true especially of the western and northeastern portions of the HR.

The initial alterations within the region specific to wetlands and associated habitats likely were forest clearing and subsequent filling or draining for agricultural production. Depressions often were filled or drained by ditches that were constructed to remove surface water and draw down the local groundwater. Drainage of Flat wetlands initially was carried out by installing a system of ditches, but the larger size and lack of topographic relief within this subclass made this technique less efficient than in Depression wetlands. The development and use of subsurface drainage pipes and tiles subsequently increased the efficiency of drainage in the Flat wetlands. Even in wetlands that could not be filled or effectively ditched, the plant communities were altered by timber harvest. Land clearing and timber harvest also occurred in the adjacent landscape, resulting in the creation of “wetland islands” surrounded mostly by agricultural land.

Worldwide, conversion for agriculture continues to be the major cause of wetland destruction (Mitsch and Gosselink 2000). However, on a regional scale this trend may be changing, especially in areas such as the HR. An assessment of mitigation in Tennessee indicated that most of the impacts to wetlands within the HR were for residential or industrial development, and road or bridge building activities (Morgan and Roberts 1999). Regardless of the mechanisms, the amount of development within the HR has been extensive, resulting not only in the loss of Depression and Flat wetlands, but also in the loss of other habitats closely associated with them.

4 Wetland Variables, Functions, and Assessment Models

Variables

The following variables are used to assess the functions that are performed by Depression and/or Flat wetlands in the HR:

1. Change in catchment size
2. Surrounding land use
3. Habitat connections
4. Wetland drainage
5. Change in wetland volume
6. Microtopographic features
7. Canopy tree diameter
8. Canopy tree density
9. Shrub density
10. Ground vegetation cover
11. Vegetation composition and diversity
12. O Horizon thickness

Each variable is defined and the rationale for its selection is discussed in the following paragraphs. The relationship of each variable to functional capacity (based on measurements taken in reference wetlands within the HR of Tennessee) is also given. Procedures for measuring each variable in the field can be found in Chapter 5.

Change in catchment size (V_{CATCH})

This variable is defined as the change in the size of a SID wetland catchment, watershed, or basin as a result of human activities in the wetland's landscape. The intent of this variable is to assess the change in 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 case of water diversions away from the SID wetland due to ditches, berms, or other features in the catchment, the change is quantified as a percent loss of catchment area by using the following formula (Equation 1):

$$Percent\ change = \left[\left(\frac{Natural\,catchment\,size - Existing\,catchment\,size}{Natural\,catchment\,size}\right)\times 100\right] \qquad (1)$$

In the case of water transfers into the wetland's catchment from another basin, the change is calculated as a percent increase in effective catchment area as follows (Equation 2):

$$Percent\ change = \left[\left(\frac{Area\,of\,catchment\ from\,which\,water\,is\,being\,transferred}{Wetland's\,natural\,catchment\,size}\right)\times 100\right] \qquad (2)$$

If the effective size of the catchment is unchanged (i.e., no water diversions), then the subindex score is 1.0. Reference standard SID wetland sites had no change in the size of the catchment (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 percent change equals 100 (Figure 6). This is based on the assumption that, as the effective size of the catchment decreases, the amount of water entering the SID 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. Additions of water to the wetland's 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 SID wetland's catchment, the percent change in effective catchment area can exceed 100 percent.

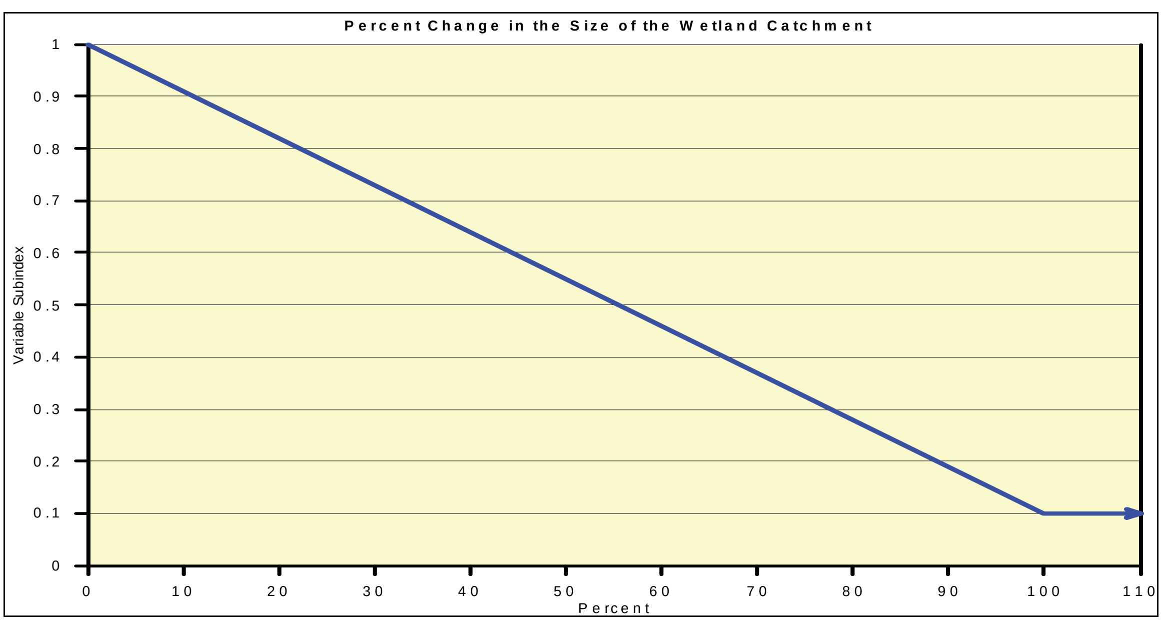

Figure 6. Relationship between the percent change in effective size of the wetland catchment (V_{CATCH}) and functional capacity for Seasonally Inundated Depression wetlands.

Surrounding Land Use ($V_{LANDUSE}$)

This variable is defined as the surface water runoff potential from the wetland catchment into a SID wetland. With increased disturbance and increased impervious surface surrounding the wetland, more surface water enters the SID than under reference standard conditions. Runoff scores are based on runoff curves developed by the Natural Resources Conservation Service (NRCS). Runoff curve numbers are a function of land use and soil hydrologic groups. Hydrologic soil groups are based on soil properties such as texture and depth to restrictive layers. A hydrologic soil group of B has been assumed for all soils throughout the HR. Therefore a subindex score for $V_{LANDUSE}$ is based on the weighted average of land uses identified in the area surrounding the SID wetland (Table 6) being assessed (see Appendix B for an example calculation). 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 latter site also provides the most current soil survey maps. $V_{LANDUSE}$ only applies to the hydrology function of SID wetlands.

Table 6. Runoff curve numbers.

Surrounding Land Use	Curve Number (CN)
Paved (roads, parking lots, roofs, etc.)	98
Commercial and business	92
Industrial	88
Gravel roads	85
Compacted soil (dirt roads, construction areas, etc.)	82
Cropland (poor condition)	80
High-density residential (1/8-acre lots)	75
Cropland (fair condition)	75
Cropland (good condition)	70
Low-density residential (1-acre lots)	68
Forest (grazed)	66
Green space (lawns, parks, golf courses, etc.)	61
Pasture and hayland	60
Orchards and tree farms	58
Forest (ungrazed)	55
Water (ponds, lakes, etc.)	0

Modified from USDA Natural Resources Conservation Service (1986)

The catchments of reference standard wetlands contained only native forest communities. Such reference standard conditions have runoff scores of 55 or less and would receive a subindex score of 1.0 (Figure 7). Land uses that significantly increase the amount of runoff into a SID 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.

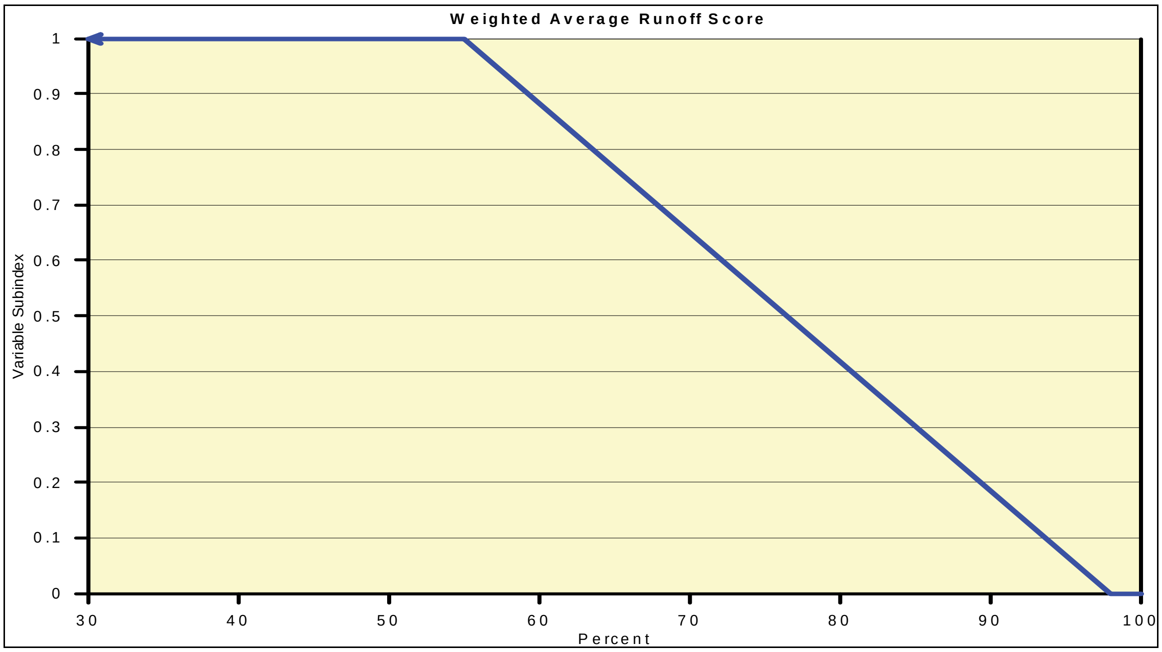

Figure 7. Relationship between weighted average runoff score ($V_{LANDUSE}$) and functional capacity in the catchment of Seasonally Inundated Depression wetlands.

Habitat connections ($V_{CONNECT}$)

This variable is defined as the weighted average of the wetland perimeter within specific width categories of suitable wetland or upland wildlife habitat that is connected to the wetland. To be considered in this calculation, a zone or buffer of suitable habitat must extend at least 10 m (32.8 ft) beyond the wetland boundary. It is assumed here that nearly all forested areas with normal stocking will provide at least minimally suitable habitat for amphibians and most other small wildlife species that may depend on wetlands and adjacent habitats for food, cover, and breeding sites. Examples of other suitable community types include prairie, savanna, and scrub/shrub habitats. Managed pine forests and 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 for Depressional wetlands.

Ideally a zone or buffer of suitable habitat should extend 150 m (492 ft) or more beyond the wetland boundary and that condition should exist at all reference standard wetlands sampled. A narrower zone or buffer can, however, provide habitat for many amphibian, reptile, and avian species that utilize depressional wetlands. This variable is measured by identifying the length of wetland perimeter that meets each of the following width categories. Each length is multiplied by the appropriate constants. If the width is ≤ 10 m (32.8 ft), multiply by 0.0; if the width is ≥ 10 m and < 30 m (32.8-98.4 ft), multiply by 0.33; if the width is ≥ 30 m and < 150 m (98.4-492 ft), multiply by 0.66; if the width is ≥ 150 m (492 ft), multiply by 1.0. Using Figure 8, convert the weighted average to a subindex for $V_{CONNECT}$. See Appendix B for an example calculation of $V_{CONNECT}$.

A subindex value of 0.0 is assigned to sites where none of the wetland perimeter is buffered by a zone of suitable habitat. Reference standard wetlands have 85 to 100 % of their perimeters suitably buffered by a zone at least 150 m (492 ft) wide. At sites where the percentage of the wetland perimeter with a suitable buffer is between 0 and 85 %, or the width is less than 10 m (32.8 ft), the relationship between the amount of suitable buffer and functional capacity is reduced.

Wetland drainage (V_{DRAIN})

This variable represents hydrologic alteration resulting from drainage activities (e.g., ditching and tiling) in the wetland. Wetland drainage structures alter the hydrologic regime by rapidly removing surface and subsurface water located in the vicinity of the drainage structure. The lateral extent of the alteration is referred to as the lateral effects distance (L_e) and is shown in Figure 8. The lateral effects distance is related to the depth of the drainage structure, the saturated hydraulic conductivity of the soil through which water is being drained, and the drainable porosity of the soil. V_{DRAIN} applies only to the hydrology, biogeochemistry, and wildlife habitat functions of Flat wetlands.

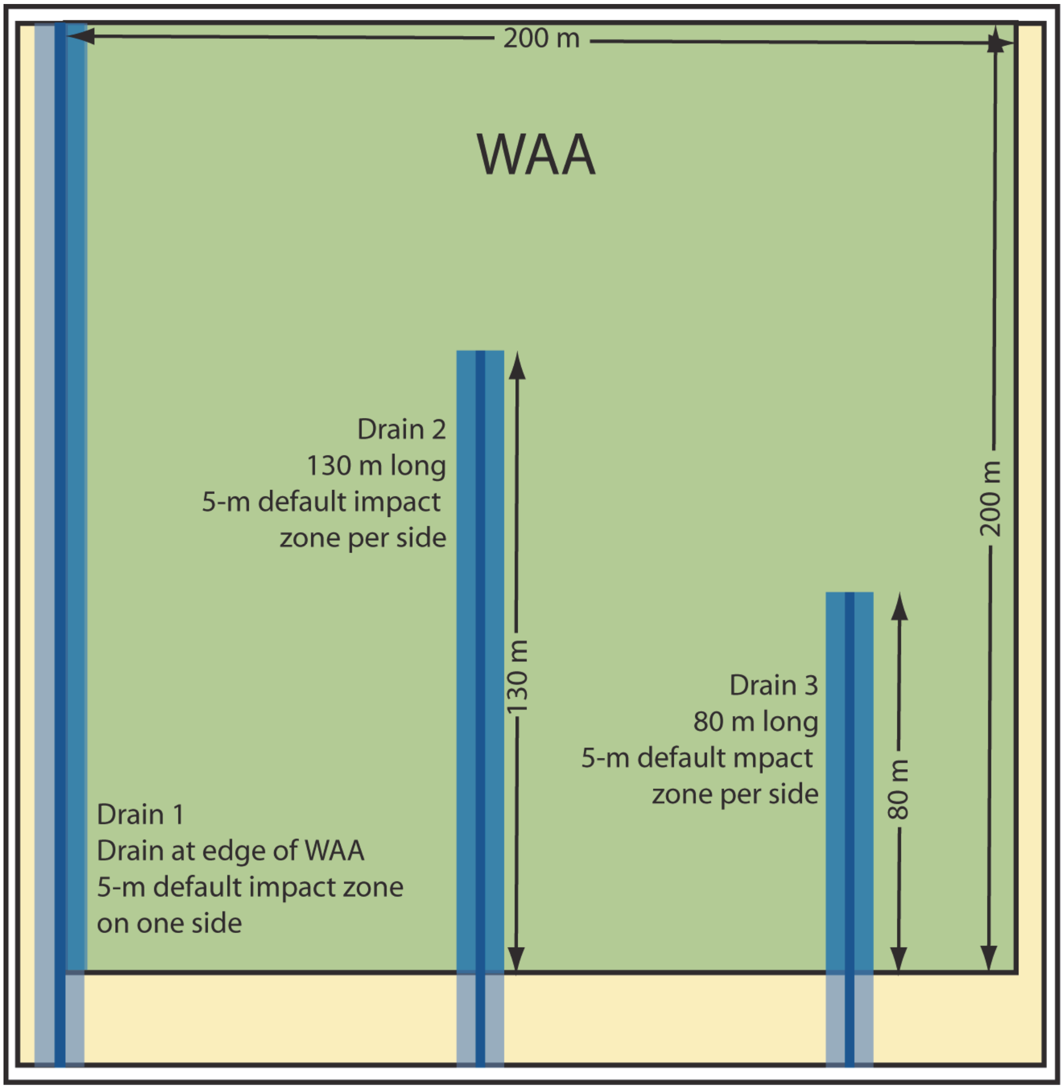

Figure 8. Lateral drainage effect of a ditch on subsurface water storage in Flat wetlands.

A number of equations have been developed to predict the effects of subsurface drainage structures on site hydrology. These equations are referred to as “Scope and Effect” equations. The Ellipse equation was used to determine the lateral effects distance based on saturated soil conditions for soils commonly found in Flat wetlands within the HR. It was determined that the hydrologic regime of any area within 16 ft (5 m) of a ditch would be significantly altered and would be assigned a subindex of 0.1. It is always recommended to use the best data available. If more precise data are readily available to assess V_{DRAIN}, they should be used.

Wetland volume (V_{WETVOL})

This variable is defined as a change in the wetland volume. SID wetlands store a certain volume of water based on the size and depth of the wetland.

Changes to the volume of a SID usually result from the placement of fill material into the wetland or from the excavation and removal of soil material from the wetland.

In reference sites within the HR, the percentage change in wetland volume ranged from 0 to 60%. Based on data from reference standard sites, a variable subindex of 1.0 is assigned to sites that had no change in wetland volume (i.e., no fill or excavation). As the percentage of alteration increases above 0%, a linearly decreasing subindex down to zero is assigned for wetlands that have been completely filled or have been excavated to the extent that the volume of a SID wetland has doubled (Figure 9). The rationale for reducing the subindex score to 0 when increasing the volume is that increasing the volume by 100% or more could potentially change the wetland from a SID to a different wetland class (i.e., deep-water habitat).

Microtopographic features (V_{MICRO})

This variable represents alteration to microtopographic features that are prominent in the majority of unaltered Flat wetlands within the HR. Water storage in micro-depressions reduces surface runoff following heavy rainfall events and promotes recharge of the underlying water table (Logan and Rudolph 1997). Accurate estimation of micro-depressional storage is challenging due to high spatial and temporal variability in surface structure. Figure 10 compares three surface profiles measured in reference standard Flat wetlands. The profiles illustrate the high natural variability in micro-topographic structure. The subindex score for V_{MICRO} is based on a categorical assessment of the condition of the wetland relative to human alteration (Table 7).

Canopy tree diameter (V_{CTD})

This variable is the average diameter at breast height (dbh) of canopy trees measured at 1.4 m (55 in.) above the ground. This variable is only measured if percent tree cover is 20% or greater. Canopy trees are defined as self-supporting woody plants ≥10 cm (4 in.) dbh, whose crowns comprise the uppermost stratum of the vegetation. Canopy trees are not immediately overtopped by taller trees and would be clearly seen from above (Figure 11). Tree diameter is a common measure of dominance in forest ecology, used either alone or in combination with tree density and basal area (Whittaker et al. 1974, Whittaker 1975, Spurr and Barnes 1980, Tritton and Hornbeck 1982, Bonham 1989). It expresses the relative age or maturity of a forest stand. V_{CTD} applies to all functions for SID and Flat wetlands.

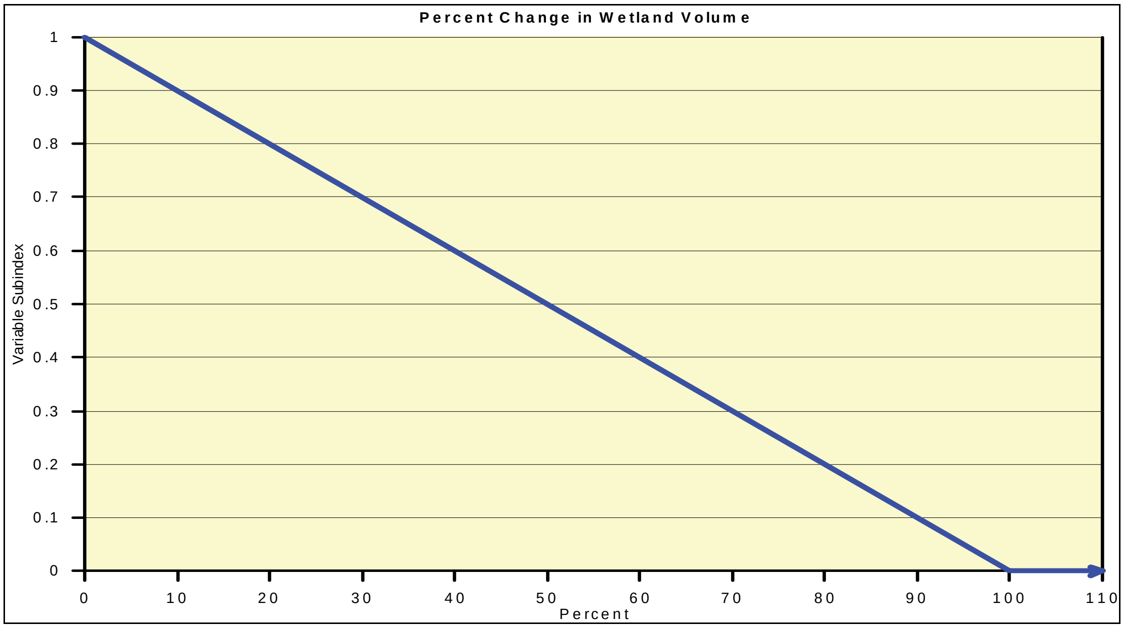

Figure 9. Relationship between change in wetland volume (V_{WEVTOL}) and functional capacity for Seasonally Inundated Depression wetlands.

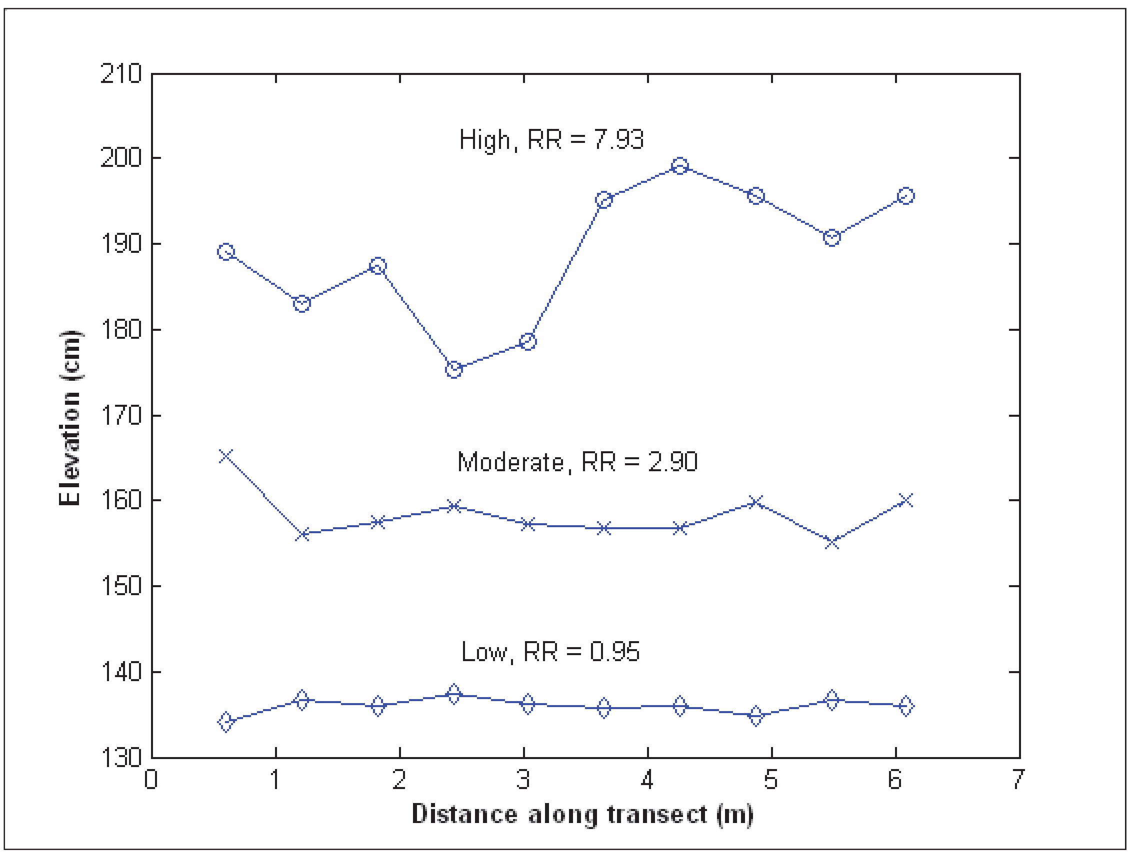

Figure 10. Three surface profiles with low, moderate, and high random roughness, which reflect the amount of microtopographic relief present in Flat wetlands.

Table 7. Microtopography Alteration

Alteration	Subindex score
Unaltered	1.0
Excavated (Ponds)	0.5
Land leveled	0.1

Canopy tree diameter (V_{CTD})

This variable is the average diameter at breast height (dbh) of canopy trees measured at 1.4 m (55 in.) above the ground. This variable is only measured if percent tree cover is 20% or greater. Canopy trees are defined as self-supporting woody plants ≥10 cm (4 in.) dbh, whose crowns comprise the uppermost stratum of the vegetation. Canopy trees are not immediately overtopped by taller trees and would be clearly seen from above (Figure 11). Tree diameter is a common measure of dominance in forest ecology, used either alone or in combination with tree density and basal area (Whittaker et al. 1974, Whittaker 1975, Spurr and Barnes 1980, Tritton and Hornbeck 1982, Bonham 1989). It expresses the relative age or maturity of a forest stand. V_{CTD} applies to all functions for SID and Flat wetlands.

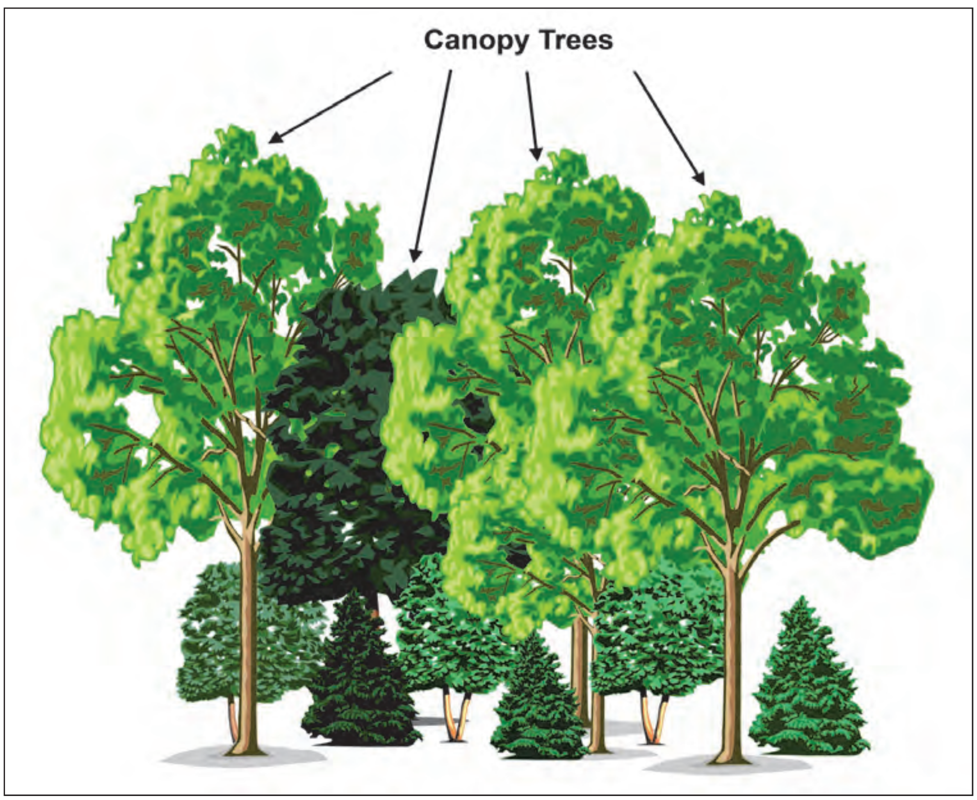

Figure 11. Example of canopy trees. Although not necessarily the tallest trees in a stand, canopy trees have no other tree foliage directly above them.

In SID and Flat wetlands within the HR, the average dbh of canopy trees ranged from 0.0 cm on sites where all trees had been removed to 44 cm (17 in.) in mature forest stands. Based on data from reference standard sites, a variable subindex of 1.0 is assigned when the mean value is ≥39 cm (15 in.) in Flat wetlands and the dbh is ≥33 cm (13 in.) in SIDs wetlands. The relationship between canopy tree diameter and functional capacity of a Flat wetland (Figure 12) and a SID wetland (Figure 13) is assumed to be linear; thus, the subindex increases linearly from 0.1 to reference standard values.

Canopy tree density (V_{CTDEN})

This variable is defined as the density of canopy trees expressed as the number of tree stems per hectare. Canopy trees are defined as woody plants ≥10 cm (4 in.) dbh whose crowns comprise the uppermost stratum of the vegetation (see V_{CTD} above) and is only measured if percent tree cover is 20% or greater. Tree density, in combination with average tree diameter, is a measure of the dominance and biomass of trees in a forest stand. V_{CTDEN} applies to all functions in SID and Flat wetlands.

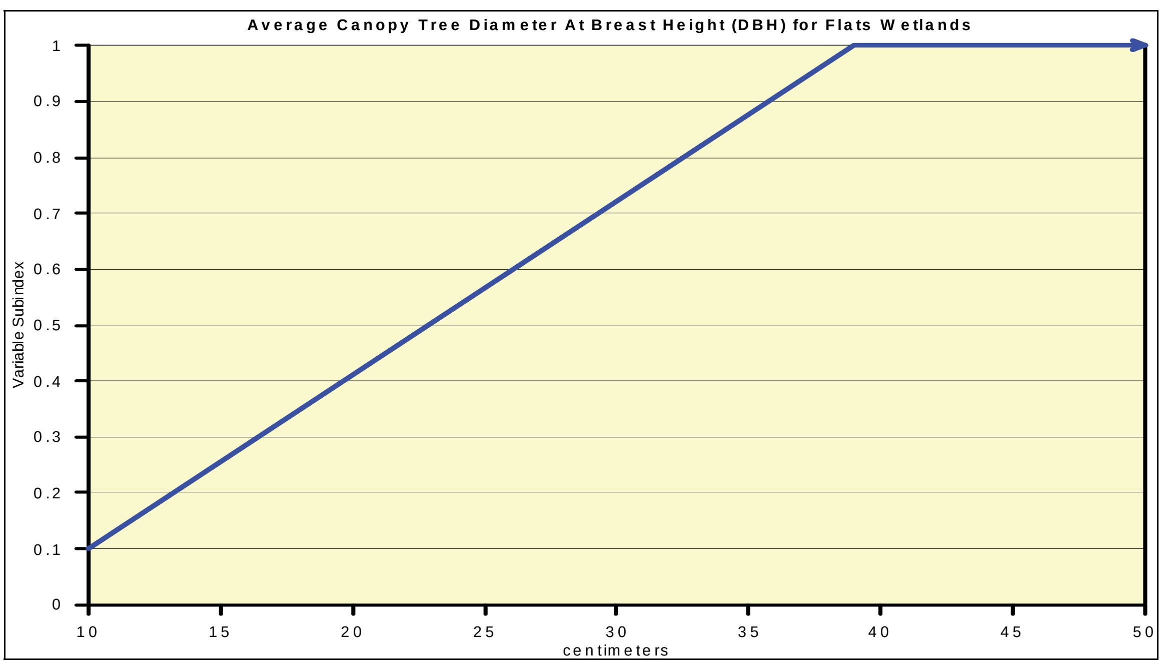

Figure 12. Relationship between average canopy tree diameter (V_{CTD}) at breast height and functional capacity for Flat wetlands.

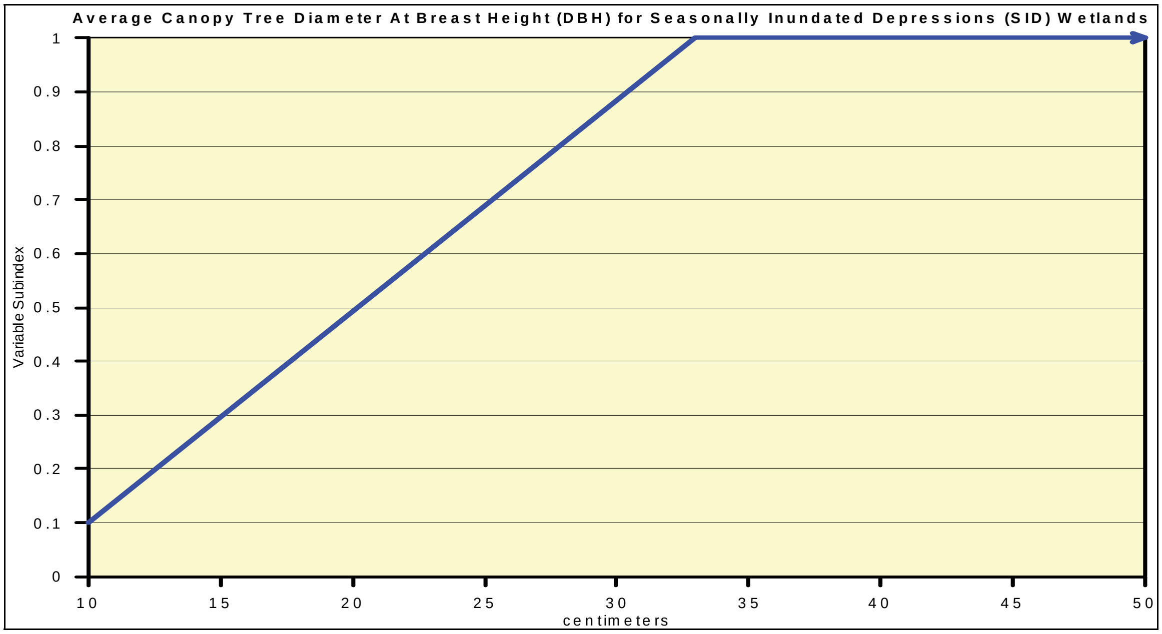

Figure 13. Relationship between average canopy tree diameter (V_{CTD}) at breast height and functional capacity for Seasonally Inundated Depression wetlands.

In SID and Flat reference wetlands within the HR, the average canopy tree density ranged from 0.0 stems/ha on sites where all trees had been removed to 975 stems/ha in the densest stands. Based on data from reference standard sites, a subindex value of 1.0 is assigned when the density of canopy trees is between 100 and 200 stems/ha for Flat wetlands (Figure 14) and between 100 and 275 stems/ha for SIDs (Figure 15). A subindex value of 0.0 is assigned to severely altered sites that lack canopy trees and have density values of zero. At sites on which canopy tree density is between zero and the minimum reference standard value, the relationship between canopy tree density and the capacity to support characteristic wetland processes is assumed to be linear. During mid-successional stages, canopy tree density may exceed that in reference standard sites and it is assumed that characteristic processes will be adversely affected.

Shrub density (V_{SDEN})

This variable is defined as the average number of stems per unit area 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 Depression or Flat wetlands during early to mid-successional stages. V_{SDEN} applies only to the biogeochemistry, plant community, and wildlife habitat functions.

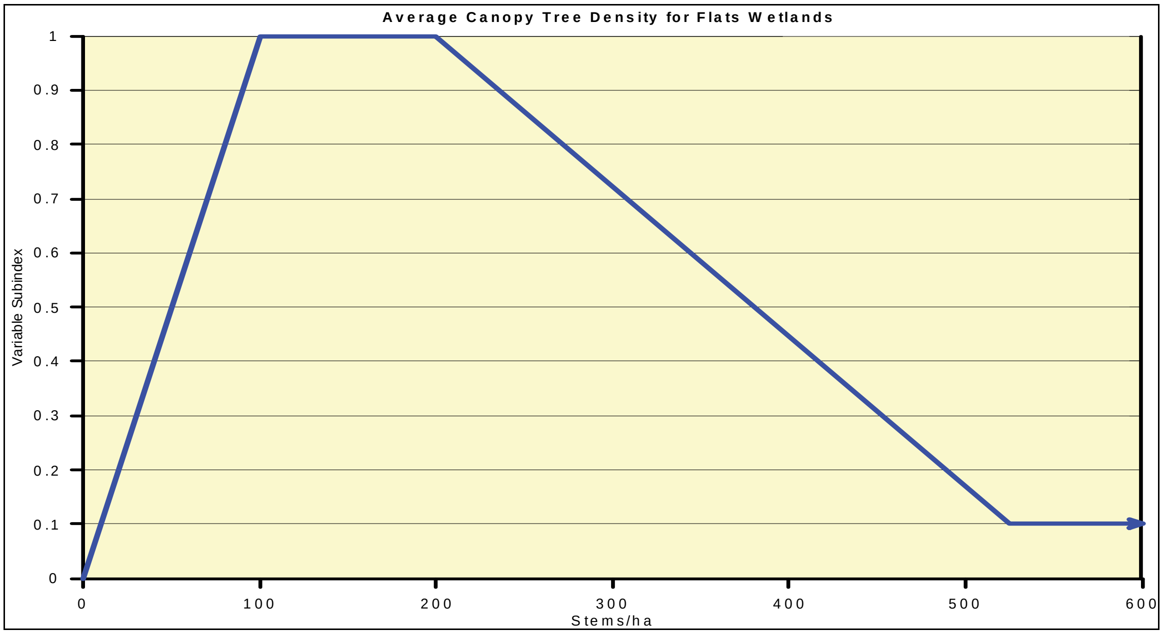

Figure 14. Relationship between average canopy tree density (V_{CTDEN}) and functional capacity for Flat wetlands.

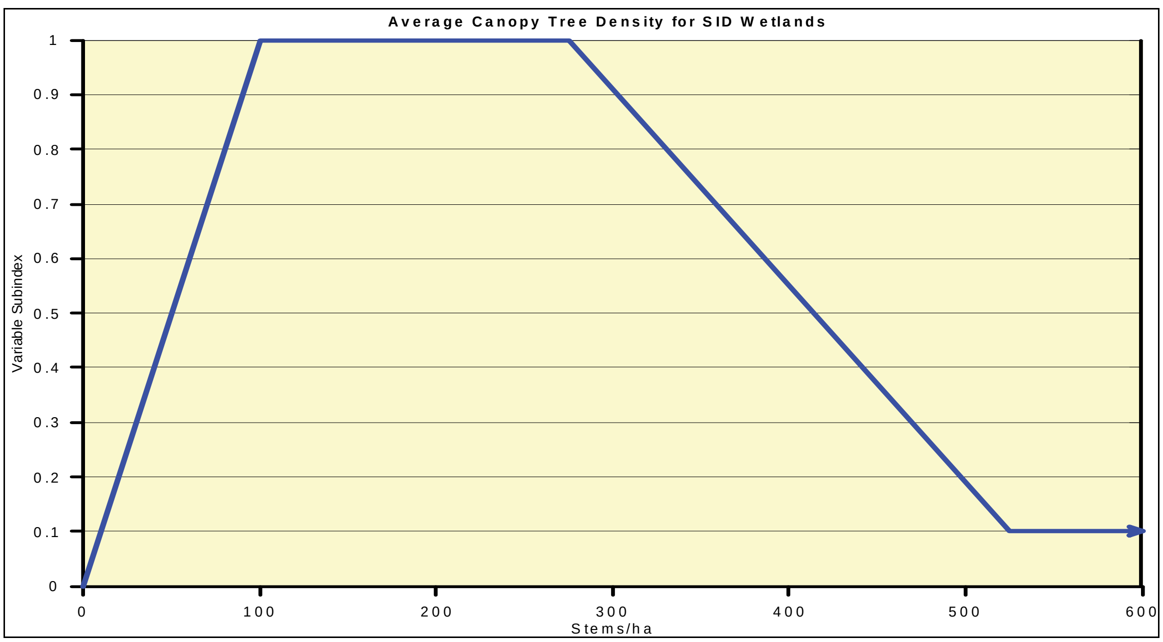

Figure 15. Relationship between average canopy tree density (V_{CTDEN}) and functional capacity for Seasonally Inundated Depression wetlands.

This variable is not used to evaluate SID or Flat wetlands within the HR that have a well-developed tree canopy. Instead, V_{SDEN} is measured only in areas with <20 % tree cover due to recent natural or anthropogenic disturbance. In this context, V_{SDEN} reflects the amount of woody regeneration on the site that contributes immediately to carbon cycling, provides habitat for wildlife, and eventually will develop into a mature forest. Therefore, higher values of shrub cover are assumed to contribute more to these functions. Based on reference data, a subindex of 1.0 is assigned when shrub density is ≥1,500 per ha in Flat wetlands (Figure 16) and ≥750 per ha in SIDs (Figure 17).

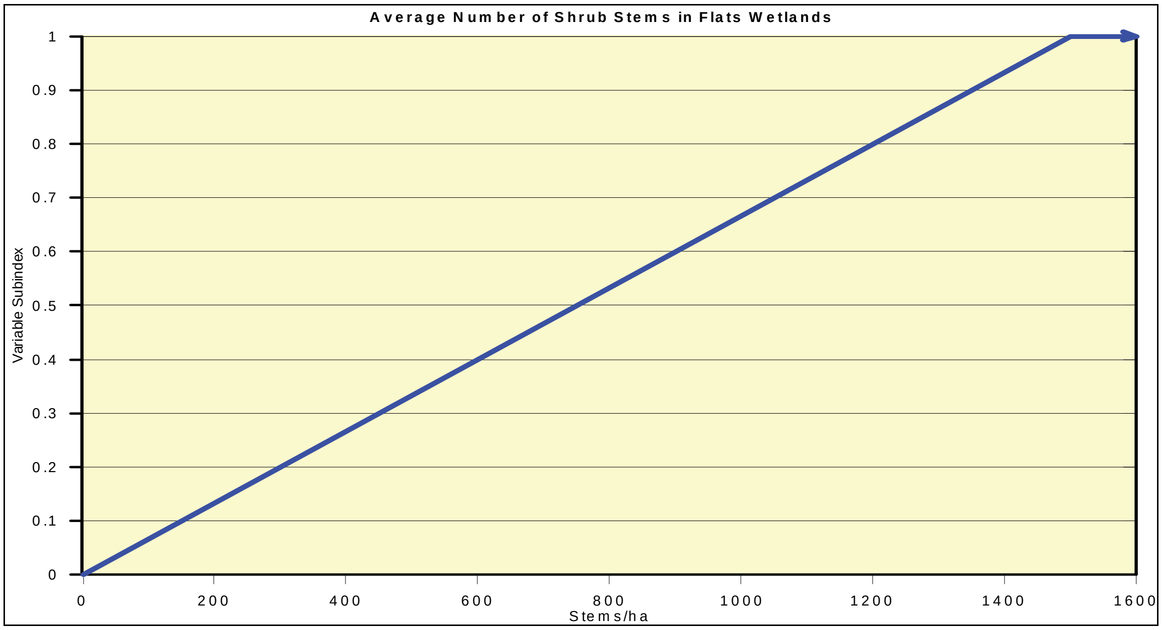

Figure 16. Relationship between average number of shrubs per hectare (V_{SDEN}) and functional capacity for Flat wetlands.

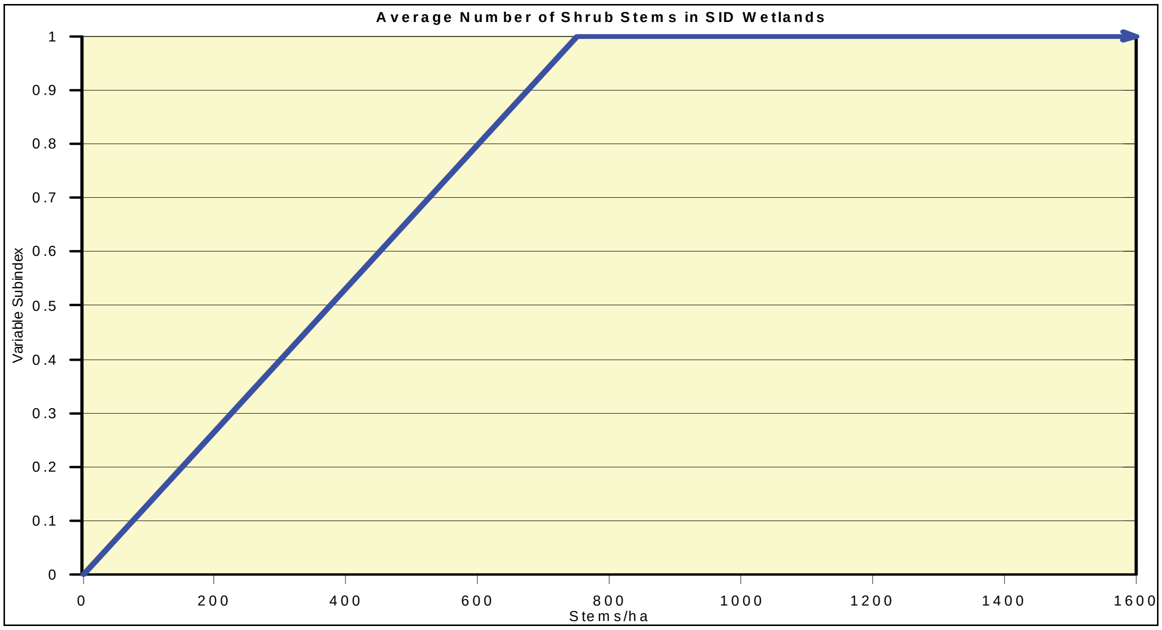

Figure 17. Relationship between average number of shrubs per hectare (V_{SDEN}) and functional capacity for Seasonally Inundated Depression wetlands.

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 related to the abundance and biomass of low-growing vegetation in both SID and Flat wetlands and affects 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%.

This variable is not used to evaluate SID or Flat wetlands that have a well-developed tree or shrub canopy. Instead, V_{GVC} is measured only in areas where tree and shrub cover are both <20% due to severe natural or anthropogenic disturbance. 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 a woody midstory and canopy. Ground vegetation cover on reference sites with <20% tree and shrub cover was highly variable and ranged from 0 to 84%, with Flat wetlands typically having higher values. A subindex of 1.0 is assigned when ground vegetation cover is ≥70% for both Flat and SID wetlands (Figure 18).

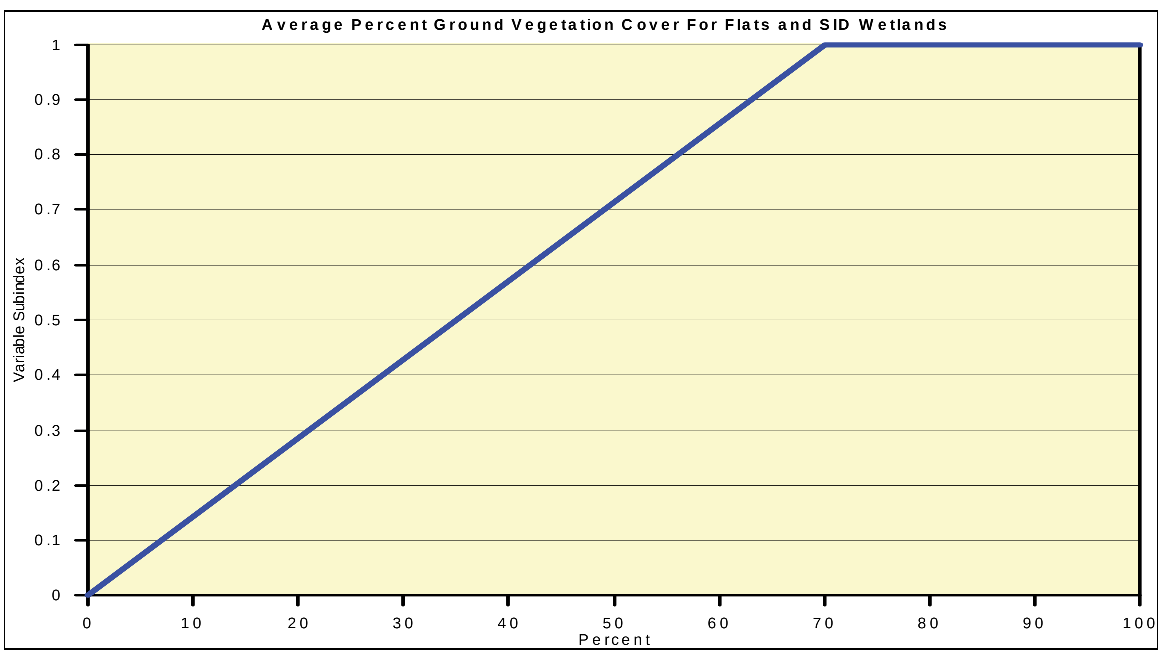

Figure 18. Relationship between average percent ground vegetation cover (V_{GVC}) and functional capacity for Flat and SID wetlands.

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, as recommended by Smith and Klimas (2002). In reference standard wetlands within the HR, 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. Implicit in this approach is the assumption that the "quality" of the tallest layer is a good indicator of overall community composition and successional patterns (i.e., appropriate sapling and shrub composition indicates 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 19. Note that the tree stratum includes all trees ≥10 cm (4 in.) dbh and not just "canopy" trees.

Steps in the 50/20 Rule for Selecting Dominant Plant Species:

1. Apply this procedure only to the tallest stratum present. To count as present, the total cover of the tree and shrub strata must be ≥20%.
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.

Figure 19. Description of the 50/20 rule.

Dominant species are classified into three groups reflecting presumed floristic quality (Table 8). Group 1 consists of species that characterize undisturbed Flat or SID wetlands in the HR. This group consists of various species of water-tolerant oaks. Group 2 consists of native trees or shrubs that often are present in Flat or SID wetlands, even in reference standard

Table 8. Quality Scores for Dominant Plant Species Used to Calculate V_{COMP}.

Scientific Name[1]	Common Name	Score
Group 1		
Quercus nigra	Water oak	1.0
Quercus alba	White oak	
Quercus phellos	Willow oak	
Quercus michauxii	Swamp chestnut oak	
Quercus palustris	Pin oak	
Quercus pagoda	Cherrybark oak	
Quercus shumardii	Shumard oak	
Quercus lyrata	Overcup oak	
Nyssa aquatica	Water tupelo	
Nyssa sylvatica	Swamp blackgum	
Cephalanthus occidentalis	Common buttonbush	
Group 2[2]		
Ulmus americana	American elm	0.66
Ulmus rubra	Slippery elm	
Liquidambar styraciflua	Sweetgum	
Nyssa sylvatica	Blackgum	
Acer negundo	Boxelder	
Cornus foemina	Stiff dogwood	
Lireodendron tulipifera	Tulip poplar	
Fraxinus pennsylvanica	Green ash	
Acer rubrum	Red maple	
Salix nigra	Black willow	
Carpinus caroliniana	American hornbeam	
Native herbaceous (SID)		
Group 3[3]		
Ligustrum vulgare	European privet	0.0
Lonicera japonica	Japanese honeysuckle	
Polygonum cuspidatum	Japanese stiltgrass	
Lythrum salicaria	Purple loosestrife	
Arundo donax	Giant reed	
Schedonorus phoenix	Tall fescue	
Phragmites australis	Common reed	

[1] Plant names according to the USDA Plants database (http://plants.usda.gov/).

[2] Other native plant species may be added to Group 2.

[3] Other non-native or invasive plant species may be added to Group 3.

sites. A minor presence in reference standard sites is acceptable, but dominance by members of this group indicates significant disturbance. Group 3 consists of non-native (exotic) species or native invasive species that usually are found only in highly degraded sites.

In reference standard HR wetlands within the reference domain, dominant vegetation composition included species from Groups 1 and 2, and the number of dominants was four or greater. As either composition or richness 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 richness and quality of dominant species. V_{COMP} applies only to the plant community function.

O horizon thickness (V_{OHOR})

This variable is defined as the soil layer dominated by organic material that consists of recognizable or partially decomposed organic matter such as leaves, needles, sticks, or twigs <0.6 cm in diameter, flowers, fruits, insect frass, moss, or lichens on or near the surface of the ground (USDA Natural Resources Conservation Service 1993). As used in this guidebook, it is synonymous with the general term humus and is distinct from the litter layer that consists of freshly fallen material that is not in an advanced stage of decomposition.

Based on data from reference standard sites, a subindex value of 1.0 is assigned when O horizon thickness is between 1.5 and 5.3 cm in Flats wetlands (Figure 20) and between 2.3 and 4.4 cm in SID wetlands (Figure 21). A subindex value of 0.0 is assigned to sites in which the O horizon has been removed by human activities, scoured away by increased surface flows, or has been buried under fill material. At sites in which the thickness is between zero and the minimum reference standard value, the relationship between the thickness of the O horizon and the capacity to support characteristic biogeochemical processes is assumed to be linear. Activities that cause increased ponding of surface water may result in O horizon thickness exceeding that in reference standard sites (e.g., due to slower decomposition rates), and it is assumed that characteristic biogeochemical processes will be adversely affected by these activities.

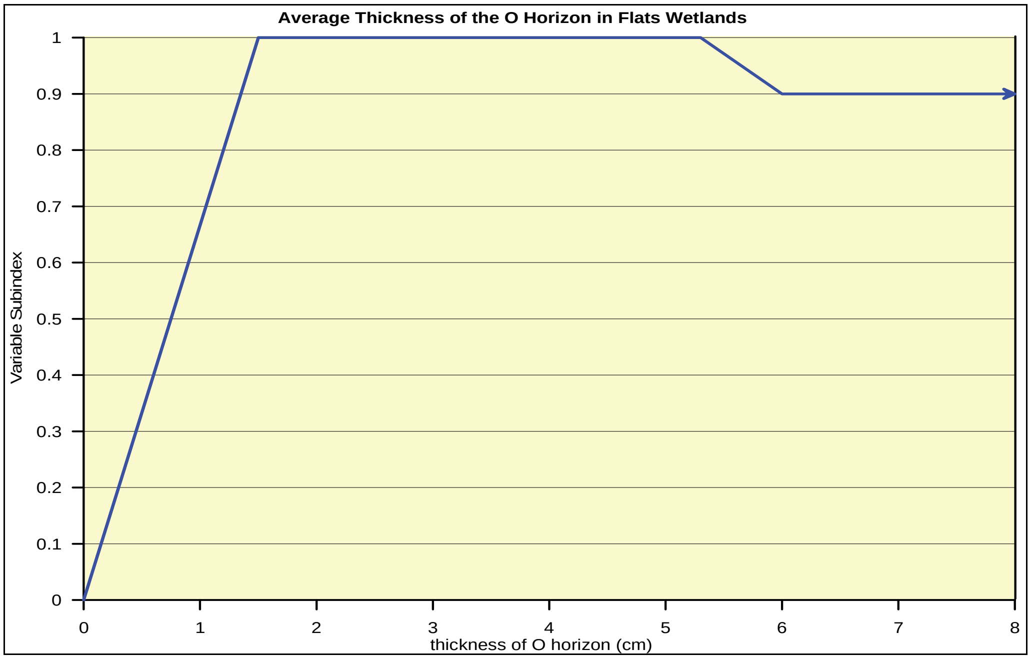

Figure 20. Relationship between O horizon thickness for Flats wetlands and the variable subindex for V_{OHOR}.

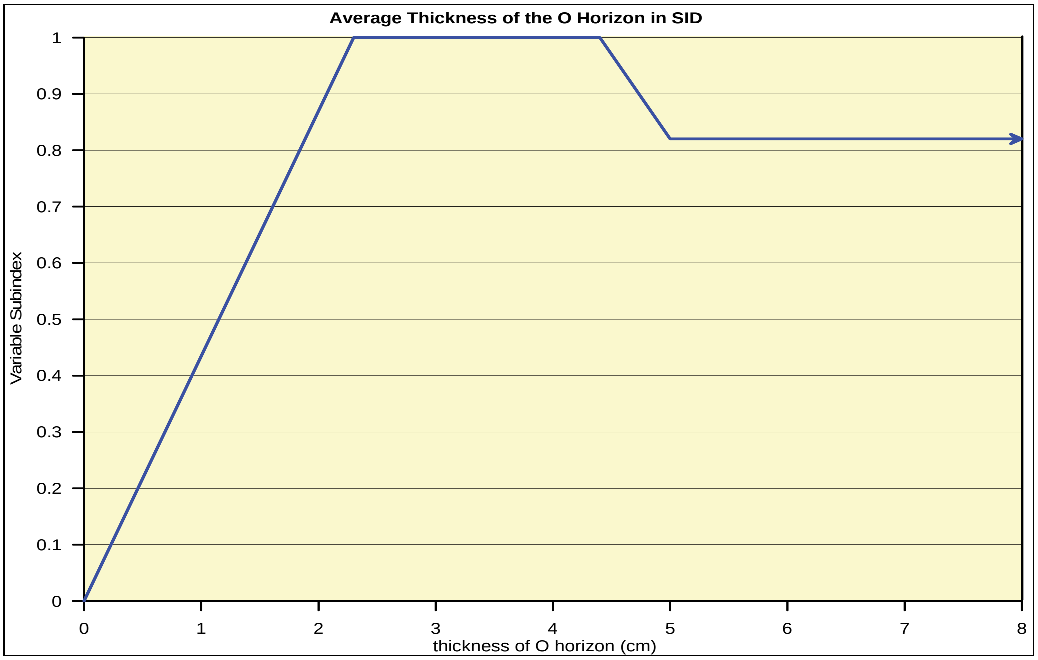

Figure 21. Relationship between O horizon thickness for Seasonally Inundated Depressions and the variable subindex for V_{OHOR}.

Functions

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

1. *Definition:* Defines the function.

2. *Rationale for selecting the function*: Provides the rationale for why a function was selected and discusses onsite and offsite effects that may occur as a result of lost functional capacity.
3. *Characteristics and processes that influence the function*: Describes the characteristics and processes of the wetland and the surrounding landscape that influence the function and lay the groundwork for the description of model variables.
4. *Functional capacity index*: Describes the assessment model from which the functional capacity index is derived and discusses how model variables interact to influence functional capacity.

Function 1: Water storage

Definition

This function reflects the ability of a SID or Flat wetland to store water within the soil and/or above the soil surface for a few weeks up to several months, characteristic of reference standard wetlands in the reference domain. The amount and duration of water stored in the wetland is a result of the balance between water inflows and outflows, topography, subsurface soil, geology, and groundwater conditions (Mitsch and Gosselink 2000). This function is assessed for the following regional wetland subclasses within the HR:

1. Seasonally Inundated Depressions (SID)
2. Flats

Rationale for selecting the function

The importance of hydrology to the establishment and maintenance of wetland ecosystems is widely recognized. Hydrology strongly influences plant community development and chemical transport and transformation in wetland ecosystems (e.g., Mitsch and Gosselink 2000). Wetland functions can be thought of in terms of a hierarchy with very general functions at the highest level and more specific functions at the lower levels (Smith and Wakeley 2001). The ability of a wetland to store water is the most general of hydrologic functions and is a composite of more specific lower level functions. Other important processes critical to wetland health, including plant community development and biogeochemical processes, rely heavily on the water storage. Specific functions commonly associated with depressional wetlands include groundwater recharge (van der Kamp and Hayashi 1998), flood peak attenuation (Ludden et al. 1983, Moore and Larson 1980, Ogawa and Male 1986, Kittelson 1988), and sediment retention (Craft and Casey 2000). The assumption is that if the water storage in a wetland is characteristic of reference standard wetlands in the reference domain, then the suite of more specific functions identified for that subclass are also being performed.

Characteristics and processes that influence the function

The capacity of a wetland to provide a characteristic hydrologic regime depends on conditions in the wetland and its watershed. For the purposes of a rapid assessment, the characteristics that are subject to anthropogenic alteration should be the primary consideration. Other factors such as climate and geology are addressed indirectly through the identification of the reference domain and creation of regional subclasses.

Runoff production in small watersheds is influenced by watershed characteristics (e.g., size, shape, slope, land use, soil type), rainfall characteristics (spatial and temporal distribution), and antecedent moisture conditions. Of these factors, watershed size (area) and land use are most often subject to anthropogenic alteration. Land use changes (e.g., urbanization) can have a dramatic impact on the hydrologic regime of wetlands (Euliss and Mushet 1996, Azous and Horner 2001). An increase in watershed imperviousness results in increased runoff volume following storm events, creating a more erratic hydrologic regime. Runoff volume is directly related to watershed area. The hydrologic regime is affected by alterations to the wetland watershed (source area) that divert water away from, or add water to, the wetland. Water additions and diversions are common in developed areas and often result from road construction (Smith et al. 1989). To illustrate, consider the four scenarios illustrated in Figure 22. Scenario a) represents an unaltered condition in the watershed (i.e., completely forested). In scenario b), a residential development has occurred, resulting in increased surface runoff. This alteration is detected by $V_{LANDUSE}$ due to an increase in curve number. In scenario c), the surface runoff from the residential development has been diverted from the wetland by an adjacent road constructed without cross drainage. The existing watershed area is now less than the historic watershed area; however, the land use condition is now unaltered ($V_{LANDUSE} = 1.0$). It can be argued that the diversion in scenario c has resulted in an improved condition over scenario b. This assumes surface runoff is a minor component of the water budget for Depressional and Flat wetlands in a natural setting. In scenario d), stormwater from a commercial development outside the natural watershed boundary is directed to the wetland, resulting in an increase in the watershed area. This alteration is detected by both $V_{LANDUSE}$ and V_{CATCH}.

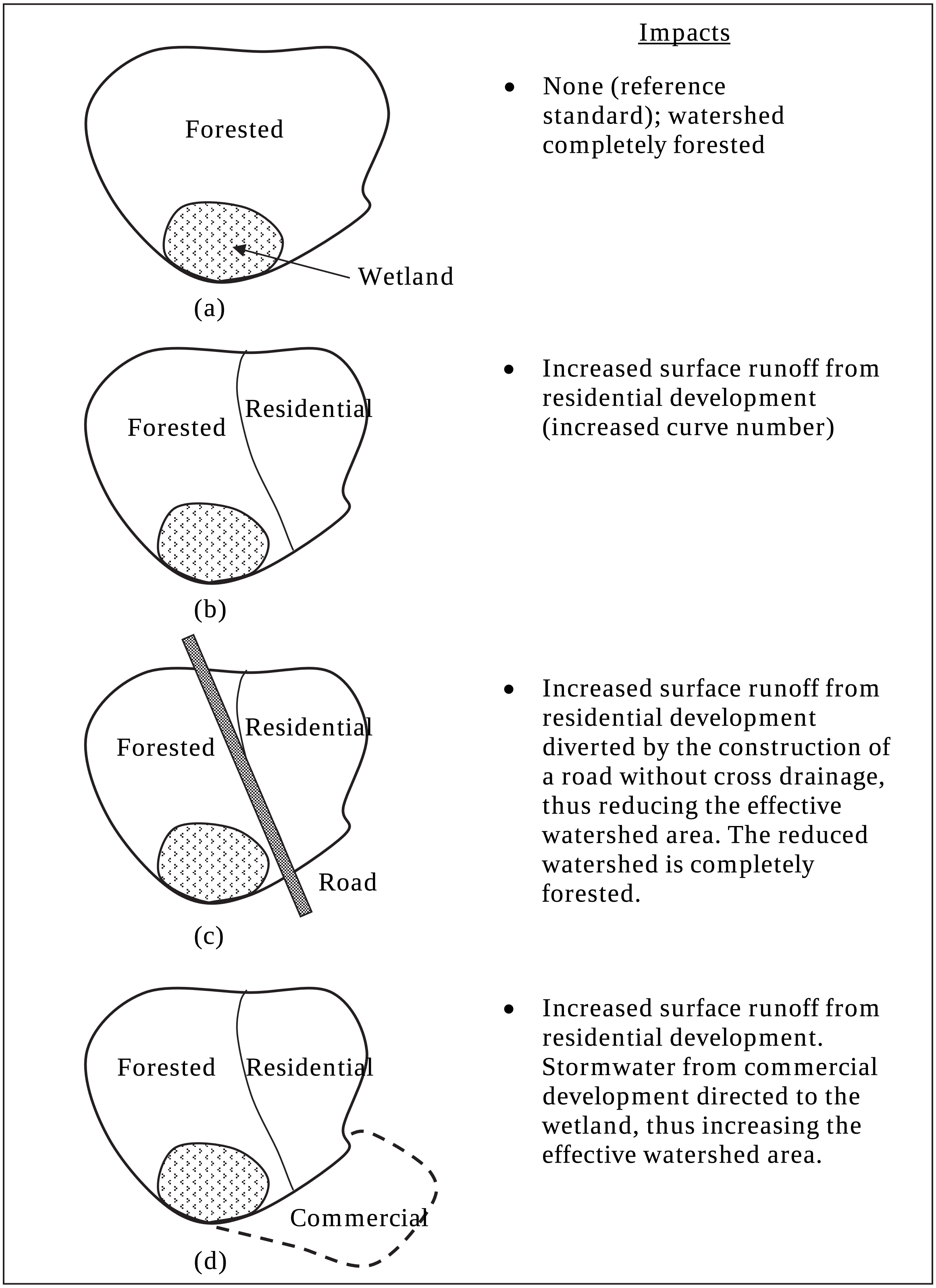

Figure 22. Four scenarios illustrating the relationship between $V_{LANDUSE}$ and V_{CATCH}.

Within the wetland itself, wetland morphology, hydraulic characteristics of the soil, and plant community affect the hydrologic regime. Wetland morphology refers to the depth, size, and shape of the wetland basin and these properties have been related to the hydroperiod of Depressional wetlands (Brooks and Hayashi 2002). Because of their geomorphic setting, Depressional wetlands are often sinks for sediment originating in the watershed. Increased sediment loads often result from activities in the watershed that accelerate erosion (e.g., construction activities). Alterations of this type are often temporary and may only cover a portion of the wetland. Alterations that produce more abrupt changes in wetland morphology include the direct placement of fill material in the wetland and artificial drainage (e.g., ditches). A distinct morphological feature of Flat wetlands is the presence of microtopography. Microtopographic features (e.g., microdepressions) result from small-scale surface irregularities. Storage in microdepressions promotes focused recharge of the underlying water table (Logan and Rudolph 1997).

Evapotranspiration (ET) is an important component of the water budget that has a major influence on the hydrologic regime of wetlands. ET is influenced by local meteorological conditions (solar radiation, wind speed, vapor pressure, etc.) and on-site vegetation. Studies have shown ET rates from wetlands to vary both temporally and spatially over short distances (Lott and Hunt 2001) and with vegetation type (Mao et al. 2002, Abtew 1996). Previous studies report conflicting results on the effects of vegetative cover on ET (Mitsch and Gosselink 2000, page 142). Idso (1981) argued that only results from in situ experiments are valid and used theoretical considerations to conclude that the ratio of vegetation-covered evaporation to open-water evaporation is generally less than one.

The hydraulic characteristics (vertical and horizontal conductivity) of the underlying soil affect movement of water from the surface to the subsurface. Hydric soils in SID and Flat wetlands within the HR typically have a relatively impermeable soil horizon, or fragipan, beginning several feet below the surface. The fragipan horizon effectively isolates the wetland from the regional water table, creating a local perched water table. Although the hydraulic properties of the soils may be altered (e.g., through compaction), the effect on the hydrologic regime is minimal because the fragipan horizon exerts an overriding influence on vertical movement of water.

Functional capacity index

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

- Change in catchment size (V_{CATCH}) (SID wetlands only)
- Surrounding land use ($V_{LANDUSE}$) (SID wetlands only)
- Wetland drainage (V_{DRAIN}) (Flat wetlands only)
- Change in wetland volume (V_{WETVOL}) (SID wetlands only)
- Microtopographic features (V_{MICRO}) (Flat wetlands only)
- Canopy tree diameter (V_{CTD})
- Canopy tree density (V_{CTDEN})

The assessment model for calculating the functional capacity index (FCI) for the Water Storage function is as follows:

For Flat Wetlands:

$$FCI = \left[V_{DRAIN} \times \left(\frac{V_{CTD} + V_{CTDEN} + V_{MICRO}}{3}\right)\right]^{1/2} \tag{3}$$

For SID Wetlands:

$$FCI = \left\{V_{WETVOL} \times \left[\frac{\left(\frac{V_{CATCH} + V_{LANDUSE}}{2}\right) + \left(\frac{V_{CTD} + V_{CTDEN}}{2}\right)}{2}\right]\right\}^{1/2} \tag{4}$$

In this model (Equation 3), the water storage capacity of Flat wetlands depends on inputs of water from precipitation. Water is removed from the system primarily by evapotranspiration. The model assumes that, if natural hydrologic inputs from precipitation and runoff from the surrounding area are unaltered, outflow is not increased by drainage ditches, and a mature forest is present to remove water through evapotranspiration at characteristic rates, then the Flat wetland is functioning at the reference standard condition.

This model addresses three main factors that influence wetland water storage. The first part of the equation reflects natural or anthropogenic alterations to the wetland (V_{DRAIN}) that affect its capacity to store water for short periods. The second part of the equation is a combination of factors, the effect of a mature tree canopy (V_{CTD} and V_{CTDEN}) on removal of water through evapotranspiration, as well as the trapping and storage in micro-depressions (V_{MICRO}). The variables in the second part of the equation are averaged, giving equal weight to the removal of and storage of water.

The two parts of the equation are combined using a geometric mean based on the assumption that V_{DRAIN} is as important as the combination of the other variables in relation to water storage. In other words, if the wetland were drained to the point that it no longer has wetland hydrology, then the subindex score for V_{DRAIN} would be 0.0 and the functional capacity for water storage would be zero as well.

The second model (Equation 4), the water storage capacity of SID wetlands, depends not only on inputs of water from precipitation, but also on runoff from the surrounding area. Water is removed from the system primarily by evapotranspiration. The model assumes that if natural hydrologic inputs from precipitation and runoff from the surrounding area are unaltered, the storage volume is not increased by excavation or decreased by filling, and a mature forest is present to remove water through evapotranspiration at characteristic rates, then the SID wetland is functioning at reference standard condition.

This model addresses three main factors that influence the ability of a SID wetlands to store water at reference standard levels. The first part of the equation reflects natural or anthropogenic alterations to the wetland (V_{WETVOL}) that affect its capacity to store water for short periods. The second part of the equation is a combination of factors affecting the supply of water from the surrounding area (V_{CATCH} and $V_{LANDUSE}$) through runoff, and the effect of a mature tree canopy (V_{CTD} and V_{CTDEN}) on removal of water through evapotranspiration. The variables in the second part of the equation are averaged, giving equal weight to the input of water and the removal of water.

The two parts of the equation are combined using a geometric mean based on the assumption that V_{WETVOL} is as important as the combination of the other variables in relation to water storage. In other words, if the wetland were filled to the point that it no longer has wetland hydrology, or excavated and changed to a lacustrine fringe wetland, then the subindex score for

V_{WETVOL} would be 0.0 and the functional capacity for water storage would be 0.0 as well.

Function 2: Cycle organic carbon

Definition

The cycle organic carbon function is defined as the ability of a SID and Flat wetland to retain and transform inorganic materials needed for biological processes into organic forms and to oxidize those organic molecules back into elemental forms through decomposition. Thus, organic carbon cycling includes the biogeochemical processes of producers, consumers, and decomposers. Potential independent, quantitative measures that may be used in validating the functional index include direct measurements of net annual productivity (gm/m^2), annual accumulation of organic matter (gm/m^2), and annual decomposition of organic matter (gm/m^2).

Rationale for selecting the function

Organic carbon cycling is a fundamental function performed by all ecosystems, but tends to be accomplished at particularly high rates in many wetland systems (Mitsch and Gosselink 2000). A sustained supply of organic carbon in the soil provides for maintenance of the characteristic plant community including annual primary productivity, composition, and diversity (Bormann and Likens 1970, Whittaker 1975, Perry 1994). The plant community (producers) provides the food and habitat structure (energy and materials) needed to maintain the characteristic animal community (consumers) (Crow and MacDonald 1978, Fredrickson 1978, Wharton et al. 1982). In time, the plant and animal communities serve as a source of detritus that is the source of energy and materials needed to maintain the characteristic community of decomposers. The decomposers break down these organic materials into simpler elements and compounds that can reenter the nutrient cycle (Reiners 1972, Dickinson and Pugh 1974, Pugh and Dickinson 1974, Schlesinger 1977, Singh and Gupta 1977, Hayes 1979, Harmon et al. 1986, Vogt et al. 1986). Interest in carbon cycling has increased recently because of the fact that many wetlands sequester carbon, a major greenhouse gas found in the soil (Faulkner 2004).

Overview of wetland biogeochemical processes

Organic carbon cycling is a function of biotic and abiotic processes that result from conditions within and around the wetland. In wetlands, carbon is stored within, and cycled among, four major compartments: (a) the soil; (b) primary producers such as vascular and nonvascular plants; (c) consumers such as animals, fungi, and bacteria; and (d) dead organic matter, such as leaf litter or woody debris, referred to as detritus. Organic carbon cycling is probably best known through plants and the processes of photosynthesis and respiration. Oxygen is needed for respiration, and the rate of diffusion of oxygen in water is 1/10,000th of that in air. Wetland plants, called hydrophytes, are unique in that they have adapted to living in water or wet soil environments. Physiological adaptations in leaves, stems, and roots allow for greater gas exchange, permit respiration to take place, and allow the plant to harvest the stored chemical energy it has produced through photosynthesis. Although there is no clear starting or ending point for carbon cycling, it can be argued that it is the presence and duration of water in the wetland that determines the characteristic plant community of hydrophytes. In turn, it is the maintenance of the characteristic primary productivity of the plant community that sets the stage for all subsequent transformations of energy and materials at each trophic level within the wetland. It follows that alterations to hydrologic inputs, outputs, or storage and/or changes to the characteristic plant community will directly affect the way in which the wetland can perform this function.

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

The ability of a SID or Flat wetland to perform this function depends upon the transfer of carbon between trophic levels within the wetland, the rate of decomposition, and the flux of materials in and out of the wetland. A change in the ability of one trophic level to process carbon will result in changes in the processing of carbon in other trophic levels (Carpenter 1988).

The ideal approach for assessing carbon cycling in SID and Flat wetlands would be to measure the rate at which carbon is transferred and transformed between and within trophic levels over several years. However, the time and effort required to make these measurements are well beyond a rapid assessment procedure. Reference data suggest that land-use practices and current treatments within the wetland have great effect on the characteristic plant community structure (species composition and coverage), diversity, and primary productivity. Changes in the vegetative cover directly affect the amount of organic carbon present in the wetland. Canopy removal in particular directly affects the amount and type of organic matter present in the wetland. Thickness of the organic surface soil layer or O horizon is an indicator of cation exchange capacity and, therefore, indicates long-term carbon and nutrient supply and a characteristic decomposer community. Altering the thickness of the surface O horizon through anthropogenic activities (e.g., filling, excavation) changes the availability of organic carbon, capacity for nutrient storage, and other factors affecting plant growth. Changes in hydrology or vegetation, deposition of fill material, excavation, or recent fire can alter the amount of soil organic matter. Soil organic matter is a characteristic that affects soil oxidation-reduction reactions. Soil alterations also change the physical features to which native plants have adapted. Changes to the hydrology of Flat wetlands through drainage have a significant effect on carbon cycling. Drainage increases the rate of decomposition of soil organic matter and, over time, changes the vegetative composition and, therefore, the type and amount of organic matter. In SID wetlands, increased ponding reduces the rate of decomposition and increases the accumulation of organic carbon, as well as changing the vegetative community. Excavation of the wetland removes the organic surface layer, altering the natural cycling of organic carbon until it accumulates, which can take many years. Filling with a mineral soil material covers the organic soil, effectively preventing carbon cycling. It is assumed that measurements of these characteristics reflect the level of carbon cycling taking place within a wetland.

Functional capacity index

The following variables are used in the assessment model for the Cycle Organic Carbon function:

- Wetland drainage (V_{DRAIN}) (Flat wetlands only)
- Change in wetland volume (V_{WETVOL}) (SID wetlands only)
- Canopy tree diameter (V_{CTD})
- Canopy tree density (V_{CTDEN})
- Shrub density (V_{SDEN}) (This variable is used only if total tree canopy cover is <20%)

- Ground vegetation cover (V_{GVC}) (This variable is used only if both tree and shrub cover are <20%)
- O horizon thickness (V_{OHOR})

The assessment models for calculating the functional capacity index (FCI) for the Cycle Organic Carbon function in SID and Flat wetlands are given below. The models 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 5 or Equation 8 is used. If dominated by shrubs (<20% canopy cover of trees but ≥20% cover of shrubs), then Equation 6 or Equation 9 is used. If neither trees nor shrubs dominate (<20% cover), then Equation 7 or Equation 10 is used.

Flats:

$$FCI = \left\{ V_{DRAIN} \times \left[\frac{V_{OHOR} + \left(\frac{V_{CTD} + V_{TDEN}}{2} \right)}{2} \right] \right\}^{1/2} \tag{5}$$

$$FCI = \left[V_{DRAIN} \times \left(\frac{V_{OHOR} + V_{SDEN}}{3} \right) \right]^{1/2} \tag{6}$$

$$FCI = \left[V_{DRAIN} \times \left(\frac{V_{OHOR} + V_{GVC}}{5} \right) \right]^{1/2} \tag{7}$$

SIDs

$$FCI = \left\{ V_{WETVOL} \times \left[\frac{V_{OHOR} + \left(\frac{V_{CTD} + V_{TDEN}}{2} \right)}{2} \right] \right\}^{1/2} \tag{8}$$

$$FCI = \left[V_{WETVOL} \times \left(\frac{V_{OHOR} + V_{SDEN}}{3} \right) \right]^{1/2} \tag{9}$$

$$FCI = \left[V_{WETVOL} \times \left(\frac{V_{OHOR} + V_{GVC}}{5} \right) \right]^{1/2} \quad (10)$$

In these models, changes in the organic carbon cycling capacity of SID and Flat wetlands relative to reference standard conditions depend on reduction or water storage, soil organic matter, or quantity of vegetation. The models are based on the assumption that if natural soils and vegetation are in place, and anthropogenic hydrologic disturbance is not present in the wetland, then carbon cycling will occur at an appropriate rate. In the first part of each equation, removal or retention of surface water is represented by V_{WETVOL} or V_{DRAIN}. In the second part, V_{OHOR} is an indication of long-term organic matter accumulation and incorporation into the soil. If either hydrology or vegetation have been altered for more than a few years, then the thickness of the surface soil organic layer will oxidize and be thinner, reflecting a decrease in organic matter content. Also, if fill material has been placed in the wetland or soil excavation has taken place, the organic matter in the previous soil surface will have been buried by the fill or removed in excavation. SID and Flat wetland vegetation is represented by the combination of V_{CTD} and V_{CTDEN}, shrub density (V_{SDEN}), or ground vegetative cover (V_{GVC}), whichever is representative of the tallest stratum within the wetland or WAA. If the amount of vegetation is reduced, then it is assumed that carbon cycling will be reduced. In contrast, if the amount of vegetation is greater than that found under the least disturbed natural conditions, then abnormal amounts of carbon may accumulate in the wetland and the FCI is reduced. In each equation the soils and vegetative parts of the equations are averaged. In Equations 6 and 9, and 7 and 10, the two parts are divided by factors of 3 and 5, respectively, to reflect the assumption that SID or Flat wetlands dominated by shrubs or ground vegetation do not produce or cycle carbon at the same rate as those dominated by a mature forest. For shrub-dominated wetlands, the maximum FCI is 0.82. For wetlands lacking both tree and shrub strata, the maximum FCI is 0.63.

The two parts of the model are combined using a geometric mean. The implications are that if all of the variables in any part of the model equal zero, then the function would receive an FCI of zero.

Function 3: Maintain a characteristic plant community

Definition

This function is defined as the degree to which a SID and Flat wetland supports a plant community that is similar in structure and composition to that found on the least disturbed sites in the reference domain. Potential independent, quantitative measures of this function, based on species composition and relative abundance, include similarity indices (Ludwig and Reynolds 1988) or ordination axis scores from detrended correspondence analysis or other multivariate techniques (Kent and Coker 1995). An alternative, independent, quantitative measure of this function, based on composition and abundance as well as environmental factors, is ordination axis scores from canonical correlation analysis (ter Braak 1994).

Rationale for selecting the function

The ability to maintain a characteristic plant community is important in part because of the intrinsic value of the species found there. In the HR landscape, the dominant community type in SID and Flat wetlands is hardwood forest. Because many plant species in these wetlands do not occur in other landforms, their maintenance and abundance are linked to the subclass. The presence of a characteristic plant community also is critical in maintaining various biotic and abiotic processes occurring in SID and Flat wetlands. For example, plant communities are the source of primary productivity, produce carbon and nutrients that may be exported to other ecosystems, and provide habitats and refugia necessary for various animal species (Harris and Gosselink 1990).

Overview of the plant community

The plant communities of SID and Flat wetlands within the reference domain are complex and variable (Ellis and Chester 1989). Sites that have been relatively undisturbed for decades or hundreds of years are composed of trees of various sizes and ages and generally predictable species composition. The community at a recently disturbed site may be composed of only a few colonizing species, mostly of the same age. Depending on the species that initially occupy a site after a major disturbance, succession can progress along different paths, but because of small-scale disturbances (i.e., individual trees dying and creating canopy gaps that may be colonized by different species), an uneven-aged forest with well-developed stratification eventually will be reached (Hunter 1990). The time it takes to reach such a state is highly variable depending in large part on the frequency of fire that historically had a significant influence of forest communities within the reference domain. In general, older stands tend to be more stratified than younger ones, and forests with several vertical strata have higher species diversity than young or middle-aged stands with few strata (Willson 1974, Hunter 1990). This is important in maintenance of the community over time, given that species diversity can be related positively to community stability (Holland et al. 1990).

Sites that have escaped significant disturbance for long periods normally will be dominated by trees in the larger diameter (measured at 1.4 m above the ground and abbreviated dbh) classes. Brower and Zar (1984) and DeGraaf et al. 1992) noted that tree basal area (and by inference, canopy tree dbh) is positively correlated with stand maturity and therefore can be assumed to be a reasonable indicator of the amount of time that has passed since significant disturbance (fire, catastrophic storm damage, harvest, etc.). U. S. Forest Service (1980) and Burns and Honkala (1990) are good sources of information on the maximum size that individual species of trees can attain. For many species that potentially can occupy the overstory in Depression and Flat wetlands, older trees may reach 80–200+ cm in diameter.

Tree density is a characteristic of forest ecosystems that varies considerably throughout the life of an individual stand. In most forested systems, tree density is very high following stand establishment and decreases as the forest matures and the crowns grow together to form the canopy (Spurr and Barnes 1980, DeGraaf et al. 1992). Stem densities often number in the thousands per hectare in early stages of succession and normally will be reduced to a few hundred per hectare at maturity (DeGraaf et al. 1992, Wilder and Roberts 2002).

The plant community in SID and Flat wetlands within the reference domain that has not been subjected to significant disturbance will be composed of native species adapted to the local site conditions (i.e., soil type, hydrologic regime, etc.). Species composition has been found to vary between the two classes (Ellis and Chester 1989, Chester and Ellis 1989, Call 2003). They are described separately in the following overview based on these studies and the data collected during this study.

Seasonally inundated depressions

In the tree layer, common dominants in SID wetlands include willow oak, green ash (*Fraxinus pennsylvanica*), sweetgum, red maple, and swamp black gum (*Nyssa sylvatica* var. *biflora*). Water oak and other oaks occur, but normally are not as abundant as willow oak. The most common shrubs are various members of the genus *Vaccinium*. Woody vines and herbaceous species that are common include common greenbriar (*Smilax rotundifolia*), poison ivy (*Toxicodendron radicans*), spikegrass (*Chasmanthium laxum*), and several species of sedges (*Carex* spp.). Shrub and herbaceous species often are found throughout the wetland, although densities tend to be lower in the center and increase near the edge.

Flats

In the tree layer, common dominants are willow oak, red maple, sweet gum, green ash, black gum (*N. sylvatica* var. *sylvatica*), white oak, and water oak. The most abundant shrub species are hoary azalea (*Rhododendron canescens*), highbush blueberry (*Vaccinium corymbosum*), possumhaw (*Viburnum nudum*), and Virginia willow (*Itea virginica*). These species occur throughout many Flat wetlands and typically occur in greater densities than in SID wetlands. Woody vines and herbaceous species that dominate Flat wetlands include common greenbriar, poison ivy, sedges (*Carex* spp.), spikegrass, partridgeberry (*Mitchella repens*), cinnamon fern (*Osmunda cinnamomea*), royal fern (*O. regalis*), and various mosses in the genus *Sphagnum*.

Some SID and Flat wetlands are easily recognizable based on their community composition alone, but in others there may be considerable overlap. Call (2003) conducted cluster analysis on vegetation data from plots located in Depression and Flat wetlands at AAFB and identified nine distinct groups. Most Depression wetlands in his study would be considered SID wetlands. The majority of the groups tended to be associated with one or the other of the wetland types, but three of the larger groups (described as "typical wetlands at AAFB") were divided relatively evenly between the two types. Call speculated that this was due to generally similar hydroperiods. The Depression wetlands had only a slightly lower Prevalence Index (PI) (Wentworth et al. 1988) than the Flat wetlands (2.61 and 2.79, respectively), supporting that supposition (note: a PI is a weighted average of the wetness tolerance of plants; OBL species are assigned a score of 1, FACW a score of 2, etc. for purposes of PI calculation). The lower the PI score, the more tolerant of ponding, flooding, or saturation the community is.

In spite of the overlap in composition, Call (2003) was able to identify a small number of species that were considered “indicator species” of both Depression and Flat wetlands. In Depression wetlands, these were swamp black gum in the subcanopy and shrub layer and cypress-swamp sedge (*Carex joorii*) and narrow plumegrass in the ground layer. Indicator species for Flat wetlands were red maple and black gum in the midstory and shrub layers, and cinnamon fern and royal fern in the ground layer.

Factors that influence the plant community

Factors that influence the development and maintenance of a characteristic plant community in most wetlands including Flat and Depression wetlands in the HR include the physical site characteristics, the hydrologic regime, fire frequency and intensity, weather events, anthropogenic disturbances, and various ecological processes such as competition, disease, browsing pressure, shade tolerance, and community succession. Alteration to these factors or processes in the wetland or to the landscape surrounding a wetland may directly affect the species composition and biodiversity of the site (Askins et al. 1987, Keller et al. 1993, Kilgo et al. 1997). Much of the descriptive work on plant communities of forested wetlands (and factors that influence their development and maintenance) was done in Riverine systems (Robertson et al. 1978, Wharton et al. 1982, Robertson 1992, Messina and Conner 1997), and less information is available regarding SID and Flat wetlands. It is logical to infer, however, that excepting the significant differences in hydrologic inputs and processes, many of the factors that influence forested wetlands in general also are important in both SID and Flat wetlands. These factors are well-documented in Mitsch and Gosselink (2000) and in HGM guidebooks for Riverine wetlands in western Kentucky (Ainslie et al. 1999) and peninsular Florida (Uranowski et al. 2003).

An appropriate hydroperiod is one of the most important factors in developing and maintaining a characteristic plant community. In SID wetlands, water delivery occurs as direct precipitation, overland flow, or groundwater discharge from the surroundings uplands. Flat wetlands primarily are created and maintained by direct precipitation (see Function 1). Activities that degrade the physical nature of a wetland, especially its hydroperiod, have the potential to have deleterious effects on the plant community and, if significant enough, may alter the plant community for extended periods, and even permanently. For example, depositing fill in a wetland fundamentally changes the substrate and hydrologic regime and, if amounts are substantial, can result in conversion of the area from wetland to non-wetland. If the site is allowed to re-vegetate, the ensuing plant community probably will be composed of a different suite of species, likely those with less tolerance for wetness.

Some alterations that occur outside the wetland may have serious negative consequences for the plant community. For example, clearing the natural vegetation in the upland watershed and adding impervious surfaces (roads, parking lots, etc.) can result in significantly more water entering a SID wetland and likely would shift the community to one dominated by more flood-tolerant species, such as baldcypress or water tupelo. If mean water depths increase beyond the ability of even these species to survive, the area would essentially become an open-water basin with vegetation existing only at the edges.

Timber extraction, particularly for large-diameter oaks, occurs in SID and Flat wetlands within the HR and has the potential to dramatically alter the structure and composition of the forest. Unless foresters specifically institute management practices to promote the regeneration of oaks, significant shifts in composition can occur following a harvest. Wetlands in the reference domain in which a timber harvest has occurred often will be dominated by shade-tolerant species such as red maple that were present in the understory, or by fast-growing species such as tulip poplar whose seeds are widely distributed by wind. Call (2003) found tulip poplar and stiff dogwood (*Cornus stricta*) (a shade-tolerant species) in the shrub strata of some plots that had been harvested approximately 15 years earlier. Many common trees in SID and Flat wetlands including sweetgum, water oak, and willow oak are classified as moderately tolerant to intolerant of shade and generally require some disturbance to release advance regeneration (Burns and Honkala 1990). In the case of willow oak, seedlings can persist for as long as 30 years under a forest canopy (Burns and Honkala 1990). Hunter (1990) and Wigley and Roberts (1994) described the effects of various forestry practices on forest communities and are good sources of information regarding various harvest and regeneration strategies.

Invasion by exotics such as common privet (*Ligustrum vulgare*), Japanese honeysuckle (*Lonicera japonica*), and Japanese stiltgrass (*Polygonum cuspidatum*) can result in significant changes in the species composition of SID and Flat wetlands, particularly in the lower strata.[1] Other than these, relatively few invasive exotics are abundant in SID and Flat wetlands within the reference domain, and overall, exotics are of minor consequence.

Except for anthropogenic impacts, SID and Flat wetlands within the HR are influenced primarily by small-scale frequent disturbances, primarily individual tree mortality, which leads to gap-phase regeneration. Fire, the primary large-scale disturbance mechanism within the HR, does not occur frequently in the wetlands themselves due to the constant moist environment. Forests that develop under such conditions generally are composed of shade-tolerant species of different age (and by inference size) classes (Hunter 1990).

One way of judging the degree of disturbance that has occurred to a SID or Flat wetland is to determine the "floristic quality" of the dominant species in the plant community following the process of Andreas and Lichvar (1995). Their approach essentially integrates many influencing factors such as hydrology and soil properties, successional patterns, and disturbances. Andreas and Lichvar assigned different rankings to the taxa present based on their degree of fidelity to synecological parameters. Plants found in many communities including disturbed sites, were assigned rankings of 1–3. Plants associated with specific communities but that tolerate moderate disturbance were assigned rankings of 4–6. Plants associated with advanced successional stages that have undergone relatively minor disturbance were assigned rankings of 7–8. Plants with a high degree of fidelity to a narrow range of synecological parameters were assigned values of 9–10. The dominant species found in reference standard SID and Flat wetlands within the HR typically would be assigned to the latter two categories.

Functional capacity index

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

- Canopy tree diameter (V_{CTD})
- Canopy tree density (V_{CTDEN})
- Shrub density (V_{SDEN}) (This variable is used only if total tree canopy cover is <20%.)

[1] Personal Communication. 2004. Geoff Call, U.S. Fish and Wildlife Service, Knoxville, TN .

- Ground vegetation cover (V_{GVC}) (This variable is used only if total tree canopy cover and shrub cover are both <20%.)
- Vegetation composition and diversity (V_{COMP})

The assessment models for calculating the FCI for the maintenance of a characteristic plant community in SID and Flat wetlands are given below. The models depend on the characteristics of the uppermost stratum of vegetation present within the wetland. If the site contains a tree layer ($\geq$20% total tree cover), then Equation 11 is used. If dominated by shrubs (<20% cover of trees but $\geq$20% cover of shrubs), then Equation 12 is used. If neither trees nor shrubs are common (<20% cover), then Equation 13 is used.

$$FCI = \left[\frac{\left(\frac{V_{CTD} + V_{CTDEN}}{2} \right) + V_{COMP}}{2} \right] \tag{11}$$

$$FCI = \left(\frac{V_{SDEN} + V_{COMP}}{4} \right) \tag{12}$$

$$FCI = \left(\frac{V_{GVC} + V_{COMP}}{6} \right) \tag{13}$$

These models represent the existing plant community in the wetland and include variables that provide insight into seral stage, structure, species composition, diversity, and stability. The models assume that the physical environment necessary to maintain the community (e.g., hydrology, soil characteristics) also is present. If not, any recent environmental changes that may affect the long-term persistence of the community should be reflected in reduced FCIs for Functions 1 and 2. In the context of this function, canopy tree diameter (V_{CTD}) and density (V_{CTDEN}) are structural indicators of seral stage and disturbance. The vegetation composition and diversity variable (V_{COMP}) reflects floristic quality and diversity, as well as seral stage and disturbance. In a forested wetland (Equation 11), subindices for V_{CTD} and V_{CTDEN} are averaged before being combined with V_{COMP}. V_{CTD} and V_{CTDEN} cannot go to zero if trees are present; therefore, the FCI will always be greater than zero if trees are present. In Equations 12 and 13, the two variables are divided by factors of 4 or 6, respectively, under the assumption that sites dominated by shrubs or ground vegetation do not provide the level of function provided by a mature forest community, even if succession will tend toward that condition eventually. For a shrub-dominated wetland, the maximum FCI is 0.50. For a wetland lacking both tree and shrub strata, the maximum FCI is 0.33.

Function 4: Provide characteristic wildlife habitat

Definition

This function is defined as the capacity of a SID or Flat wetland to provide critical life requisites to selected components of the vertebrate wildlife community. Wetlands within the subclasses provide habitat for numerous species of amphibians, reptiles, birds, and mammals. Birds and amphibians were selected as the focus of this function. Birds were chosen because they are of considerable public and agency interest, and they respond rapidly to changes in the quality and quantity of their habitats. In addition, birds are a diverse group and individual species have strong associations with the different strata of the multi-layered forests that characterize reference standard SID and Flat wetlands. Birds have been shown to be sensitive indicators and integrators of environmental change such as that brought about by human use and alteration of landscapes (Morrison 1986, Croonquist and Brooks 1991, O'Connell et al. 2000). Amphibians were chosen because of the importance of SID wetlands as breeding habitat. Various species of salamanders and frogs breed in shallow streams, wetlands that pond water, and even moist duff or leaf litter. In the adult stages, they often disperse into suitable habitat in the adjacent uplands.

A potential independent, quantitative measure of this function that could be used to validate the assessment model (Wakeley and Smith 2001) is the combined species richness of birds and amphibians that use SID and Flat wetlands throughout the annual cycle. Data requirements for model validation include direct monitoring of wildlife communities using appropriate techniques for each taxon. Ralph et al. (1993) described field methods for monitoring bird populations. Gibbons and Semlitsch (1981) described procedures for sampling small animals including reptiles and amphibians. Heyer et al. (1994) and Dodd (2003) described monitoring procedures for amphibians.

Rationale for selecting the function

Wetlands are recognized as valuable habitats for a diversity of animal species including both vertebrates and invertebrates. For example, waterfowl, a group dependent on wetlands in both their breeding and wintering ranges, number in the millions and include important game species. In the reference domain, the wood duck (*Aix sponsa*) uses forested wetlands, especially depressions, year around. Songbirds, such as the prothonotary warbler (*Protonotaria citrea*) and Acadian flycatcher (*Empidonax virescens*), are associated with forested wetlands within the reference domain and provide recreational opportunities for birdwatchers and nature enthusiasts. Further, because birds are highly mobile, they serve as a transfer mechanism for nutrients and energy from wetlands to other ecosystems. Several mammals, including the mink (*Mustela vison*) and raccoon (*Procyon lotor*), also are closely associated with wetlands and similar environments. They are important predators in wetlands and riparian areas and, as such, play key roles in ecosystem structure and stability. Amphibians are common in most wetland ecosystems, but many are secretive and seldom seen. In some situations, they can be extremely abundant. Burton and Likens (1975) reported that amphibians constitute the single largest source of vertebrate biomass in some ecosystems. Because many amphibians require both wetland and adjacent upland habitats, they serve as a conduit for energy exchange between the two systems (Mitchell et al. 2004). Wharton et al. (1982), Johnson (1987), Whitlock et al. (1994), Crowley et al. (1996), Mitsch and Gosselink (2000), and Bailey et al. (2004) are all good sources of information regarding animal communities of wetlands.

Many wildlife species associated with wetlands have experienced serious population declines. Within the United States, approximately one third of the plant and animal species listed as threatened or endangered are associated with wetlands during some part of their life cycles (Dahl and Johnson 1991). Wetlands constitute a relatively small percentage of the landscape within the reference domain, and the upland matrix in many areas is dominated by agricultural land, managed forests, and residential and commercial development. Therefore, SID and Flat wetlands likely are important for the maintenance of local populations of many species.

Overview of the wildlife community

Within the reference domain, numerous game and non-game species from four vertebrate classes commonly use SID and Flat wetlands for shelter, as breeding or foraging areas, or as sources of drinking water. This general discussion includes information about reptiles and mammals although, as noted previously, birds and amphibians are the focus of the wildlife model.

Miller (1995) found that many species of amphibians and reptiles used Depression or Flat wetlands at AAFB for a least some portion of their life cycle. He documented a total of 27 species including 7 salamanders, 13 frogs, 4 snakes, and 3 turtles. The bullfrog (*Lithobates catesbeiana*), green frog (*R. clamitans*), midland water snake (*Nerodia sipedon*), yellowbelly water snake (*N. erythrogaster*), snapping turtle (*Chelydra serpentina*), and red-eared slider (*Trachemys scripta*) were restricted to wetlands (presumably Depressions), whereas the spotted salamander (*Ambystoma maculatum*), marbled salamander (*A. opacum*), mole salamander (*A. talpoideum*), tiger salamander (*A. tigrinum*), smallmouth salamander (*A. texanum*), red-spotted newt (*Notophthalmus viridescens*), four-toed salamander (*Hemidactylium scutatum*), southern cricket frog (*Acris gryllus*), gray treefrog (*Hyla chrysoscelis*), barking treefrog (*H. gratiosa*), spring peeper (*Pseudacris crucifer*), upland chorus frog (*P. feriarum*), gopher frog (*Rana capito*), southern leopard frog (*R. sphenocephala*), American toad (*Bufo americanus*), Fowler's toad (*B. fowleri*), eastern spadefoot toad (*Scaphiopus holbrooki*), eastern narrowmouth toad (*Gastrophryne carolinensis*), eastern ribbon snake (*Thamnophis sauritis*), eastern garter snake (*T. sirtalis*), and eastern mud turtle (*Kinosternon subrubrum*) used both wetlands and adjacent upland habitats. Barbour (1971) and Mount (1975) are good general sources of information on amphibians and reptiles that have been found or might be found within the reference domain. Petranka (1998) is a comprehensive work on salamanders in the United States and Canada. Bailey et al. (2004) provide excellent coverage of the ecology, management, and conservation of amphibians and reptiles in the Southeast.

Roberts and Peterson (2001) documented substantial use of Depression and Flat wetlands at AAFB by avian species during winter and spring. Species identified during spring included both breeding birds and those that used wetlands as "stopover" habitat during migration to more northern areas. They identified 46 species during winter and 59 species during spring/summer that used either the wetlands themselves or the upland forests adjacent to the wetlands. Bird abundance and species richness both were higher in the wetlands and to a distance of approximately 100 m from the wetland boundary than in more distant habitats. Species that were more abundant in the wetlands and adjacent forest habitat were the blue-gray gnatcatcher (*Polioptila caerulea*), blue jay (*Cyanocitta cristata*), Carolina chickadee (*Poecile carolinensis*), Carolina wren (*Thryothorus ludovicianus*), eastern wood-peewee (*Contopus virens*), tufted titmouse

(*Baeolophus bicolor*), great crested flycatcher (*Myiarchus crinitus*), Kentucky warbler (*Oporornis formosus*), northern cardinal (*Cardinalis cardinalis*), red-bellied woodpecker (*Melanerpes carolinus*), and scarlet tanager (*Piranga olivacea*). The birds documented in Depression and Flat wetlands at AAFB can be found in Roberts and Peterson (2001), but their study did not detect some species known to use these habitats (e.g., the prothonotary warbler). A comprehensive list of the birds present at AAFB can be found in Lamb (2004). Other reports with relevance to avian communities in wetlands in the mid-South include Ford (1990), and Hamel (1992).

Several mammals routinely use SID and Flat wetlands within the reference domain. Some species (or their sign) were observed during the development of this guidebook. These included the raccoon, eastern cottontail rabbit (*Sylvilagus floridanus*), gray squirrel (*Sciurus carolinensis*), and white-tailed deer (*Odocoileus virginianus*). These and many other species of medium- to large-sized mammals that occur in the reference domain (e.g., mink, opossum (*Didelphis marsupialis*), and gray fox (*Urocyon cinereoargenteus*)) likely use SID or Flat wetlands as foraging sites or as sources of drinking water. The mink and raccoon, especially, are known to be associated with wetland habitats. Several chiropterans, including the red bat (*Lasiurus borealis*) and evening bat (*Nycticeius humeralis*), occur within the reference domain and favor wetlands as foraging habitat.[1] Small mammals such as mice, voles, and shrews often use a variety of habitats, but two, the golden mouse (*Ochrotomys nuttalli*) and southeastern shrew (*Sorex longirostris*), tend to be associated with wetlands and occur throughout the reference domain (Kays and Wilson 2002).

Characteristics and processes that influence the function

Hydrologic alterations to SID and Flat wetlands have the potential to impact a number of wildlife species, but the most serious impacts would be to amphibians. Animals with direct dependence on water, such as amphibians that use SIDs or seasonally ponded micro-depressions within Flat wetlands for reproduction, are highly vulnerable to filling or to wetland drainage (e.g., by ditching) for human developments. Even partial draining or filling could impact breeding activity because of the length of time needed for egg development and maturation of the young. There is considerable variability in development time among species. Most anurans require the presence of

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[1] Personal Communication. 2004. M. J. Harvey, Tennessee Tech University, Cookeville, TN.

water for 2-3 months (Duellman and Trueb 1986). Some species, however, require substantially shorter periods of time. The eastern spadefoot toad, for example, needs only 2-3 weeks to mature.[1] Conversely, artificially increasing the amount of time that surface water is present in a wetland by excavating or by augmenting runoff into the wetland can potentially reduce the suitability for amphibians by allowing fish populations to become established in SID wetlands. Bailey et al. (2004) noted that predatory fish prey on breeding amphibians, their eggs, and tadpoles. They recommended that wherever wetlands free of fish exist, efforts should be made to avoid accidental or deliberate introductions.

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

Habitat structure is probably the most important determinant of wildlife species composition and diversity (Wiens 1969, Anderson and Shugart 1974). This is especially well documented with birds, who 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) first documented the positive relationship between the vertical distribution of foliage (i.e., the presence of different layers or strata) and avian diversity, and other researchers have since corroborated their findings. For example, Ford's (1990) study of birds and their habitats in bottomland hardwood

[1] Personal Communication. 2004. M. A. Bailey, Conservation Southeast, Inc., Andalusia, AL.

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 SID and Flat wetlands within the reference domain. Hunter (1990) provides a good overview of the importance of plant community structure to wildlife.

Undisturbed SID or Flat wetlands within the HR normally contain multiple strata. This structural complexity provides a myriad of habitat conditions for animals and allows numerous species to coexist in the same area (Schoener 1986). 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 various Habitat Suitability Index (HSI) models (Schroeder 1985, Allen 1987) and in other HGM guidebooks (Ainslie et al. 1999, Smith and Klimas 2002). They are discussed briefly in the following paragraphs.

Tree size is an indicator of forest maturity (Brower and Zar 1984, DeGraaf et al. 1992) 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, red-bellied woodpeckers, and other species. In forests containing 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 shrubs, and a herbaceous or ground layer. Young forests composed of sapling to pole-sized trees tend to be less stratified.

Tree density is also an indicator of forest maturity and time since significant disturbance. In most forested systems, the density of tree seedlings and saplings is very high following stand establishment and decreases as the forest matures (Spurr and Barnes 1980, Hunter 1990, DeGraaf et al. 1992). 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. Canopy cover also affects the lower strata by controlling the amount of sunlight that reaches the forest floor. Generally, there is an inverse relationship between canopy cover and understory density (Hunter 1990).

A well-developed shrub layer (i.e., woody stems <10 cm (4 in.) dbh) is present in most undisturbed Flat and many SID wetlands, and has a significant influence on the wildlife community. Bird species that are closely associated with the shrub layer include the northern cardinal, Carolina wren, brown thrasher (*Toxostoma rufum*), white-eyed vireo (*Vireo griseus*), Kentucky warbler, and hooded warbler (*Wilsonia citrina*). Roberts and Peterson (2001) found both bird abundance and species richness to be positively correlated with percent shrub cover in Depression and Flat wetlands in central Tennessee.

Land use surrounding the wetland also has a major impact on the wetland wildlife community. Historically, the reference domain was largely forested and the wildlife community evolved in a landscape with wetlands surrounded by vast tracts of forests or savannas maintained by frequent fires. Human activities have dramatically altered the HR and much of the area is now devoted to commercial pine plantations, crop production and pasture, residential and commercial developments, and other "open" land uses. Consequently, SID and Flat wetlands now often occur as isolated patches within an open landscape matrix. Adverse effects of the "fragmentation" of formerly forested landscapes have been especially well documented for avian species and communities (Askins et al. 1987, Keller et al. 1993, Kilgo et al. 1997) and for reptiles and amphibians (Laan and Verboon 1990, Semlitsch 1998, Semlitsch and Jensen 2001, Rothermel and Semlitsch 2002, Bailey et al. 2004). Research into the effects of fragmentation on mammals has been less common (Nilon 1986, VanDruff and Rowse 1986, Nilon and VanDruff 1987).

Biological and genetic diversity are reduced as habitat fragmentation and urbanization occur in an area. Larger and more specialized animal species, especially those having large home ranges, are affected from the onset of the fragmentation (VanDruff et al. 1996). Habitat specialists are often the first to be extirpated from an area or region. Eventually, however, 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 (VanDruff et al. 1996, McKinney 2002).

Although dependent on SID wetlands, microdepressions in Flat wetlands, ponds, and other aquatic habitats for breeding, many southeastern frogs and some salamanders spend the remainder of the year in terrestrial habitats, often in hardwood forests (Mitchell et al. 2004). Semlitsch and Jensen (2001) noted that suitable terrestrial habitat surrounding the breeding site is critical for feeding, growth, maturation, and maintenance of juvenile and adult populations of pond-breeding salamanders. Bailey et al. (2004) concurred, stating that “a seasonal wetland without appropriate surrounding upland habitat will lose its amphibian and reptile fauna.” Semlitsch and Jensen (2001) suggested that the terrestrial habitat be referred to as part of the “core habitat” used by the animals, because it is as essential as the breeding site itself. This is different from the traditional concept of the “buffer zone” commonly recommended around wetlands to protect various wetland functions (Boyd 2001).

Semlitsch and Bodie (2003) reviewed the literature on terrestrial habitats used by amphibians. Habitat features such as leaf litter, coarse woody debris (i.e., logs), boulders, small mammal burrows, cracks in rocks, spring seeps, and rocky pools were important for foraging, refuge, or over-wintering. A well-developed canopy (for shade) and coarse woody debris and litter (for refuge and food) were considered to be essential habitat features. The abundance of litter is related to the age of forest stands. The litter layer in an older forest usually is much thicker than in a younger forest due to the differential amount of foliage produced. Young stands do not begin to contain significant amounts of litter and coarse woody debris until natural thinning begins. Coffey (1998) reported that minimal woody debris was found in bottomland hardwood stands younger than 6 years of age. Such a pattern probably also exists in upland forests. Shade, which is critical to some amphibian species in slowing or preventing dehydration (Spight 1968, Rothermel and Semlitsch 2002), is provided to some extent in all forest stands but likely is not effective until tree canopies begin to close (Rothermel and Semlitsch 2002). In the absence of more specific information regarding how amphibians might respond to different conditions, it is assumed here that nearly all forested areas, savannas, shrub habitats, and native grasslands will provide at least minimally suitable terrestrial habitat for dispersing amphibians. Managed pine forest is considered suitable 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).

In addition to the structural characteristics of contiguous habitats, the size of such areas also is important to many amphibian and reptile species. 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 to evaluate the adequacy of the Massachusetts Wetland Protection Act. She concluded that the 30-m (100-ft) buffer required by the Act 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) for various groups included 218 m (715 ft) for salamanders considered separately from other amphibians, 368 m (1,207 ft) for frogs, 304 m (997 ft) for snakes, and 287 m (942 ft) for turtles.

Terrestrial areas immediately adjacent to wetlands are also important to the integrity of the wetland ecosystem itself. Such areas serve to reduce the amounts of silt, contaminants, and pathogens that enter the wetland, and to moderate physical parameters such as temperature (Rhode et al. 1980, Young et al. 1980, Hupp et al. 1993, Snyder et al. 1995, Daniels and Gilliam 1996, Semlitsch and Jensen 2001, Semlitsch and Bodie 2003). These functions directly or indirectly affect amphibians through improved water quality and provide benefits to the entire wildlife community. Semlitsch and Bodie (2003) recommended a 30- to 60-m- (100- to 200-ft-) wide “buffer” around the wetland for this purpose alone.

Birds are also known to be impacted adversely by habitat fragmentation due to increased predation, nest parasitism by the brown-headed cowbird (*Molothrus ater*), and possibly other factors (Askins et al. 1987, Keller et al. 1993, Kilgo et al. 1997). Several of the species associated with SID and Flat wetlands and adjacent forests within the reference domain are considered "interior" (Hamel 1992) or "area-sensitive" species (Robbins et al. 1989). Area-sensitive species tend to have lower reproductive output in smaller habitat patches or they simply avoid small patches altogether.[1] While 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 acres). In spite of that very large value, 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).

Functional capacity index

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

- Change in catchment size (V_{CATCH}) (SID wetlands only)
- Surrounding land use ($V_{LANDUSE}$) (SID wetlands only)
- Habitat connections ($V_{CONNECT}$)
- Wetland drainage (V_{DRAIN}) (Flat wetlands only)
- Change in wetland volume (V_{WETVOL}) (SID wetlands only)
- Canopy tree diameter (V_{CTD})
- Canopy tree density (V_{CTDEN})
- Shrub density (V_{SDEN}) (This variable is used only if total tree cover is <20 percent.)
- Ground vegetation cover (V_{GVC}) (This variable is used only if tree and shrub cover are both <20 percent.)

The models for deriving the functional capacity index for the wildlife habitat function of Flat and SID wetlands depend, in part, on the characteristics of the uppermost stratum of vegetation within the wetland. If the site supports a tree layer ($\geq$20% total tree cover), then Equation 14 or 17 is used. If dominated by shrubs (<20% cover of trees but $\geq$20% cover of shrubs), then Equation 15 or 18 is used. If neither trees nor shrubs are common (<20% cover), then Equation 16 or 19 is used.

[1] Personal Communication. 2004. D.A. Buehler, University of Tennessee, Knoxville, TN.

Flats:

$$FCI = \left[V_{DRAIN} \times \left(\frac{V_{CTD} + V_{CTDEN}}{2} \right) \right]^{1/2} \quad (14)$$

$$FCI = \left[V_{DRAIN} \times \left(\frac{V_{SDEN}}{2.5} \right) \right]^{1/2} \quad (15)$$

$$FCI = \left[V_{DRAIN} \times \left(\frac{V_{GVC}}{5} \right) \right]^{1/2} \quad (16)$$

SID:

$$FCI = \left\{ \left[V_{WETVOL} \times \left(\frac{V_{CATCH} + V_{LANDUSE}}{2} \right) \right]^{1/2} \times \left[\frac{\left(\frac{V_{CTD} + V_{CTDEN}}{2} \right) + V_{CONNECT}}{2} \right] \right\}^{1/2} \quad (17)$$

$$FCI = \left\{ \left[V_{WETVOL} \times \left(\frac{V_{CATCH} + V_{LANDUSE}}{2} \right) \right]^{1/2} \times \left[\frac{V_{SDEN} + V_{CONNECT}}{5} \right] \right\}^{1/2} \quad (18)$$

$$FCI = \left\{ \left[V_{WETVOL} \times \left(\frac{V_{CATCH} + V_{LANDUSE}}{2} \right) \right]^{1/2} \times \left[\frac{V_{GVC} + V_{CONNECT}}{10} \right] \right\}^{1/2} \quad (19)$$

These models are assumed to reflect the ability of SID and Flat wetlands to provide critical life requisites for wildlife, with an emphasis on amphibians and birds. If the components of this model are similar to those found under reference standard conditions, then it is likely that the entire complement of amphibians and birds characteristic of SID and Flat wetlands within the HR will be present.

The first part of each equation is an expression of the hydrologic integrity of the wetland and involves one or more of the variables V_{DRAIN}, V_{WETVOL}, V_{CATCH}, and $V_{LANDUSE}$. In the context of this function, a characteristic hydrologic regime is essential as a source of water for breeding amphibians and to support the plant community upon which the animal community depends. The second part of each equation contains variables that reflect seral stage, cover potential, food production potential, nest site potential, availability of dispersal habitat, and other factors that depend on stand structure, maturity, and connectivity. In Flats and SID wetlands V_{CTD} and V_{CTDEN} are used when the wetland is dominated by trees; V_{SDEN} is used in shrub-dominated wetlands; and V_{GVC} is used in wetlands lacking sufficient trees or shrubs. Other features of forested wetlands such as snags, logs, and leaf litter 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, shrub, and ground cover layer are appropriate, then these additional features will be present in the appropriate numbers or amounts. The final variable in the equation for SID wetlands is $V_{CONNECT}$, which represents the availability of suitable habitat beyond the wetland boundary. This terrestrial buffer helps protect wetland water quality, provides critical habitat for numerous species of amphibians, and is important in protecting some species of birds from nest predators and parasites. Given the current land use and small size of most SID wetlands within the HR, the maintenance of an extremely large buffer of terrestrial habitat is impractical. A distance of 150 m from the edge of the SID wetland (approximately the minimum core terrestrial habitat suggested by Semlitsch and Bodie (2003) was selected as the minimum value that would be appropriate for use in this model. 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)). In SID or Flat wetlands dominated by trees, the maximum possible FCI is 1.0. Wetlands dominated by shrubs and few or no large trees are assumed to have lower values for birds and amphibians; the maximum FCI in shrub wetlands is 0.63. Wetlands dominated by herbaceous species with few trees or shrubs are assumed to have even lower values for birds and amphibians; the maximum FCI in herbaceous wetlands is 0.45.

5 Assessment Protocol

Introduction

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

1. Define assessment objectives
2. Characterize the project area
3. Screen for red flags
4. Define the Wetland Assessment Area
5. Determine the wetland subclass
6. Collect the data
7. Analyze the data
8. Apply assessment results

Define assessment objectives

Begin the assessment process by unambiguously identifying the purpose of the assessment. This can be as simple as stating, “The purpose of this assessment is to determine how the proposed project will impact 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.

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

Characterize the project area

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

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 9). Many red flag features, such as those based on national criteria or programs, are similar from region to region. Other red flag features are based on regional or local criteria. Screening for red flag features represents a proactive attempt to determine if the wetlands or other natural resources in and around the project area require special consideration or attention that may preempt or postpone an assessment of

Table 9. Red Flag Features and Respective Program/Agency Authority

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

[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

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.

Define the wetland assessment area (WAA)

The WAA is an area of wetland within a project area that belongs to a single regional wetland subclass and is relatively homogeneous with respect to the site-specific criteria used to assess wetland functions (i.e., hydrologic regime, vegetation structure, topography, soils, successional stage, etc.). In many project areas, there will be just one WAA representing a single wetland subclass, as illustrated in Figure 23. 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.

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 24). The second situation exists when more than one regional wetland subclass occurs within a project area (Figure 25). 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 cultural alteration (e.g., logging, surface mining, hydrologic alterations) (Figure 26). Designate each of these areas as a separate PWAA and conduct a separate assessment on each area.

There are elements of subjectivity and practicality in determining what constitutes a significant difference in portions of the WAA. Field experience with the regional wetland subclass under consideration should provide a sense of the range of variability that typically occurs, and the understanding necessary to make reasonable decisions about defining multiple PWAAs. For example, in Flats and Depressional wetlands, recent logging in a portion of a wetland area may be a criterion for designating two PWAAs. The presence of relatively minor differences resulting from natural variability should not be used as a basis for dividing a contiguous wetland into multiple PWAAs. However, zonation caused by different hydrologic regimes or disturbances caused by rare and destructive natural events (e.g., hurricanes) should be used as a basis for defining PWAAs.

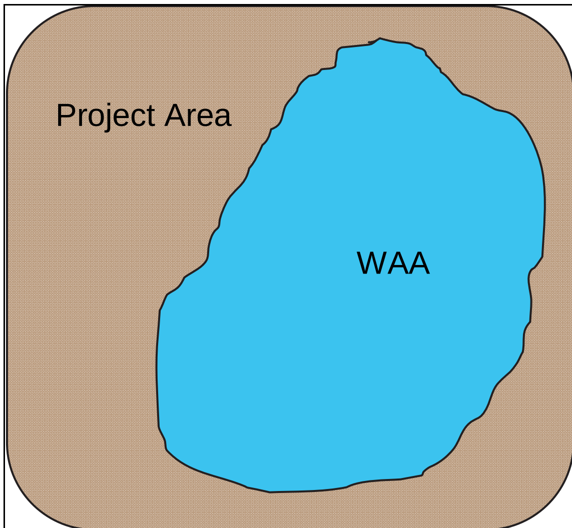

Figure 23. A single WAA within a project.

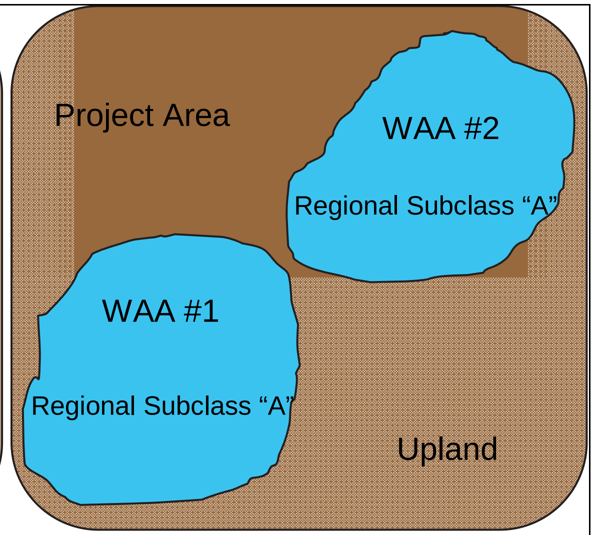

Figure 24. Spatially separated WAAs from the same regional subclass within a project.

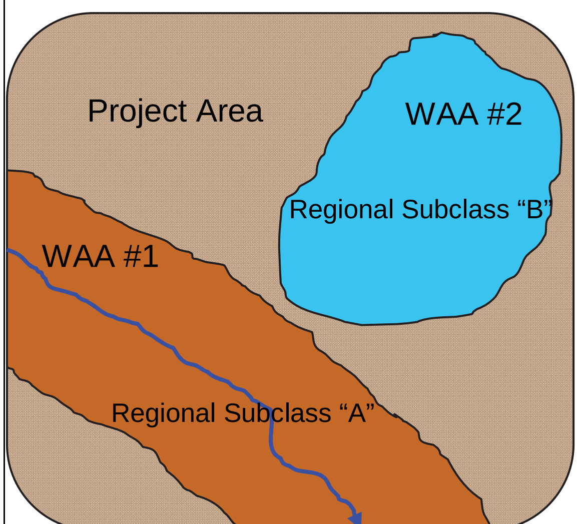

Figure 25. More than one regional subclass within a project area.

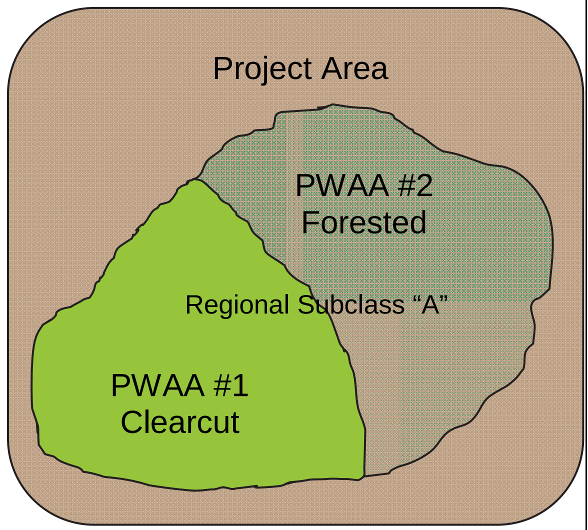

Figure 26. PWAAs defined on the basis of differences in site-specific characteristics.

Determine the wetland subclass

This guidebook can be used to assess functions in two subclasses of wetlands (i.e., SID and Flat) within the HR. Determining the correct subclass is essential to completing a meaningful HGM assessment. Subclasses are based on hydrogeomorphic characteristics. Depression and Flat wetlands in the reference domain were described previously in Chapter 3. Seasonally Inundated Depression wetlands are concave in form and receive their hydrology from direct precipitation and from overland flow within the watershed. Flat wetlands are generally level in form and receive their hydrology from direct precipitation. Current aerial photographs, topographic maps, soils maps, NWI maps, local knowledge, or other available information can be used to help identify SID and Flat wetlands and distinguish them from riverine, slope, and fringe systems. In some cases, however, it will not be possible to determine the wetland subclass from remotely sensed data or maps, and on-site investigation will be necessary. Some extremely disturbed sites will be difficult to evaluate even during an on-site examination. In these cases, historical aerial photographs or knowledge of local experts may be helpful in determining the wetland subclass.

Collect the data

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

Variables used in the models to assess wetland functions were defined and discussed in Chapter 4. Information needed to estimate the variables is collected at various spatial scales. Three variables (V_{CATCH}, $V_{LANDUSE}$, and $V_{CONNECT}$) are landscape-scale variables that describe conditions in the wetland's catchment or watershed. These variables are evaluated using aerial photographs, maps, and field reconnaissance of the area surrounding the WAA. A walking reconnaissance, as well as the remote sensing tools described for the preceding variables and in some cases measurements of the area impacted in the WAA itself are needed to evaluate two variables, V_{DRAIN} and V_{WETVOL}. Finally, detailed, site-specific data collected within sample plot(s) or subplots at representative locations within the WAA are needed to estimate V_{CTD}, V_{CTDEN}, and the remaining variables. The data sheets shown in Figure 27 are organized to facilitate data collection at each spatial scale. Instructions for measuring each variable are given below.

Highland Rim Depressions/Flats Wetland HGM Field Data Sheet and Calculator
Site and WAA Data Form for Seasonally Inundated Depression (SID) Wetlands

Team: ______ UTM Easting: ______

Project Name: ______ UTM Northing: ______

Location: ______ Sampling Date: ______

WAA Number: ______ WAA Size(ha): ______

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

Sample Variables 1-3 using aerial photography, topographic maps, soil survey maps, etc.

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

Size of original catchment

If diversion: Size of current catchment

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

2 $V_{LANDUSE}$ Weighted average of runoff score for catchment (Used only in **SID** wetlands). The majority of soils in the Highland Rim fall into Soil Group B, so that group is assumed. Soils determination is not required.

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

3 $V_{CONNECT}$ Weighted average of scores for wetland perimeter connected to suitable habitat of different widths. (Used only in **SID** wetlands.) Enter a 0 if the wetland if a given buffer width range isn't present.

Length of wetland perimeter (meters) with a buffer at least 150 m wide (1)

Length of wetland perimeter (meters) with a buffer ≥30 m and <150 m wide (0.66)

Length of wetland perimeter (meters) with a buffer ≥10 m and <30 m wide (0.33)

Length of wetland perimeter with a buffer <10 m wide (0)

Total wetland perimeter

Figure 27. Field data sheet for Highland Rim Depressional and Flat wetlands (Continued).

Highland Rim Depressions/Flats Wetland HGM Field Data Sheet and Calculator
Site and WAA Data Form for Seasonally Inundated Depression (SID) Wetlands

Team: ______ UTM Easting: ______
Project Name: ______ UTM Northing: ______
Location: ______ Sampling Date: ______
WAA Number: ______ Plot Number: 0 of 0 WAA Size(ha): ______
Top Stratum in WAA (trees, sapling/shrub, herbs): Tree Stratum | Project/Mitigation Site (circle one) | Before/After Project (circle one)

Sample Variables 4-6 within the entire WAA.

4 V_{DRAIN} Hydrologic effect of ditches in flat wetlands. (Only Used in **FLATS**) For each ditch present, enter a length in meters, check the box to indicate if only one side of the drain lies within the WAA, and mark the impact zone override, if necessary. If no ditches are present, enter 0 for the length of Ditch 1. — Not Used

Total area of flat wetland in ha.

Drain	Length (m)	Check here if only one side of drain impacts WAA	Check here if data supports overriding the default 5-m per side impact zone	Data-supported impact width per side (in m)
Ditch 1:		☐	☐	
Ditch 2:		☐	☐	
Ditch 3:		☐	☐	
Ditch 4:		☐	☐	
Ditch 5:		☐	☐	
Ditch 6:		☐	☐	
Ditch 7:		☐	☐	
Ditch 8:		☐	☐	

Percent of flat wetland subject to draining effects of ditches (0.1):
Percent of flat wetland NOT subject to draining effects of ditches (1.0):

5 V_{WETVOL} Percent change in the Wetland Volume. (Only used in **SID** wetlands)
Choose One:

If 'Partial conversion by fill or excavation' is selected, enter the following (in m):

Average radius of SID wetland: ______ Depth of SID wetland at deepest point: ______

If Fill: Length: ______ Width: ______ Depth: ______

If Excavation: Length: ______ Width: ______ Depth: ______

Volume expressed in cubic meters:

SID WAA: ______ Fill ______ Excavation: ______

6 V_{MICRO} Weighted Average of Microtopographic Alteration Score for the WAA. (Only used in **FLAT** wetlands) — Not Used

Microtopographic Alteration (Choose From Drop List)	Variable Subindex	% in WAA	Running Percent (not >100)

Notes:

Figure 27. Field data sheet for Highland Rim Depressional and Flat wetlands (Continued).

Highland Rim Depressions/Flats Wetland HGM Field Data Sheet and Calculator
Site and WAA Data Form for FLAT Wetlands

Team:		UTM Easting:	
Project Name:		UTM Northing:	
Location:		Sampling Date:	
WAA Number:		WAA Size(ha):	
Top Stratum in WAA (trees, sapling/shrub, herbs):	Tree Stratum	Project/Mitigation Site (circle one)	Before/After Project (circle one)

Sample Variables 1-3 using aerial photography, topographic maps, soil survey maps, etc.

1	V_{CATCH}	Percent change in the size of the catchment. (Used only in SID wetlands). If there is no water diversion or augmentation in the catchment, percent change = 0.	Not Used
		Size of original catchment	
		If diversion: Size of current catchment	
		If augmentation: Size of catchment from which water is being diverted.	
2	$V_{LANDUSE}$	Weighted average of runoff score for catchment (Used only in SID wetlands). The majority of soils in the Highland Rim fall into Soil Group B, so that group is assumed. Soils determination is not required.	Not Used

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

3	$V_{CONNECT}$	Weighted average of scores for wetland perimeter connected to suitable habitat of different widths. (Used only in SID wetlands.) Enter a 0 if the wetland if a given buffer width range isn't present.	Not Used
		Length of wetland perimeter (meters) with a buffer at least 150 m wide (1)	
		Length of wetland perimeter (meters) with a buffer ≥30 m and <150 m wide (0.66)	
		Length of wetland perimeter (meters) with a buffer ≥10 m and <30 m wide (0.33)	
		Length of wetland perimeter with a buffer <10 m wide (0)	
		Total wetland perimeter	

Figure 27. Field data sheet for Highland Rim Depressional and Flat wetlands (Concluded).

Landscape-scale variables

Change in catchment size (V_{CATCH})

Measure/Units: Percent change in the effective size of the catchment or watershed surrounding the SID wetland. Use the following procedure to measure V_{CATCH}:

1. If there are no ditches, drains, or water diversions in the wetland's catchment, and no augmentation of hydrology through inter-basin 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, or field reconnaissance to delineate the catchment or watershed.
2. Determine the total area of the catchment under natural conditions (i.e., overlooking any diversions or drains that may be present).
3. 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.
4. Use Equation 1 or 2 in Chapter 4, whichever is appropriate, to calculate the percent change in effective catchment size.
5. Use Figure 6 to determine the subindex score for V_{CATCH}. If the effective size of the catchment is unchanged (e.g., no water diversions), the subindex score is 1.0.
6. Or, enter total area of the catchment, size of the current catchment, and size of any diversion in the appropriate yellow cells in the calculator spreadsheet. The percent change and variable subindex will be calculated automatically.

Surrounding land use ($V_{LANDUSE}$)

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

1. Use topographic maps or other sources to delineate the existing catchment or watershed of the SID 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. Using GIS techniques, recent aerial photos, or field reconnaissance, determine the percentage of the catchment represented by each combination of land-use category shown in Table 6.
3. Determine the runoff score for each combination of land-use category and soil hydrologic group present in the catchment (Table 6).
4. Determine a weighted (by area) average runoff score for the catchment. An example can be found in Appendix B.

5. Use Figure 7 to determine the subindex score for $V_{LANDUSE}$.
6. Or, select the land-use category from the drop-down menu on the spreadsheet calculator, and enter the percent in catchment in the yellow cell. Continue until the running percent equals 100. Runoff scores, the weighted average, and the variable subindex will be calculated automatically.

Habitat connections ($V_{CONNECT}$)

Measure/Units: Weighted average of the wetland's perimeter and width that is connected to suitable habitat. Use the following procedure to measure $V_{CONNECT}$:

1. Determine the total length in meters of the wetland perimeter using field reconnaissance, topographic maps, aerial photographs, or GIS techniques.
2. Determine the length of the wetland perimeter that does not have suitable habitat buffer at least 10 m (32.8 ft) in width. See Chapter 4 for examples of suitable habitat types. If none of the perimeter has suitable habitat ≥10 m (32.8 ft) wide, the subindex score will equal zero and the rest of the steps can be skipped.
3. Determine the length of wetland perimeter with suitable habitat with a width ≥10 m and <30 m (32.8-98.4 ft) wide. Divide this length by the total length and multiply by 100 to convert to a percent of the total wetland perimeter.
4. Determine the length of wetland perimeter with suitable habitat with a width ≥30 m and <150 m (98.4-492 ft). Divide this length by the total length and multiply by 100 to convert to a percent of the total wetland perimeter.
5. Determine the length of wetland perimeter with suitable habitat with a width ≥150 m (492 ft). Divide this length by the total length and multiply by 100 to convert to a percent of the total wetland perimeter.
6. Total the results of the four width categories of wetland perimeter to get a weighted average for $V_{CONNECT}$.
7. Use Figure 8 to convert the weighted average to a subindex score for $V_{CONNECT}$.
8. Or, enter the total length of the wetland perimeter, the length of the wetland perimeter for each with suitable habitat at least 10 m wide and the average width of the buffer into the yellow cells on the calculator spread-sheet. Percent connectivity and the variable subindex will be calculated automatically.

Wetland-scale variable

Wetland drainage (V_{DRAIN})

Measure/Units: This variable is quantified by the weighted average of the area impacted by located within the Flat wetland. Use the following procedure to measure V_{DRAIN}:

1. If wetland hydrology is unaltered and there are no ditches within the Flat wetland, then the subindex score for V_{DRAIN} is 1.0. Enter a 0 for the length of Ditch 1 in the appropriate yellow cell of the calculator, and this subindex will be calculated.
2. If wetland hydrology has been altered, and a drainage ditch is present within the wetland, determine its length and record that information in the yellow cells in the V_{DRAIN} section of the calculator. Up to eight ditches may be entered. The area within 5 m (16 ft) on either side of the ditches will be calculated, and added together, and the percentage of the overall wetland subject to drainage will be calculated automatically. A subindex score of 0.1 will be assigned to this area, and a subindex of 1 will be assigned to the remainder of the WAA.
3. An overall subindex score for V_{DRAIN} will be calculated for the WAA based on a weighted average of the drained and undrained areas.

Change in wetland volume (V_{WETVOL})

Measure/Units: This variable is defined as a change in the volume of a SID wetland. Use the following procedure to measure V_{WETVOL}:

1. If no excavation or fill activity has occurred in the SID wetland, then the variable subindex is 1.0. Select 'No Fill or Excavation' from the dropdown menu. The variable subindex for V_{WETVOL} will be calculated automatically.
2. If fill or excavation activity has occurred and wetland hydrology is no longer present within the WAA or PWAA or the SID wetland has changed to a lacustrine fringe wetland or permanent open water, then the subindex score would be zero. Select 'Entire SID wetland converted to upland or open-water/fringe wetland' from the drop-down menu. The variable subindex for V_{WETVOL} will be calculated automatically.
3. If the wetland has only partially been filled or excavated, select that option from the drop-down menu. Using geographic information system (GIS) techniques, planimeter, global positioning system (GPS), or other means, measure the diameter of the wetland along the longest and shortest axis.

Average the two diameters and use half of this average diameter for the radius of the wetland. Enter average radius in the appropriate yellow cell of the calculator.

4. Measure the depth of the SID wetland at the deepest point, and enter that information into the appropriate yellow cell. The original volume of the wetland prior to alteration by fill or excavation will be calculated automatically using a cone volume formula.
5. Measure the length, width, and thickness of the fill material or excavation. The volume of the alteration will be calculated automatically. An example of this calculation can be found in Appendix B.
6. The calculator will automatically determine the percent change in volume.
7. The calculator will automatically use the formula depicted in Figure 9 to determine the subindex score for V_{WETVOL}.

Microtopographic features (V_{MICRO})

Measure/Units: This variable represents alterations to microtopographic features in Flat wetlands. Use the following procedure to measure V_{MICRO}:

1. Select a microtopgraphic alteration from Table 7 or the drop-down menu of the calculator. If there is no alteration on the site, select "Unaltered."
2. Assign the percent of the WAA that the microtopgraphic alteration applies to. If unaltered, enter 100.
3. If multiple alterations exist at a site, select another alteration and percent cover in the next row, until 100% of the site is accounted for. A weighted average will be automatically calculated if using the calculator.

Plot-scale variables

Data on vegetation and soil conditions in SID and Flat wetlands are collected within one or more 0.04-ha (0.1-acre) sample plot(s), each divided into four equal subplots (Figure 28). Plots are needed to determine the density of trees, if present. They also make the estimation of percent cover of shrubs, ground-layer vegetation, and organic litter easier and more accurate. Some vegetation and soil variables are sampled on subplots as a way to determine average conditions when there is variability across the larger plot.

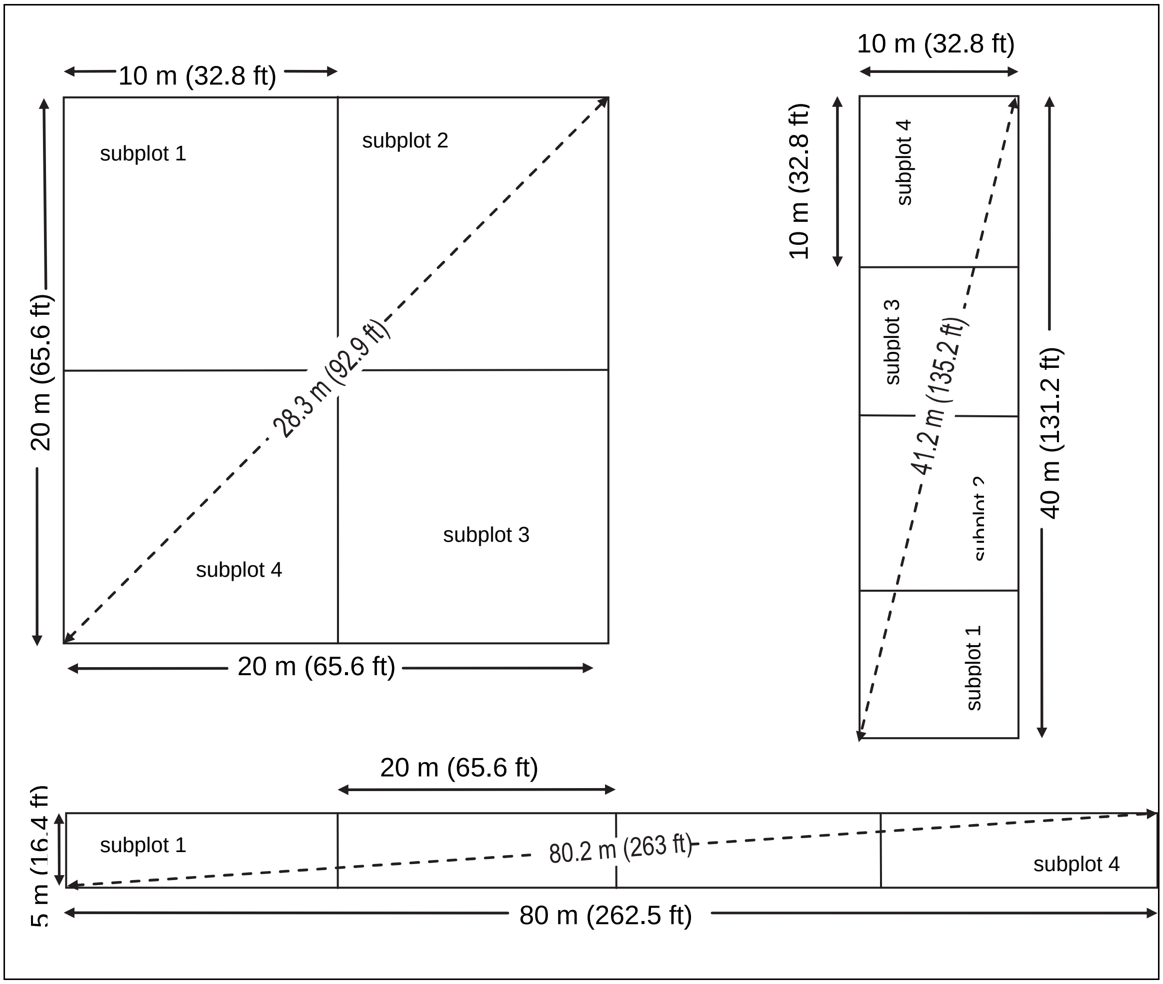

Figure 28. Examples of plot and subplot shapes that equal 0.04 ha (0.1 acre).

The following equipment is needed to establish the sample plot(s) and measure the plot-based variables.

- A 50-m measuring tape, stakes, corner prism (optional), and flagging
- Plant identification references or keys
- Soil probe or sharpshooter shovel

While a 0.04-ha (0.1-acre) square plot is fairly easy to lay out, the size and shape of the wetland may require a rectangular plot or some other shape. Figure 28 shows examples of rectangular plots measuring 10×40 m and 5×80 m, which also cover 0.04 ha but may fit better within a narrow, linear wetland. Furthermore, the subplots do not need to be contiguous if separating them would better fit the shape of the wetland. Any combination of plot sizes and shapes that equals 0.04 ha is acceptable. If the wetland is smaller than 0.04 ha, the entire wetland may be sampled. In cases where

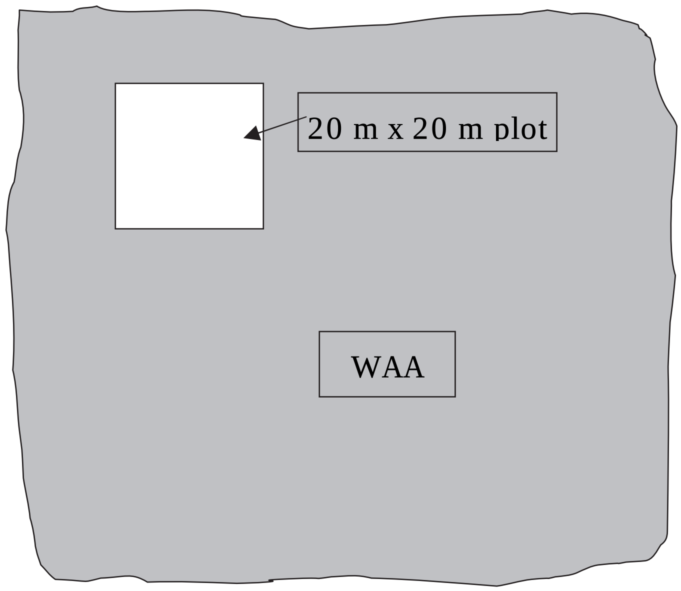

Figure 29. Placement of a 20-m x 20-m plot within the WAA.

odd-sized plots or the entire wetland are sampled, the area sampled will need to be determined to calculate the density of canopy trees (V_{CTDEN}) in stems/ha. Figure 29 illustrates the placement of the plot within the WAA and Figure 30 illustrates the variables that are collected within the plot or subplots.

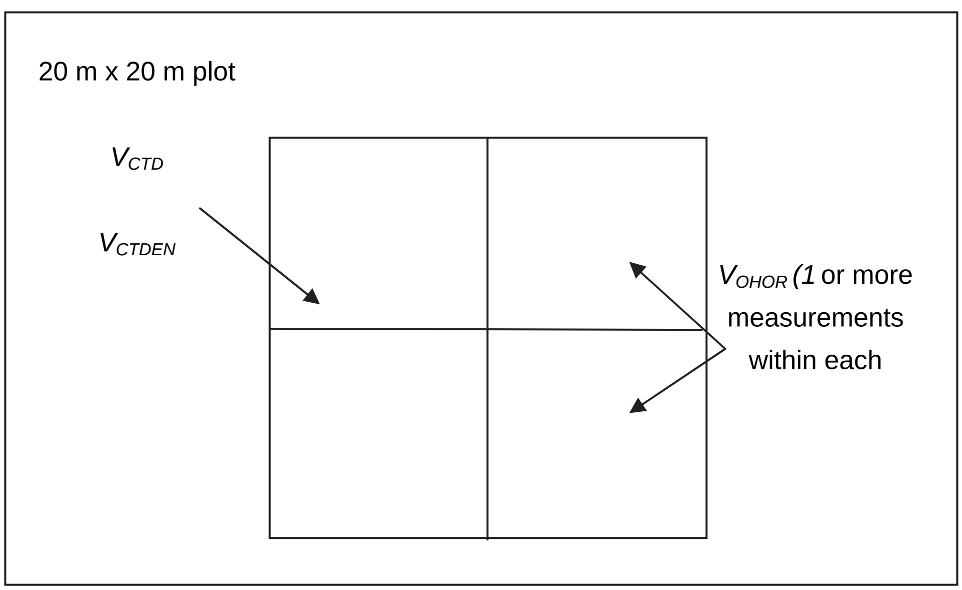

Figure 30. Sample plot and subplot dimensions and layout for field sampling.

Canopy tree diameter (V_{CTD})

Measure/Units: Average diameter at breast height (dbh in cm) of all *canopy* trees within a 0.04-ha (0.1-acre) plot. Use the following procedure to measure V_{CTD}:

1. This variable is measured only if the total cover of trees $\geq$10 cm (4 in.) dbh in the wetland is $\geq$20%. If tree cover is <20%, the following steps may be skipped.
2. Measure the dbh (cm) of all *canopy* trees within a 0.04-ha (0.1-acre) plot or, alternatively, within each of four 0.01-ha (0.025-acre) subplots. See Chapter 4 and Figure 11, or the Glossary, for the definition of a canopy tree. Enter the dhh measurements (in centimeters) into the yellow cells in the V_{CTD} section on the calculator.
3. The mean canopy tree diameter will be automatically calculated and transferred to the Data Summary tab.
4. If multiple 0.04-ha plots are sampled, the calculator will average the results from all plots before calculating a subindex score.
5. The calculator will use the formula in Figure 12 for Flat wetlands and Figure 13 for SID wetlands to determine the subindex score for V_{CTD}.

Canopy tree density (V_{CTDEN})

Measure/Units: Number of canopy trees (or stems) per hectare. Use the following procedure to measure V_{CTDEN}:

1. This variable is only calculated if the total cover of trees $\geq$10 cm (4 in.) dbh in the wetland is $\geq$20%. If tree cover is <20%, the following steps may be skipped.
2. Use the data gathered for V_{CTD} to determine the number of canopy trees in a 0.04-ha (0.1-acre) plot and convert this result to a per hectare basis by multiplying by 25 (there are 25 0.04-ha plots in each hectare). The calculator will make all the necessary calculations and transfer the information to the Data Summary Tab.
3. If multiple 0.04-ha plots are sampled, the calculator will average the results from all plots.
4. The calculator will use the formula depicted in Figure 14 for Flat wetlands and Figure 15 for SID wetlands to determine the subindex score for V_{CTDEN}.

Shrub density (V_{SDEN})

Measure/Units: Number of shrub stems per unit area. Use the following procedure to measure V_{SDEN}:

1. Measure this variable only if total tree cover is <20% and cover of shrubs is $\geq$20%. See Chapter 4 or the Glossary for the definition of shrubs.
2. Count the number of shrubs within a 0.04-ha (0.1-acre) plot or, alternatively, within each of the four 0.01-ha (0.025-acre) subplots. Some shrubs have multiple stems. If branching occurs near the ground (i.e., < 1 m) each individual stem should be counted. Enter the number of shrub stems for each subplot in the yellow cells in the V_{SDEN} section of the calculator.
3. The calculator will automatically convert the number of stems to a per hectare measurement by multiplying by 25. This number will be transferred to the Data Summary Tab.
4. If multiple 0.04-ha plots are sampled, the calculator will average the results from all plots.
5. The calculator will use the formula depicted in Figure 16 for Flat wetlands and Figure 17 for SID wetlands to determine the subindex score for V_{SDEN}.

Ground vegetation cover (V_{GVC})

Measure/Units: Average percent cover of ground-layer vegetation. Use the following procedure to measure V_{GVC}:

1. Measure this variable only if tree and shrub cover are each <20%. See Chapter 4 or the Glossary for the definition of ground-layer vegetation.
2. Visually estimate the percent 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. Enter the percent cover data for each subplot in the yellow cells in the V_{GVC} section of the calculator. The calculator will automatically average the data across subplots, and transfer the average to the Data Summary Tab.
3. If multiple 0.04-ha plots are sampled, the calculator will average the results from all plots.
4. The calculator will use the formula depicted in Figure 18 for Flat wetlands and SID wetlands 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%, then V_{COMP} is determined for the tree stratum. If tree cover is <20% and shrub cover is $\geq$20%, then V_{COMP} is determined for the shrub stratum. If tree cover and shrub cover are both <20%, then V_{COMP} is determined for the ground layer, even if the ground layer has <20% vegetation cover.
2. Use the "50/20 rule" (see Figure 19) to identify the dominant species in the appropriate vegetation stratum. For sites containing a tree stratum, be sure to consider all trees $\geq$10 cm (4 in.) dbh and not just "canopy" trees.
3. On the data form, place a check beside each dominant species that appears in either Group 1 or 2 (Table 8). If a dominant species is not listed but is a native species within the reference domain, it can be added to Group 1 or 2 using the blanks provided. For non-native invasive species in the reference domain (Group 3), check all species encountered on the plot without regard to dominance or stratum. If a non-native invasive species is not listed, it can be added using the blanks provided. The data form does not list herbaceous plants due to the potentially exhaustive list. Assign all native herbaceous species to Group 1. Assign all non-native, non-invasive herbaceous species to Group 2. Assign all non-native invasive herbaceous species to Group 3.
4. Using the checked dominants in Groups 1 and 2, and the checked non-native invasive species in Group 3, the calculator will automatically calculate an initial quality index (Q) using the following formula:

$$Q = \begin{bmatrix} (1.0 \times number\ of\ checked\ dominants\ in\ Group\ 1) + \\ (0.66 \times number\ of\ checked\ dominants\ in\ Group\ 2) + \\ (0.0 \times number\ of\ checked\ species\ in\ Group\ 3) \end{bmatrix} \Big/ total\ number\ of\ checked\ species\ in\ all\ groups$$

5. The calculator will then automatically calculate an adjusted quality index (R) that takes species richness into consideration. It will multiply Q by one of the following constants:

a. If four or more species from Groups 1 or 2 occur as dominants, 1.0 (i.e., R = Q × 1.0).
b. If three species from Groups 1 or 2 occur as dominants, 0.75 (i.e., R = Q × 0.75).
c. If two species from Groups 1 or 2 occur as dominants, 0.50 (i.e., R = Q × 0.50).
d. If one species from Groups 1 or 2 occurs as a dominant, 0.25 (i.e., R = Q × 0.25).
e. If 0 species from Groups 1 or 2 occur as dominants, 0.0 (i.e., R = Q × 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).

6. The calculator will calculate the square root of the Adjusted Quality Index to determine the subindex for vegetation composition and diversity (V_{COMP}).

O horizon thickness (V_{OHOR})

Measure/Units: Average thickness of the O horizon in centimeters. Use the following procedure to measure V_{OHOR}:

1. At four representative locations within each 0.04-ha (0.1-acre) plot, or at one representative location in each 0.01-ha (0.025-acre) subplot, use a soil probe or shovel and excavate the soil to a depth of about 30 cm (12 in.). Measure the thickness of the O horizon in centimeters. Enter this information in the appropriate yellow cell in the V_{OHOR} section of the calculator.
2. Average all thicknesses across sampling points. If using the calculator, this will be averaged automatically and the result will be transferred to the Data Summary Tab.
3. If multiple 0.04-ha plots are sampled, the calculator will average the results from all plots.
4. The calculator will use the formula depicted in Figure 20 for Flat wetlands and Figure 21 for SID wetlands to determine the subindex score for V_{OHOR}.

Analyze the data

The first step in analyzing the field data is to transform the field measure of each assessment variable into a variable subindex on a scale of 0 to 1.0. This can be done using the graphs and tables in Chapter 4. The second step is to insert the variable subindices into the equations for each assessment model and calculate the FCIs using the relationships defined in the models. Again, this can be done manually or automatically using a spreadsheet. Finally, multiply the FCI for each function by the total size of the WAA to calculate the number of Functional Capacity Units (FCUs) for each function (Smith et al. 1995). All of this will be accomplished automatically on the FCI Calculator Tab of the calculator.

Apply assessment results

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

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

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

References

Abtew, W. 1996. Evapotranspiration measurements and modeling for three wetland systems in south Florida. *Water Resources Bulletin* 32(3):465-473.

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.

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

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

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: U. S. Army Engineer Waterways Experiment Station.

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* 39:129-52.

Azous, A.L., and R. R. Horner. 2001. *Wetlands and urbanization: Implications for the future*. Boca Raton, FL: CRC Press.

Bailey, M. A., and K. A. Bailey. 2000. *Wetland fauna and drainage basin studies: Amphibian and reptile habitat utilization*. Contract No. F40650-95-D-0006, Prepared for Arnold Engineering Development Center, TN.

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

Barbour, R. A. 1971. *Amphibians and reptiles of Kentucky*. Lexington, KY: University of Kentucky Press.

Baskin, J. M., C. C. Baskin, and E. W. Chester. 1999. The big barrens region of Kentucky and Tennessee. Chapter 11 in *Savannas, Barrens, and Rock Outcrop Communities of North America*, ed. R. C. Anderson, J. S. Fralish, and J. M. Baskin. Cambridge University Press.

Beaulac, N. M., and K. H. Reckhow. 1982. An examination of land use nutrient export relationships. *Water Resources Bulletin* 18(6):101324.

Bolen, E. G., L. H. Smith, and H.L. Schramm. 1989. Playa lakes - prairie wetlands of the southern high plains. *Bioscience* 39:615-23.

Bonham, C. D. 1989. *Measurements for terrestrial vegetation.* New York: John Wiley and Sons.

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.

Braun, E. L. 1950. *Deciduous forests of eastern North America*. London, UK: The Free Press, Collier Macmillan Press.

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

______. 1995a. Assessing wetland functions using HGM. *National Wetlands Newsletter,* January/February. Washington, DC: Environmental Law Institute.

______. 1995b. The hydrogeomorphic approach explained. *National Wetlands Newsletter,* November/December. Washington, DC: Environmental Law Institute.

Brinson, M. M., F.R. Hauer, L.C. Lee, W.L. Nutter, R.D. Rheinhardt, R.D.Smith, and D.Whigham. 1995. *A guidebook for application of hydrogeomorphic assessments to riverine wetlands*. Technical Report WRP-DE-11. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

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 *Proceedings, INTECOL International Wetland Conference, Perth, Australia*.

Brinson, M. M., W.L.Nutter, R. Rheinhardt, and B.A. Pruitt. 1996. *Background and recommendations for establishing reference wetlands in the Piedmont of the Carolinas and Georgia*. EPA/600/R-96/057. Corvallis, OR: U.S. Environmental Protection Agency National Health and Environmental Effects Laboratory, Western Division.

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

Brooks, R. T., and M. Hayashi. 2002. Depth-area-volume and hydroperiod relationships of ephemeral (vernal) forest pools in southern New England. *Wetlands* 22(2): 247-255.

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

Burns, R. M., and B. H. Honkala. 1990. *Silvics of North America, Volume 2, Hardwoods*. Agriculture Handbook 654. Washington, DC: U.S. Department of Agriculture, Forest Service.

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

Call, G. 2003. Investigation of vegetation and hydric soil indicators in flats and depressions of Arnold Air Force Base, Tennessee. M. S. thesis, Tennessee Technological University, Cookeville, TN.

Carlisle, V. W. 2000. *Hydric soils of Florida handbook, 3d ed*., 95-101. Gainesville, FL: Florida Association of Environmental Soil Scientists.

Carpenter, S. R. 1988. *Complex interactions in lake communities*. New York: Springer Verlag.

Chester, E. W., and W. H. Ellis. 1989. Plant communities of northwestern middle Tennessee. *Journal of the Tennessee Academy of Science* 64(3):75-78.

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

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

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

Craft, C. B., and W. P. Casey. 2000. Sediment and nutrient accumulation in floodplain and depressional freshwater wetlands of Georgia, USA. *Wetlands* 20(2):323-332.

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

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

Crowley, S. C. W., P. Cavanaugh, and C. Griffin. 1996. *WETHINGS, Habitat Assessment Procedures for Wetland Dependant Birds in New England* Amherst, MA: Department of Forestry and Wildlife Management, University of Massachusetts.

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

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

DeGraff, R. M., M. Yamasaki, and W.B. Leak. 1992. Management of New England northern hardwoods, spruce-fir, and eastern white pine for neotropical migratory birds. In *Status and Management of Neotropical Migratory Birds*, ed. D.M. Finchand P. W. Stangel. General Technical Report RM-229. Fort Collins, CO: U.S. Forest Service.

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

Dodd, C. K., Jr. 2003. *Monitoring amphibians in Great Smoky Mountains National Park*. Circular No. 1258. Washington, DC: U.S. Geological Survey.

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

Ellis, W. H., and E. W. Chester. 1989. Upland swamps of the Highland Rim of Tennessee. *Journal of the Tennessee Academy of Science* 64(3):97-101.

Environmental Laboratory. 1987. *Corps of Engineers wetlands delineation manual*. Technical Report Y-87-1. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

Euliss, N. H., and D. M. Mushet. 1996. Water-level fluctuation in wetlands as a function of landscape condition in the prairie pothole region. *Wetlands* 16(4):587-593.

Ewel, K. C. 1984. Effects of fire and wastewater on understory vegetation in cypress domes. *Cypress swamps,* ed. K. C. Ewel and H. T. Odum. Gainesville, FL: University of Florida Press.

Eyre, F. H. 1980. *Forest cover types of the United States and Canada*. Washington, DC: Society of American Foresters.

Faulkner, S. 2004. Soils and sediment. In *Wetlands*, ed. S.L. Spray and K.L. McGothlin. Lanham, MA: Rowman and Littlefield Publishers Inc.

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: South Florida Water Management District.

Ferren, W. R., Jr., P. L. Fiedler, and R. A. Leidy. 1996a. Wetlands of California. Part I. History of wetland habitat. *Madrono* 43:105-24.

Ferren, W. R., Jr., P. L. Fiedler, R. A. Leidy, K. D. Lafferty, and L. A. K. Mertes. 1996b. Wetlands of California. Part II. Classification and description of wetlands of the central California and southern California coast and coastal watershed. *Madrono* 43:125-82.

Ferren, W. R., Jr., P. L. Fiedler, R. A. Leidy, K. D. Lafferty, and L. A. K. Mertes. 1996c. Wetlands of California. Part III. Key to the catalogue of wetlands of the central California and southern California coast and coastal watershed. *Madrono* 43:183-233.

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

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

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

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

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

Hamel, P. B. 1992. *Land manager's guide to the birds of the southeast.* Chapel Hill, NC: The Nature Conservancy, Southeastern Region.

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

Harris, L. D., and J. G. Gosselink. 1990. Cumulative impacts of bottomland hardwood forest conversion on hydrology, water quality, and terrestrial wildlife. In *Ecological processes and cumulative impacts illustrated by bottomland hardwood wetland ecosystems,* J. G. Gosselink, L. C. Lee, and T. A. Muir, ed., 259-322. 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* 40:51730.

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

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

Holland, I. I., G. L. Rolfe, and D. A. Anderson. 1990. *Forests and forestry*. Danville, IL: Interstate Publishers.

Hubbard, D. E. 1988. *Glaciated prairie wetland functions and values: A synthesis of the literature.* Biological Report 88(43). Washington, DC: U.S. Fish and Wildlife Service.

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

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

Idso, S.B. 1981. Relative rates of evaporative water losses from open and vegetation covered water bodies. *Water Resources Bulletin* 17(1):46-48.

Jennings, J. N. 1986. *Karst geomorphology*. Oxford, UK: Blackwell.

Johnson, T. R. 1987. *The amphibians and reptiles of Missouri.* Jefferson City, MO: Missouri Department of Conservation.

Jones, R. L. 1989. A floristic study of wetlands on the Cumberland Plateau of Tennessee. *Journal of the Tennessee Academy of Science* 64(3):131-134.

Kantrud, J. A., G. L. Krapu, and G. A. Swanson. 1989. *Prairie basin wetlands of the Dakotas: A community profile.* Biological Report 85. Washington, DC: U.S. Fish and Wildlife Service.

Kays, R. W., and D.E.Wilson. 2002. *Mammals of North America*. Princeton, NJ: Princeton University Press.

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

Kent, M., and P. Coker. 1995. *Vegetation description and analysis, a practical approach.* New York: John Wiley and Sons.

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* 25:878-85.

King, D. M., and K. J. Adler. 1992. Scientifically defensible compensation ratios for wetland mitigation. In *Effective mitigation: Mitigation banks and joint projects in the context of wetland management plans,* 64-73. Association of State Wetland Managers.

Kittelson, J. M. 1988. Analysis of flood peak moderation by depressional wetland sites. In *The ecology and management of wetlands, Volume1: Ecology of Wetlands,* 98-111. Portland, OR: Timber Press.

Kurz, H., and K. A. Wagner. 1953. Factors in cypress dome development. *Ecology* 34:157-64.

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

Lamb, J. 2004. *AAFB birds, mammals, herps reports.* Arnold Air Force Base. Unpublished Reports.

Leibowitz, S. G., and J. B. Hyman. 1997. *Use of scale invariance in assessing the quality of judgment indicators*. Corvallis, OR: U.S. Environmental Protection Agency Laboratory.

Logan, W.S., and D. L. Rudolph. 1997. Microdepression-focused recharge in a coastal wetland, La Plata, Argentina. *Journal of Hydrology* 194:221-238.

Lott, R. B., and R. J. Hunt. 2001. Estimating evapotranspiration in natural and constructed wetlands. *Wetlands* 21(4):614-628.

Ludden, A. P., D. L. Frink, and D. H. Johnson. 1983. Water storage capacity of natural wetland depressions in the Devils Lake Basin of North Dakota. *Journal of Soil and Water Conservation* 38:45-48.

Ludwig, J. A., and J.F. Reynolds. 1988. *Statistical ecology: A primer on methods and computing.* New York: John Wiley and Sons.

Luther, E. T. 1977. *Our restless earth: The geologic regions of Tennessee*. Knoxville, TN: University of Tennessee Press.

MacArthur, R. H., and J. W. MacArthur. 1961. On bird species diversity. *Ecology* 42:549-98.

Mao, L. M., M. J. Bergman, and C. C. Tai. 2002. Evapotranspiration measurement and estimation of three wetland environments in the upper St. Johns River basin, Florida. *Journal of the American Water Resources Association* 38(5):1271-1285.

McKinney, L. E. 1989. Vegetation of the eastern Highland Rim of Tennessee. *Journal of the Tennessee Academy of Science* 64(3):145-147.

McKinney, M. L. 2002. Urbanization, biodiversity, and conservation. *BioScience* 52:883-890.

Messina, M. G., and W. H. Conner. 1997. *Southern forested wetlands: Ecology and management*. Boca Raton, FL: Lewis Publishers.

Miller, B. T. 1995. *An investigation and assessment of rare, threatened, and endangered fauna and their habitats on Arnold Air Force Base, Coffee and Franklin Counties, Tennessee: Amphibian and reptile survey*. Murfreesboro, TN: Middle Tennessee State University.

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

Mitsch, W. J., and J. G. Gosselink. 1993. *Wetlands*. New York: Van Nostrand Reinhold.

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

Moore, I. D., and C. L. Larson. 1980. Hydrologic impact of draining small depressional watersheds. *Journal of the Irrigation and Drainage Division, ASCE* 106(IR 4):345-363.

Morgan, K. L., and T.H. Roberts. 1999. *An assessment of wetland mitigation in Tennessee.* Nashville, TN: Tennessee Department of Environment and Conservation, Division of Water Pollution Control.

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

Morrison, M. L., B. C. Marcot, and R .W. Mannan. 1992. *Wildlife habitat relationships: Concepts and applications*. Madison, WI: University of Wisconsin Press.

Mount, R. H. 1975. *The reptiles and amphibians of Alabama*. Auburn, AL: Auburn University Agricultural Experiment Station.

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

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, 53-59. Columbia, MD: National Institute for Urban Wildlife.

Noble, C. V., R. Evans, M. McGuire, K. Trott, M. Davis, and E.J.Clairain. 2002. *A Regional Guidebook for Applying the Hydrogeomorphic Approach to assessing wetland functions of Flats Wetlands in the Everglades*. ERDC/EL TR-02-19. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

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

Ogawa, H., and J.W. Male. 1986. Simulating the flood mitigation role of wetlands. *Journal of Water Resources Planning and Management* 112(1):114-128.

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

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

Petranka, J. W. 1998. *Salamanders of the United States and Canada*. Washington, DC: Smithsonian Institution Press.

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

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

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

Rheinhardt, R. D., M. M. Brinson, and P. M. Farley. 1997. A preliminary reference data set for wet forested flats in North Carolina and its application to wetland functional assessment, mitigation, and restoration. *Wetlands* 17:195-215.

Rheinhardt, R. D., M. C. Rheinhardt, and M. M. Brinson. 2002. *A Regional Guidebook for applying the Hydrogeomorphic Approach to assessing wetland functions of Wet Pine Flats on mineral soils in the Atlantic and Gulf Coastal Plains*. ERDC/EL TR-02-9. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

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

Robbins, C. S., D. K. Dawson, and B. A. Dowell. 1989. Habitat area requirements of breeding forest birds in the middle Atlantic states. *Wildlife Monographs* 103:1-34.

Roberts, T. H., and M. S. Peterson. 2001. *Wetland fauna and drainage basin studies: Spatial aspects of habitat use by birds in and around forested depressional and flats wetlands*. Arnold Engineering Development Center, Contract No. F40650-95-D-006, CDRL No. A005.

Robertson, P. A. 1992. Environmental factors affecting tree growth on three wetland sites in southern Illinois. *American Midland Naturalist* 128:218-326.

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* 48:249-67.

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* 16:1324-1332.

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

Schneider, D. C. 1994. *Quantitative ecology: Spatial and temporal scaling*. New York: Academic Press.

Schoener, T. W. 1986. Resource partitioning. In *Community ecology: Patterns and processes,* ed. J. Kikkawa and D. J. Anderson, 91-126. Melbourne, Australia: Blackwell.

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

Scott, A. F., E.W. Chester, and D.H. Snyder. 1980. *A study of potential natural areas in the lower Cumberland River Basin of Tennessee.* Nashville, TN: Tennessee Department of Conservation, Heritage Program.

Semeniuk, C. A. 1987. Wetlands of the Darling System: A geomorphic approach to habitat classification. *Journal of the Royal Society of Western Australia* 69:95-112.

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

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

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

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

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

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

Smalley, G. W. 1983. Classification and evaluation of forest sites on the eastern Highland Rim and Pennyroyal. General Technical Report SO-38. New Orleans, LA: USDA Forest Service.

Smith, B. J., H. W. Browers, T. E. Dahl, D. E. Nomsen, and K. F. Higgins. 1989. Indirect wetland drainage in association with federal highway projects in the prairie pothole region. *Wetlands* 9(1):27-39.

Smith, R. D. 2001. *Hydrogeomorphic approach to assessing wetland functions: Guidelines for developing regional guidebooks; Chapter 3, Developing a reference wetland system*. ERDC/EL TR-01-29. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Smith, R. D., A. Amman, C. Bartoldus, and M. M. Brinson. 1995. *An approach for assessing wetland functions based on 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. http://www.wes.army.mil/el/wetlands/pdfs/trel02-4.pdf, Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Smith, R. D., and J .S. Wakeley. 2001. *Hydrogeomorphic approach to assessing wetland functions: Guidelines for developing regional guidebooks; Chapter 4, Developing assessment models*. ERDC/EL TR-01-30. 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. In *Clean water, clean environment – 21st century. Volume III: Practices, systems, and adoption.* Proceedings of a conference March 5-8, 1995, Kansas City, Mo., American Society of Agricultural Engineers, St. Joseph, MI, 259-262.

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

Spurr, S. H., and B.V. Barnes. 1980. *Forest ecology*. New York: John Wiley and Sons.

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.

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: The Terrene Institute.

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

ter Braak, C. J. F. 1994. Canonical community ordination. Part 1: Basic theory and linear methods. *Ecoscience* 1:127-140.

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

Uranowski, C., Z. Lin, M. DelCharco, C. Huegel, J. Garcia, I. Bartsch, M.S. Flannery, S.J. Miller, J. Bacheler, and W. Ainslie. 2003. *A Regional Guidebook for applying the hydrogeomorphic approach to assessing wetland functions of low-gradient, blackwater riverine wetlands in peninsular Florida*. ERDC/EL TR-03-3. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

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

U.S. Department of Agriculture (USDA) Soil Conservation Service. 1981. *Soil survey of White and Van Buren counties, Tennessee.*

U.S. Department of Agriculture (USDA) Soil Conservation Service. 1993. *Soil Survey Manual*. USDA Handbook 18. Washington, DC.

U.S. Department of Agriculture (USDA) Natural Resources Conservation Service. 2006. *Land resource regions and major land resource areas of the United States, the Caribbean, and the Pacific Basin*. Agriculture Handbook 296. Washington, DC: U.S. Department of Agriculture. (http://soils.usda.gov/survey/geography/mlra/index.html)

U.S. Fish and Wildlife Service. 1980. *Habitat evaluation procedures*. Ecological Services Manual 102. Washington, DC.

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

van der Kamp, G., and M. Hayashi. 1998. The groundwater recharge function of small wetlands in the semi-arid Northern Prairies. *Great Plains Research* 8: 39-56.

VanDruff, L. W., and R. N. Rowse. 1986. Habitat association of mammals in Syracuse, New York. *Urban ecology* 9:413-434.

VanDruff, L. W., E.G. Bolen, and G.J. San Julian. 1996. Management of urban wildlife. *Research and management techniques for wildlife and habitats,* 5th ed., ed. T. Bookhout507-530. Bethesda, MD: The Wildlife Society.

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.

Wakeley, J. S., and R.D. Smith. 2001. *Hydrogeomorphic Approach to assessing wetland functions: Guidelines for developing Regional Guidebooks - Chapter 7, Verifying, field testing, and validating assessment models.* ERDC/EL TR-01-31. Vicksburg, MS: U.S. Army Engineer Research and Development Center. (http://el.erdc.usace.army.mil/wetlands/pdfs/trel01-31.pdf).

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

Wentworth, T. R., G. P. Johnson, and R. L. Kologiski. 1988. Designation of wetlands by weighted averages of vegetation data: A preliminary evaluation. *Water Resources Bulletin* 24:389-396.

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.* Report FWS/OBS-81/37. Washington, DC: U.S. Fish and Wildlife Service, Office of Biological Services.

Whitlock, A. L., N.M. Jarman, and J.S. Larson. 1994. *WEThings; Wetland habitat indicators for nongame species, wetland-dependent amphibians, reptiles and mammals of New England.* Publication 94-1. Amherst, MA: The Environmental Institute, University of Massachusetts.

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* 44:233-54.

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

Wigley, T. B., and T.H. Roberts. 1994. Forest management and wildlife in forested wetlands of the southern Appalachians. *Water, Air, and Soil Pollution* 77:445-456.

Wilcove, D. 1985. Nest predation in forest tracts and the decline of migratory songbirds. *Ecology* 66:1211-14.

Wilder, T. C., and T.H. Roberts. 2002. *A regional guidebook for assessing the functions of low gradient riverine wetlands in western Tennessee.* Technical report ERDC/EL TR-02-7. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

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

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

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

Zedler, P. H. 1987. *The ecology of southern California vernal pools: A community profile*. Biological Report 85(7.11). Washington, DC: U.S. Fish and Wildlife Service.

Appendix A: Glossary

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 for conducting an assessment of wetland functions. 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 classifying wetlands within a region, identifying reference wetlands, constructing assessment models, defining reference standards, and calibrating assessment models.

Canopy tree: Self-supporting woody plants ≥10 cm (4 in.) dbh, whose crowns comprise the uppermost stratum of the vegetation. Canopy trees are not immediately overtopped by taller trees and would be clearly seen by an airborne observer (Figure 11).

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.

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 dredged material or fill.

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

Exotics: See **Invasive species**.

Facultative species (FAC): A plant species equally likely to occur in wetlands or non-wetlands (estimated probability of occurrence in wetlands 34-66%).

Facultative upland species (FACU): A plant species that usually occurs in non-wetlands but sometimes is found in wetlands (estimated probability of occurrence in wetlands 1-33%).

Facultative wetland species (FACW): A plant species that usually occurs in wetlands (estimated probability 67-99%), but sometimes is found in non-wetlands.

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 relative 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.

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.

Highest sustainable functional capacity: The level of functional capacity achieved across the suite of functions by a wetland under reference standard conditions in a reference domain. This approach assumes that 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.

O horizon: A soil layer dominated by organic material that consists of recognizable or partially decomposed organic matter such as leaves, needles, sticks, or twigs <0.6 cm in diameter, flowers, fruits, insect frass, moss, or lichens on or near the surface of the ground.

Obligate upland (UPL): A plant species that almost always occurs in non-wetlands under natural conditions (estimated probability of occurrence in wetlands <1%).

Obligate wetland (OBL): A plant species that almost always occurs in wetlands (estimated probability >99%) under natural conditions.

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

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

Partial wetland assessment area (PWAA): A portion of a WAA that is identified a priori, or while applying the assessment procedure to an area relatively homogeneous and 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 of accomplishing a project. 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.

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).

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 10 cm (4 in.) in diameter at breast height.

Site potential: The highest level of functioning possible, given local constraints of disturbance history, land use, or other factors. Site capacity may be equal to or less than levels of functioning established by reference standards for the reference domain, and it may be equal to or less than the functional capacity of 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 (Carlisle 2000).

Value of wetland function: The relative importance of a 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: Supplementary Information on Model Variables

This appendix contains the following information:

1. Comparison Charts for Visual Estimation of Foliage Cover – page 114
2. Change in Wetland Volume Example – page 115
3. Weighted Average Method for Determining $V_{LANDUSE}$ – page 121

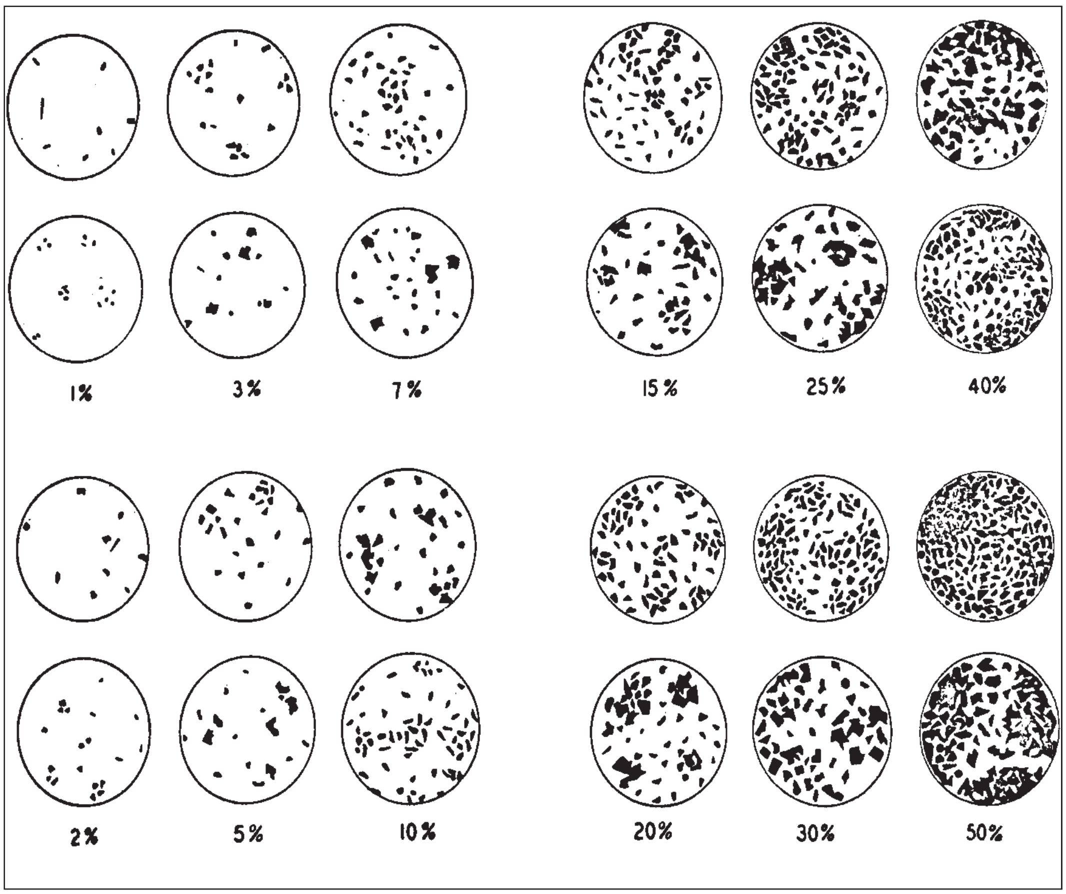

Figure B1. Comparison charts for visual estimation of foliage cover.

Change in wetland volume example

Determine the volume of the wetland.

1. Measure the distance from the diameter of the wetland along the longest and shortest axis in meters. Average the two diameters and determine the average radius of the wetland.
2. Measure the depth of the wetland in meters.

Using the formula for the volume of a simple cone:

$$V = \frac{1}{3}\pi r^2 h \quad \text{(B1)}$$

$$V = 1.0476 \times r^2 h \quad \text{(B2)}$$

If the diameter of the long axis were 150 m and the diameter along the short axis were 50 m, then the average radius of the example wetland is 100 m, and the depth is 0.5 m, the result is:

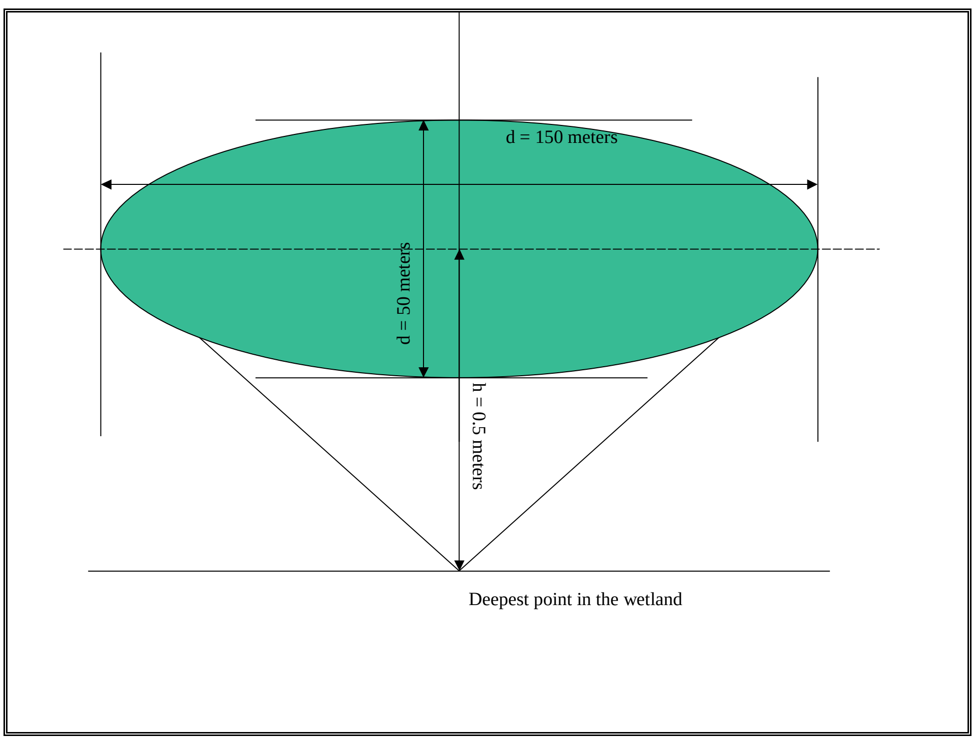

Figure B2. Illustration of change in wetland volume calculation.

$$V = 1.0476 \text{ x } 100^2 \text{ x } 0.5 \quad \text{(B3)}$$

$$V = 1.0476 \text{ x } 1000 \text{ x } 0.5 \quad \text{(B4)}$$

$$V = 5238m^3$$

Measure the size of the fill area and determine the volume of the fill.

If the fill material is rectangular in shape, measure the length of one of the long sides and one of the short sides and the height of the fill material.

In the example, if the fill material is:

Length = 50 m
Width = 40 m
Height = 1 m (only use that portion of the fill material that would affect the wetland).

Since the wetland is only 0.5 m deep, use 0.5 as the height rather than 1 m.

$$50 \text{ x } 40 \text{ x } 0.5 = 500 \text{ m}^3 \quad \text{(B5)}$$

Determine the percent that 500 m^3 is of the total wetland volume.

500/5238 x 100 = 9.6% of the volume has been changed.

Procedure for delineating a watershed

1. Obtain a topographic map of the wetland and the surrounding area (Figure B3). Scanned USGS topographic maps, or digital raster graphics (DRGs), can be downloaded from the TN GIS Data Server (http://www.tngis.org).
2. Locate and mark the watershed outlet (Figure B4). The outlet is the most downstream point where water exits the wetland. Some watersheds do not have outlets, and are referred to as "closed."
3. Starting at the watershed outlet, locate and mark the high points along the watercourse. Work your way around the watershed until you get back to the watershed outlet, as shown in Figure B5.
4. From the watershed outlet, draw a line connecting the high points. The line should always cross the contours at right angles (perpendicular).
5. Continue the line around the head of the watershed and down, until it connects with the watershed outlet, as shown in Figure B6.

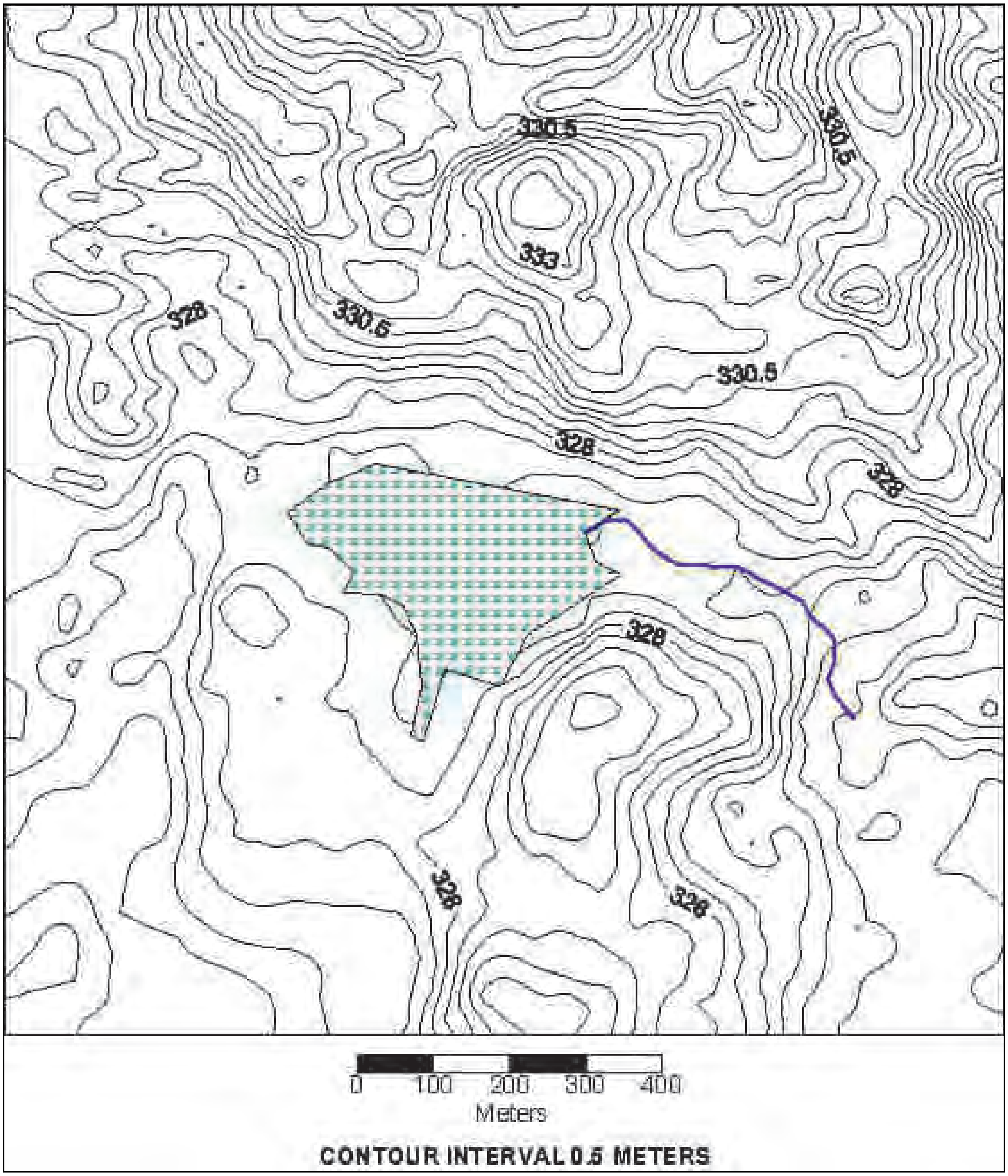

Figure B3. Topographic map of wetland and surrounding area.

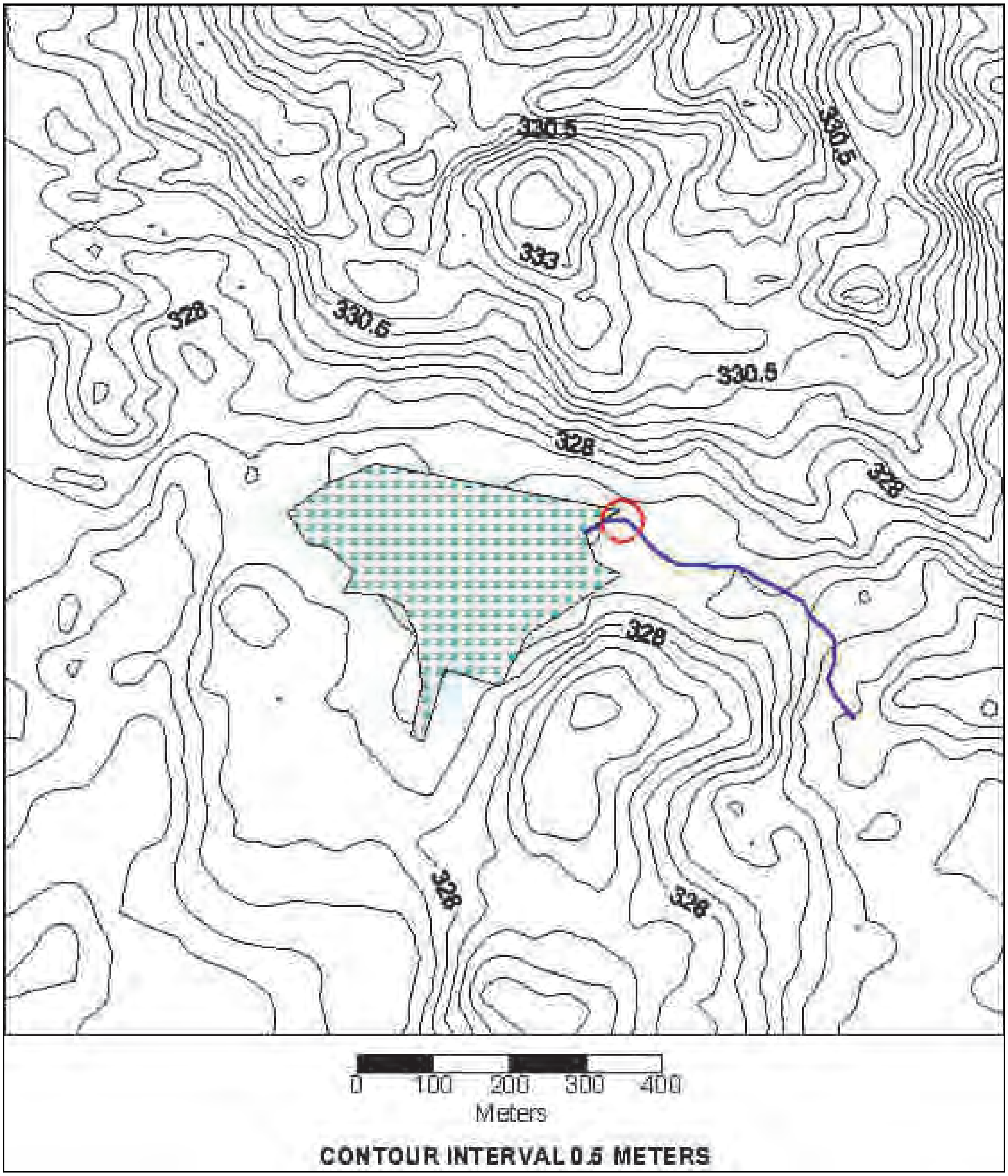

Figure B4. Location of watershed outlet.

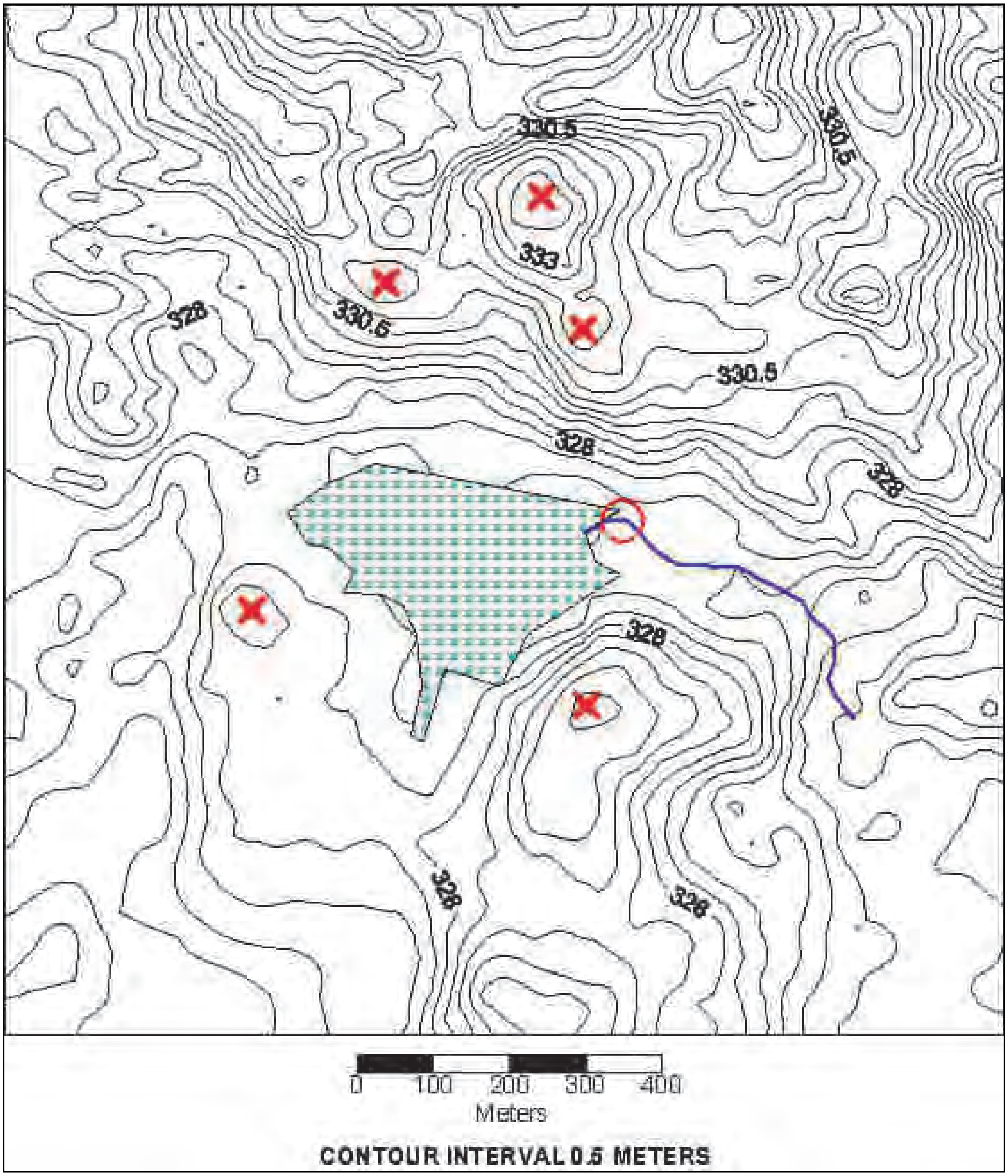

Figure B5. Location of high points.

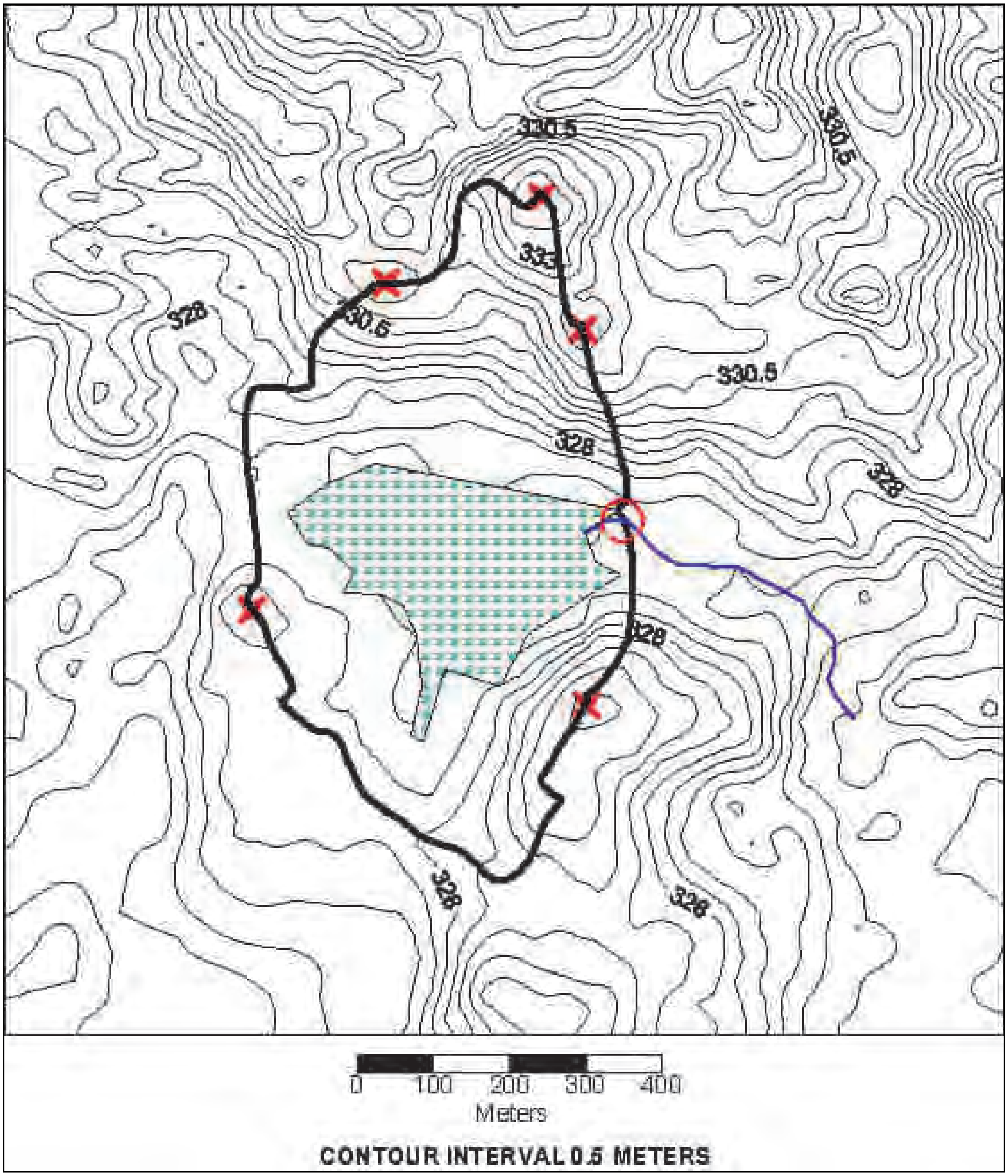

Figure B6. Delineated watershed boundary.

Weighted average method for determining $V_{LANDUSE}$

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

Identify the different land-use types within the catchment of the WAA using recent aerial photography (Figure B7). Estimate the percentage of the catchment in each land-use type. Verify during onsite reconnaissance.

Figure B7. Aerial photograph illustrating the cover types found within the catchment of a wetland.

Identify the different land uses within the catchment (Figure B8).

Determine the runoff curve number for each combination of land-use and hydrologic soil group present (Table B1).

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

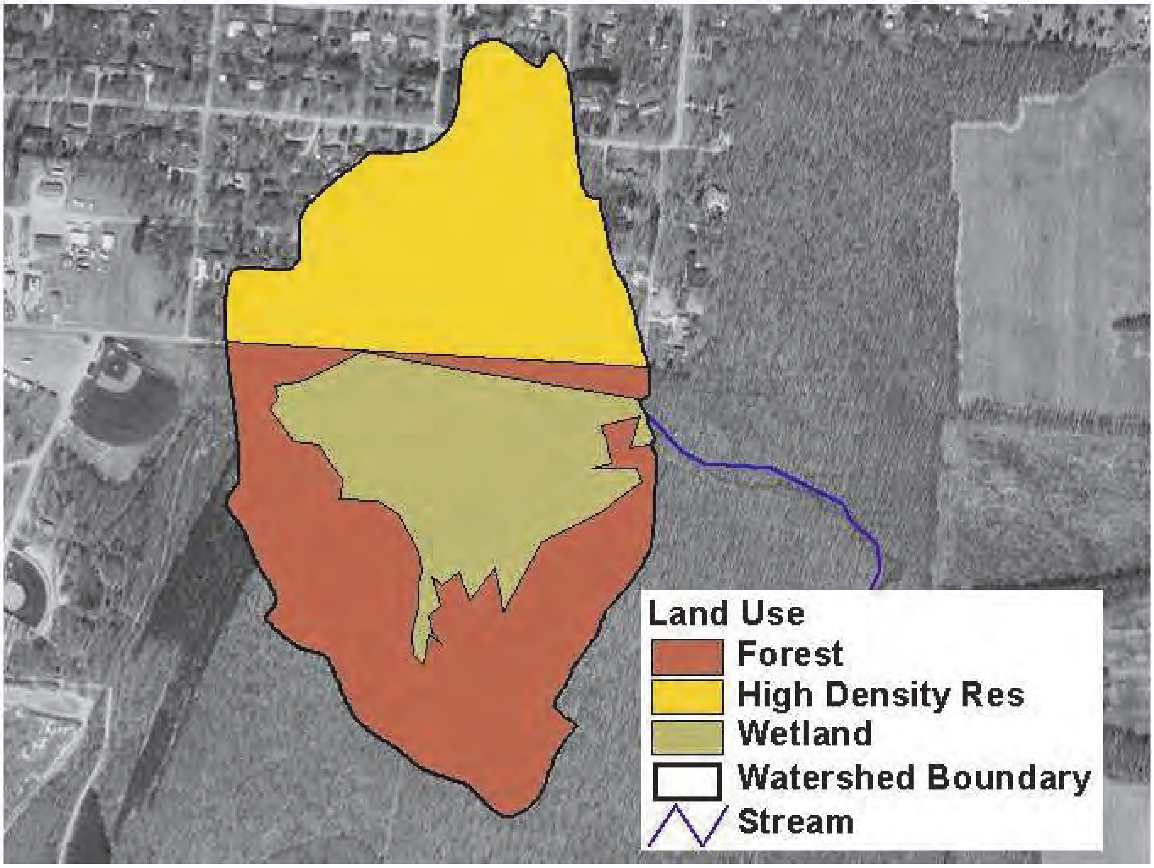

Figure B8. Landuse distribution in the watershed.

For this example, the weighted average runoff score is:

$$\left[\frac{(55\times 52.8)+(68\times 47.2)}{100}\right]=61 \qquad \text{(B6)}$$

Using the graph for $V_{LANDUSE}$, determine the variable subindex score that corresponds to a runoff score of 61 (Figure 23). The variable subindex score for this example is 0.86.

Habitat connections example

The following example shows how to estimate weghted average for Habitat connections using the four buffer widths described in Chapter 4. Using GIS and field verification or field measurements determine the length of the wetland permiter with the defined buffer widths for SID wetlands:

- <10m
- ≥10m and <30m

- ≥30m and <150m
- ≥150m

2	$V_{LANDUSE}$	Weighted average of runoff score for catchment (Used only in **SID** wetlands). The majority of soils in the Highland Rim fall into Soil Group B, so that group is assumed. Soils determination is not required.	61.11	0.86

Land Use (Choose From Drop List)	Soil Group	Runoff Score	% in Catchment	Running Percent (not >100)
Forest (ungrazed)	B	55	53	53
Low density residential (1 acre lots)	B	68	47	100
	B			
	B			
	B			
	B			
	B			
	B			

Figure B9. Illustration of the calculator for $V_{LANDUSE}$ for the example in Figure B12. The calculator determines the weighted average and subindex score for $V_{LANDUSE}$.

Most sites will not have all four buffer widths.

In the example illistrated in Figure B10, the weighted average would be calculated as shown in equation B7. Based on the assumption that the total wetland perimeter is 1000 m:

- Buffer width ≥150m and 200m in length, receives a score of 1.0.
- Buffer width ≥30m and <150m and 300m in length, receives a score of 0.66.
- Buffer width ≥10m and <30m and 200m in length, receives a score of 0.33.

The buffer width <10m and 300m in length receives a score of 0.0 and is not used in the calculation.

$$\left[\frac{(200\times1.0)+(300\times0.66)+(200\times0.33)}{1000}\right]=0.46 \qquad \text{(B7)}$$

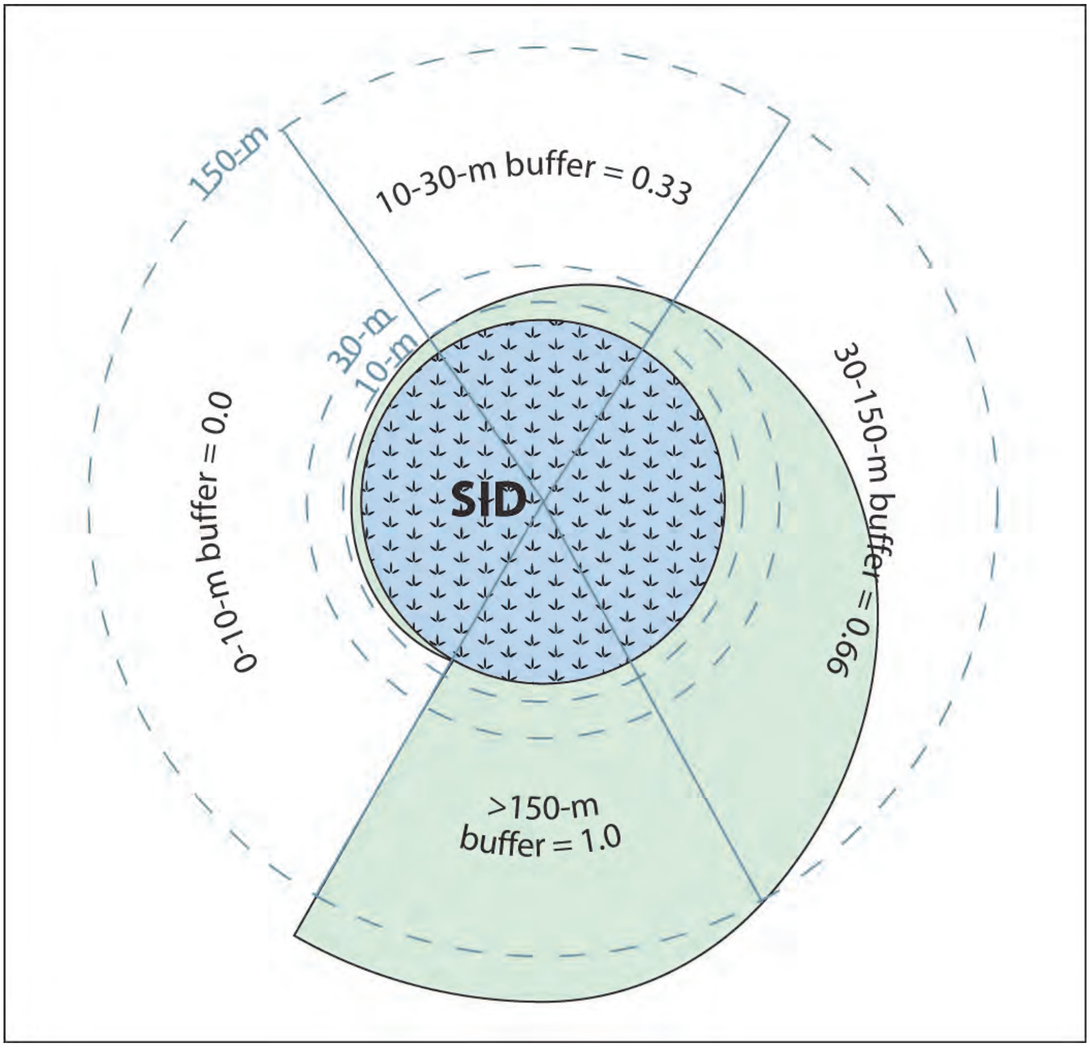

Figure B10. Illustration of a SID wetland and the appropriate buffer score based on buffer width for $V_{CONNECT}$.

The Excel calculator developed for the guidebook calculates the weighted average and only requires entry of the length of each category of buffer width Figure B11.

3 $V_{CONNECT}$	Weighted average of scores for wetland perimeter connected to suitable habitat of different widths. (Used only in **SID** wetlands.) Enter a 0 if the wetland if a given buffer width range isn't present.	0.46	0.46
	Length of wetland perimeter (meters) with a buffer at least 150 m wide (1)	200 m	
	Length of wetland perimeter (meters) with a buffer ≥30 m and <150 m wide (0.66)	300 m	
	Length of wetland perimeter (meters) with a buffer ≥10 m and <30 m wide (0.33)	200 m	
	Length of wetland perimeter with with a buffer <10 m wide (0)	300 m	
	Total wetland perimeter	1000 m	

Figure B11. Data entry into the data sheet or calculator for $V_{CONNECT}$ based on Figure B10 assuming a total wetland perimeter of 1000 m.

Wetland drainage example

The following example shows how to estimate a weighted average for Habitat connections using the four buffer widths described in Chapter 4. Using GIS and field verification or field measurements, determine the length of all drains (ditches) within the WAA for Flats wetlands. The default method described in the guidebook assumes a 5-m zone of drainage impact on each side of the drain (Figure B12). If the drain is on the edge of the WAA, a 5-m impact zone is used only for the portion within the WAA as shown for Drain 1 (Figure B12). In some cases more accurate information related to drainage is available, and should be used. Based on the total area of the WAA, a weighted average is calculated on the area of impact for all drains.

In the example illistrated in Figure B12, first the percent area of impact is calculated using the length of each drain and the width of impact by the total areq of the WAA in meters (200 x 200). Note that Drain 1 has a 5-m impact zone (Equation B8).

$$\left[\frac{(200\times5)+(130\times10)+(80\times10)}{40000}\right]=7.8\% \tag{B8}$$

The weighted average is based on the percent of impacted zone to unimpacted area. The percent area of impact zone is assigned a score of 0.1 and the unimpacted area is assigned a score of 1.0. Equation B9 shows the weighted average for Figure B12.

$$\left[\frac{(7.8\times0.1)+(92.3\times1.0)}{2}\right]=93.0 \tag{B9}$$

The Excel calculator developed for the guidebook calculates the weighted average and only requires entry of the length of each drain. The calculator allows for the input of data for the impact of drains from other sources by checking the box titled “Check here if data supports overiding the default 5-m per side impact zone” in the fourth column (Figure B13).

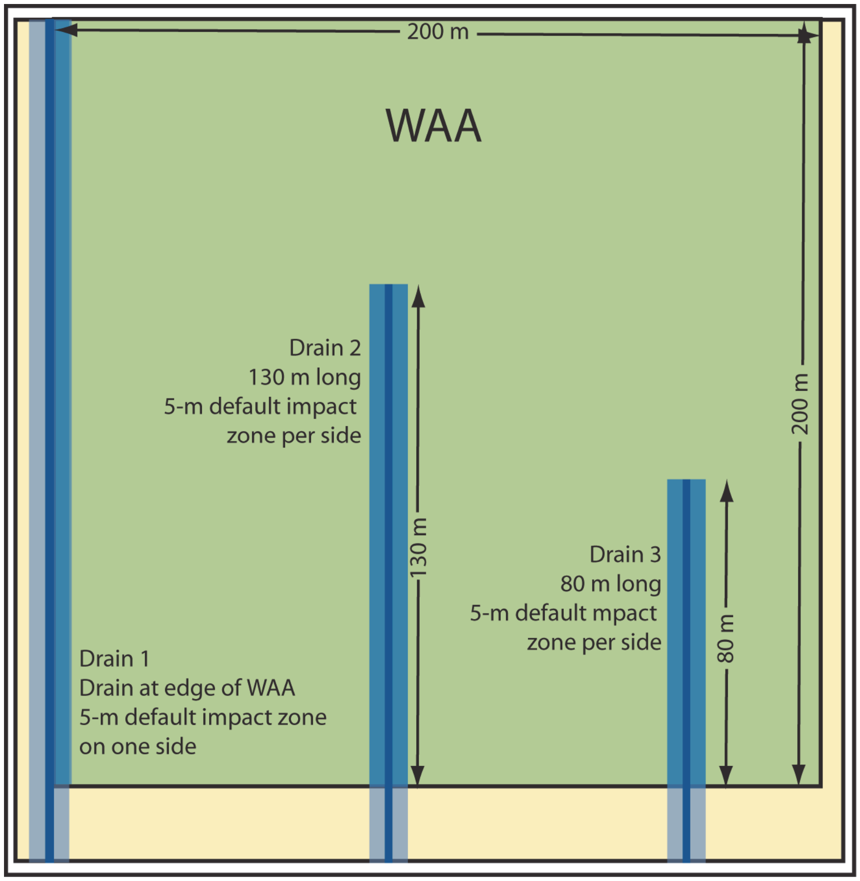

Figure B12. Illustration of WAA with three drains of different lengths. Note that Drain 1 only impacts the portion of the WAA on the right, so the box is checked in the data sheet or calculator ("Check here if only one side of drain impacts WAA.").

4 V_{DRAIN} Hydrologic effect of ditches in flat wetlands. (Only Used in **FLATS**) For each ditch present, enter a length in meters, check the box to indicate if only one side of the drain lies within the WAA, and mark the impact zone override, if necessary. If no ditches are present, enter 0 for the length of Ditch 1. 0.93 0.93

Total area of flat wetland in ha. 4.0

Drain	Length (m)	Check here if only one side of drain impacts WAA	Check here if data supports overriding the default 5-m per side impact zone	Data-supported impact width per side (in m)
Ditch 1:	200 m	☑	☐	
Ditch 2:	130 m	☐	☐	
Ditch 3:	80 m	☐	☐	
Ditch 4:		☐	☐	
Ditch 5:		☐	☐	
Ditch 6:		☐	☐	
Ditch 7:		☐	☐	
Ditch 8:		☐	☐	

Percent of flat wetland subject to draining effects of ditches (0.1): 7.8%
Percent of flat wetland NOT subject to draining effects of ditches (1.0): 92.3%

Figure B13. Data entry into the data sheet or calculator for V_{DRAIN} based on Figure B12 and a total WAA size of 4 ha.

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14. ABSTRACT

The Hydrogeomorphic (HGM) Approach is a collection of concepts and methods for developing functional indices and subsequently using them to assess the capacity of a wetland to perform functions relative to similar wetlands in a region. The approach was initially designed to be used in the context of the Clean Water Act Section 404 Regulatory Program permit review sequence. This Regional Guidebook (a) characterizes the Depression and Flat wetlands within the Highland Rim and Pennyroyal Major Land Resource Area, (b) describes and provides the rationale used to select functions for the Depression and Flat wetland subclass, (c) describes model variables and metrics, (d) describes the development of assessment models, (e) provides data from reference wetlands and documents their use in calibrating model variables and assessment models, and (f) outlines protocols for applying the functional indices to the assessment of wetland functions.

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