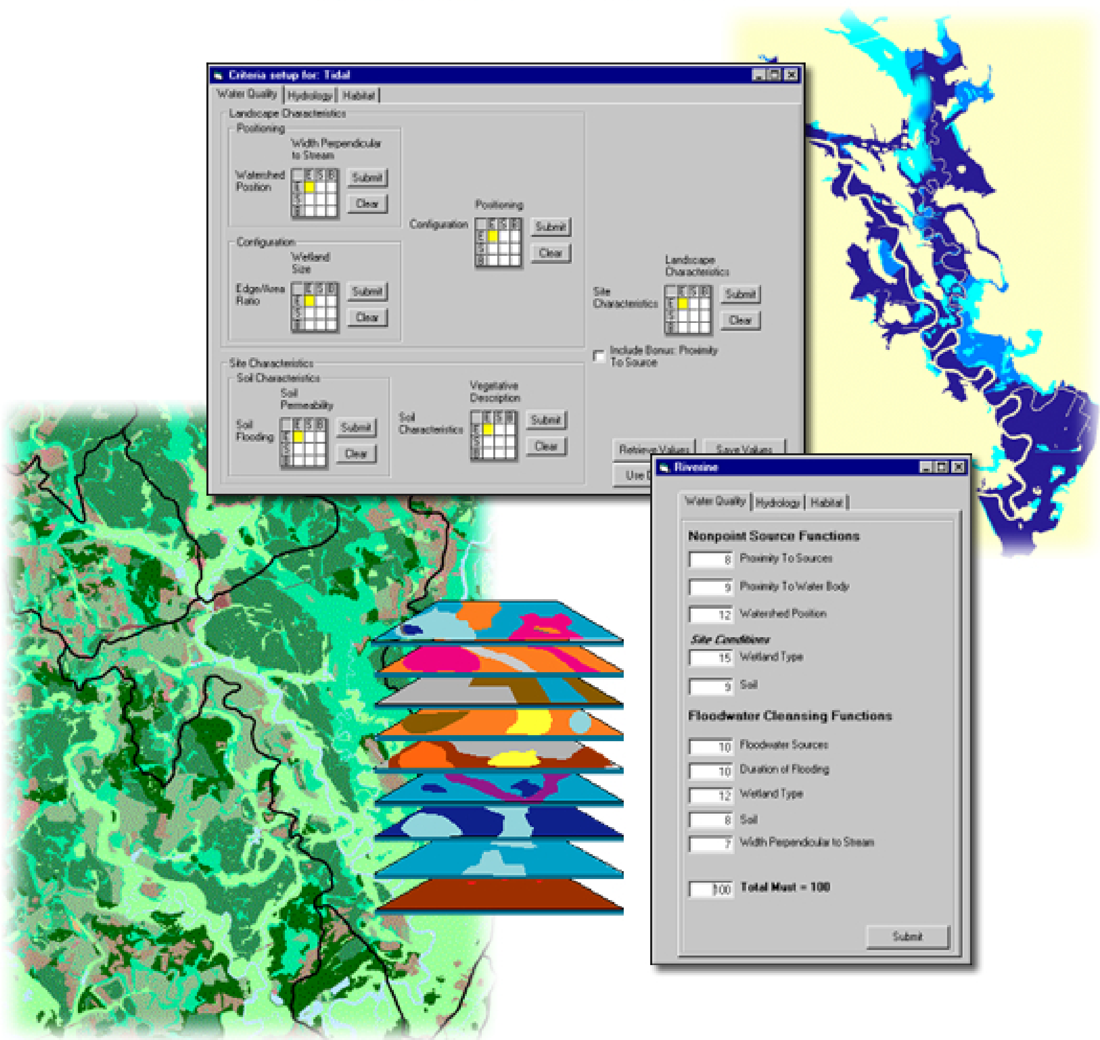
# Spatial Wetland Assessment for Management and Planning (SWAMP)

## Technical Discussion

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**Spatial Wetland Assessment for Management and Planning (SWAMP): Technical Discussion**

**By**

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## Overview

Spatial Wetland Assessment for Management and Planning (SWAMP) is a tool for examining wetland functions. SWAMP has two modules, tidal and riverine, that examine how individual wetlands within a watershed contribute to three wetland functions: water quality, hydrology, and habitat. SWAMP uses site-specific characteristics (obtained from soil, vegetation, and land use descriptions) and landscape characteristics (obtained from geographic information system analyses) to derive the parameters used for examining these wetland functions. The analyses used to derive the parameters are coded in Avenue® and require use of the ArcView® Spatial Analyst®, produced by the Environmental Systems Research Institute (ESRI). After data layers describing the basic parameters are derived, a unique interface allows users of SWAMP to determine how these parameters are assembled into overall assessments of water quality, hydrology, and habitat functions. Microsoft Visual Basic was used to develop this interactive interface.

SWAMP was developed for the Ashepoo-Combahee-Edisto (ACE) River Basin, South Carolina, and is transferable to other locations provided that appropriate knowledge about the local wetland systems is obtained. This technical report describes the design of and parameters within SWAMP (Appendix I summarizes the parameters). A separate tutorial provides instructions on the use of SWAMP, as well as information about the interactive interface.

## Introduction

Wetlands are a large portion of the natural coastal landscape and contribute to water quality, flood attenuation, estuarine productivity, and wildlife habitat. Wetlands continue to be drained or filled for development even though agricultural conversion, historically the most frequent cause of wetland loss, has largely stopped (Hefner and Brown 1985; Dahl 1990, 2000). As wetlands are lost, so too are the functions these habitats provide to coastal ecosystems (National Research Council 1995; Mitch and Gosselink 1986, 1996, 2000). As a result, the protection and restoration of wetlands is a significant concern to coastal managers (Keddy 2000).

The primary objective of SWAMP is to aid land use planning and management by providing information about the relative ecological importance of wetlands within a watershed. SWAMP examines wetlands by applying assessment rules in a prescribed manner (i.e., it is a rule-based model). These assessments are based on published research or a consensus of experts with local knowledge when the published literature does not provide adequate guidance. The basic rules, or parameters, for assessing the contributions of individual wetlands are fixed within SWAMP. However, a specially designed interface allows users to determine how these parameters should be combined into an overall assessment of the relative contributions individual wetlands make to the water quality, hydrology, and habitat function of their watershed. These assessments should be viewed as predictions about individual wetlands that should be tested via site-specific examinations or other means.

SWAMP is based on NC-CREWS (North Carolina Coastal Region Evaluation of Wetland Significance, Sutter et al. 1999). Both NC-CREWS and SWAMP are rule-based models that use a geographic information system (GIS) to organize input data and to apply the rules that allow the examination of wetland functions (in both SWAMP and NC-CREWS, these rules are termed "parameters"). The distinguishing feature of SWAMP is the interface that allows users to customize how the parameters are combined into an overall assessment. In NC-CREWS, the step of combining parameters into an overall assessment is hard-wired into the model and malleable only by altering the program code.

**Definitions**
To clarify discussions in this report, the following definitions apply:

*Ecological significance* refers to the contribution that a wetland makes to its watershed as determined by the functions that the wetland performs.

*Function* refers to a process that occurs in a wetland (Adamus et al. 1991). This process occurs regardless of whether humans recognize that the process is occurring. A wetland may perform many functions; SWAMP examines three: water quality, hydrology, and habitat.

V*alue* or *ecological service* are synonymous terms that refer to the value society places on the functions a wetland performs (Taylor et al. 1990).

*Parameter* or *rule* refers to a feature that is measured in order to make a judgment about how that feature (or group of features) is contributing to the watershed. The link between a parameter and a function may be direct, or several parameters may be combined to create a new, derived parameter (or sub-function) that is then related directly to function. For example, wetlands that are situated in a particular position in the landscape (e.g., along a main stem of a stream) with particular soils (e.g., organic) and particular vegetation (e.g., emergent) likely contribute more to floodwater cleansing than a riparian wetland separated from its hydrologic source with compacted soils and little vegetation. In this example, watershed position, soils, and vegetation are parameters (or rules). Floodwater cleansing is referred to as a sub-function.

*Decision framework* refers to the parameters for examining wetland function and the process used for combining those parameters into an overall assessment of the level of function a wetland provides to the landscape. SWAMP contains six decision frameworks, three for riverine wetlands and three for tidal wetlands.

## Structure and Data Requirements

**Hydrogeomorphic Class**
The hydrogeomorphic (HGM) classification system for wetlands (Brinson 1993) classifies wetlands into categories based on landscape position (geomorphic setting), water source, and hydrodynamics. HGM is being increasingly used as the basis for wetland classification and for systems that assess wetland functions. HGM classification focuses on the abiotic features of wetlands, which is an alternative to extant wetland classification systems that focus on species composition.

Several features of the HGM classification system make it a useful starting point for examining wetland functions. Since the HGM system is based on geomorphic, physical, and chemical properties of wetlands, it aggregates wetlands with similar functions into classes. The HGM class of a wetland, in itself, indicates much about the functions of a wetland. The HGM approach also includes consideration of factors external to the wetland site, such as water source. This helps relate the wetland and its functions to the larger landscape.

The HGM class of a wetland (i.e., tidal or riverine) determines which module of SWAMP is used to examine wetland functions. The parameters used to examine water quality, hydrology, and habitat functions are different for each module, or HGM class (Appendix I).

**Input data**

SWAMP requires input data in a format suitable for a GIS. While this report and accompanying tutorial use data from the ACE Basin to illustrate SWAMP, the screening tool allows users to load data from different geographies. The GIS data layers required by SWAMP are (1) wetland boundaries and types, (2) land cover, (3) soil boundaries and types, (4) hydrography, (5) watershed boundaries, and (6) roads.

*Wetland Boundaries, Wetland Types, and Land Cover*

Wetland boundaries came from work that the South Carolina Department of Natural Resources (SCDNR) contracted with the U.S. Fish and Wildlife Service (USFWS) National Wetland Inventory (NWI). Under this contract, the USFWS updated previously existing NWI maps (1:24,000 scale) using aerial photography collected during 1994. Under this contract, SCDNR also had USFWS interpret the photography to assign land cover for the uplands to an Anderson Level II classification. Thus, a single data layer provided both wetland boundaries and land cover. When applying SWAMP to other areas, the data layers should be imported separately using the tool's Data Loader, and SWAMP will merge wetlands and land cover into a single data source.

Inclusion of wetland type—defined by dominant vegetation and landscape position—within SWAMP recognizes that the consideration of biological properties of a particular wetland along with hydrogeomorphic properties enables a more detailed examination of function than when either property is considered alone. The wetland types used in this application of SWAMP were typical of the ACE Basin. They result from collapsing the Cowardin (1979) wetland classes in the NWI data layer (Table 1) and then dissolving the unnecessary boundaries. The resulting layer becomes the basic wetland input into SWAMP.

SWAMP uses wetland type as an indicator of the types and levels of ecological functions performed. Sutter et al. (1999) describe the relationships between wetland type and function that are used by NC-CREWS, and these same relationships were used for SWAMP. These relationships should be reexamined when SWAMP is applied to other areas.

*Soil Boundaries and Soil Types*

Soil boundaries and types originated from 1:24,000-scale county soils maps produced by the U.S. Department of Agriculture's National Resource Conservation Service (NRCS). In SWAMP, the soil series underlying a wetland is identified from the soils data layer. The properties of the series are then used to determine whether the soil has the capacity to facilitate the particular wetland function being examined (assuming a well-established relationship exists between soil series and that function).

| **Table 1. Collapsed Wetland Types (Cowardin classes of the Ashepoo Basin assigned to each category)** | | | |
|---|---|---|---|
| *Intertidal persistent salt marshes* | | *Freshwater temporary or seasonal coniferous forest* | |
| E2EM1Ph | E2EM1Pdh | PFO4S | PFO4/SS3S |
| E2EM1P | E2EM1N | | |
| E2EM1Nh | E2EM1Mh | *Freshwater temporary or seasonal broadleaf coniferous forest* | |
| E2EM1/USN | E2EM1/SS3P | PFO3R | PFO1/3R |
| | | | |
| *Intertidal salt scrub forest* | | *Freshwater seasonal deciduous forest (probably disturbed bottomland hardwood)* | |
| E2SS3P | E2SS3Ph | PFO4R | PFO4/1R |
| E2SS1P | | PSS1/3R | |
| | | | |
| *Sub-tidal* | | *Freshwater semi-permanent deciduous scrub* | |
| PAB3V | | PSS1T | PSS3T |
| | | PSS1/3T | |
| *Freshwater semi-permanent emergent* | | | |
| PEM1N | PEM1Nh | *Freshwater temporary or seasonal deciduous scrub* | |
| PEM1/SS3T | PEM1T | PSS1R | PSS1Rh |
| PEM1Th | | PSS1/4R | PSS1S |
| | | PSS1/4S | |
| *Freshwater temporary or seasonal emergent* | | | |
| PEM1R | PEM1Rh | *Freshwater temporary or seasonal coniferous scrub* | |
| PEM1S | | PSS3/1R | PSS3S |
| | | PSS4R | PSS3Rh |
| Freshwater semi-permanent deciduous forest | | PSS3R/PEM1R | PSS3R |
| PFO1/2T | | PSS4S | PSS4Sh |
| | | | |
| *Freshwater temporary or seasonal deciduous forest* | | *Freshwater irregularly flooded broadleaf scrub* | |
| PFO1R | PFO1Rh | PSS3P | PSS1/3 |
| PFO1/3R | PFO1S | | |
| PFO1Sh | PFO1/4S | | |
| PFO1/3S | PFO2/SS3R | | |

*Hydrography*
The hydrography data layer consists of 1:24,000-scale U.S. Geological Service (USGS) digital line graphs (DLGs) converted to ArcInfo® coverages. These data, however, did not include Strahler stream order, an attribute required by SWAMP. Stream order was developed from 1:100,000 "RF3" files produced by the U.S. Environmental Protection Agency, which designed the RF3 database for indexing and modeling but which recently converted this database into a geospatial format. RF3 data align all stream segments, or reaches, in a uniform direction. To obtain stream order, the RF3 data were overlaid with a digital elevation model, resulting in an attribute representing Strahler stream order that was then added to the RF3 attribute files.

*Watershed Boundaries*
The watersheds used in the ACE Basin application of SWAMP are relatively small hydrologic units (ca. 10,000 hectares) delineated by NRCS and modified by the South Carolina Department of Natural Resources (SCDNR) Marine Resource Research Institute to match state-defined watershed boundaries. These watersheds are based on 1:24,000-scale base data provided by USGS.

*Roads*
The roads data consists of 1:24,000-scale USGS digital line graphs (DLGs) converted to ArcInfo coverages that were then converted to grids. SCDNR worked with USGS to convert the DLGs to coverages using 1:12,000-scale digital orthophotography as a backdrop to correctly align and label the roads. The photography also ensured roads continued seamlessly between quadrangles (within 0.5 meters). More information about how this was done can be found at *www.dnr.state.sc.us/gisdata/index.html*.

*Data Format*
SWAMP uses a raster data format. This format was chosen over a vector format to simplify computations, expedite processing speed, and to allow for the development of a user interface that lends itself to rapid "what if" examinations. Once SWAMP is initiated for an area, one of its first actions is to convert input vector data into grids. The cell size of the grids is established by the user, with a default equal to the cell size of the input land cover raster data. In the ACE Basin example, the cell size was set to 10 meters. The examinations SWAMP makes are at the level of grid cells. Several grid cells constitute what might have been an individual wetland polygon in a vector input data layer. In some cases, the assessments SWAMP makes about an individual grid cell are based on properties of the contiguous grid cells that have the same attributes. This cluster of cells is referred to as an "area" and essentially is the same as the NWI wetland polygon, subject to the redefinition and collapsing of polygons that are described in Table 1.

**Structure of SWAMP**
SWAMP uses a hierarchical structure to examine and combine individual parameters until an overall prediction of a wetland's relative level of function is made (Figures 1a and 1b). Predictions are made by determining the degree to which a wetland has the capacity to perform a specific function. SWAMP examines three wetland functions: water quality, hydrology, and habitat. The parameters for assessing these functions are fixed within SWAMP, but users are allowed to determine how the parameters are combined into an overall prediction of the level of function each wetland provides to the watershed. This flexibility should allow managers to better tailor the results of SWAMP to the rules and policies of a particular coastal management program and to specific knowledge about how local wetlands function. Default rules for combining the parameters are provided if needed, but users are urged to develop their own rules based on local knowledge.

The objective of SWAMP is to predict the relative level of function a wetland provides to its watershed. The levels of function are assessed on a discrete scale: exceptional (E), substantial (S), and beneficial (B). This discrete assessment is preferred over continuous, numeric scores because this approach better reflects the state of the underlying science and data. As scientific understanding and data reflecting assessment increase, it is reasonable to expect that specific numerical assignments can be integrated into SWAMP.

This qualitative scale also is used at the parameter level. For each parameter, an E, S, or B rating is assigned based on characteristics of the wetland with respect to that parameter and how those characteristics are likely to contribute to the wetland function being considered. For example, if the soils underlying a wetland have properties that are highly conducive to the function being considered, the soil characteristics parameter is rated E; if soil properties are less conducive to performing the function, the parameter is rated S; and if soil properties are not conducive to the function, the parameter is rated B. As noted previously, SWAMP determines how ratings are applied within a parameter. But users determine how the parameters are assembled into an assessment of the level of function provided by the wetland; that is, how individual parameter ratings are combined to give an E, S, or B rating for each function.

The process of successively combining parameters into an overall assessment is the most complex aspect of using SWAMP. Combining the individual parameters should be based on an understanding of how wetlands function within a landscape. Since ecological processes can interact in complex ways, combining ratings is more than a simple summation of individual ratings. Some parameters are more important than others and, thus, should be weighed more heavily in the combined value. In some cases, there can be different combinations of individual parameter ratings that result in the same expected level of function. Each of the possible combinations of parameters must be considered. SWAMP has a default scheme for combining parameters, but the user should evaluate whether these combinations are appropriate for the system being evaluated. Three different interfaces were developed to allow users to explore how the parameters should be combined. All three interfaces achieve the same endpoint; they just provide users with alternative environments within which to work, thereby allowing users to choose the one that is most comfortable.

SWAMP maintains all of the individual parameter ratings and combinations in a database-like format. Since the combining process is complicated, it may not be obvious why a wetland receives an E, S, or B rating for the function being considered. The database makes it possible to trace through the parameters and couplings that produce the rating. This database also makes it possible for users to examine a specific parameter alone or in combination with others. For example, SWAMP's assessment of habitat function includes parameters that target wading birds, amphibians, and waterfowl. If a user wants to examine the value of wetlands to just one of these species groups, the database enables this examination.

*Opportunity and Capacity*
For a wetland to actually perform a given function, it must have both the opportunity and the capacity for that function. To consider non-point source pollution as part of a water quality function, for example, there must be a source of potentially polluted runoff entering the wetland to provide an opportunity, and the wetland must have the internal capacity to hold the runoff and remove the pollutants before releasing the water. In this case, opportunity to perform a function is determined by factors external to the wetland, while capacity to perform the function is determined by properties of the wetland itself, along with landscape position.

SWAMP includes opportunity parameters where appropriate and follows specific conventions. A present high opportunity to perform a function can result in an evaluation of E for the function, but high capacity can also result in an E rating even if present opportunity is lacking. Lack of present opportunity alone should not lower ratings. Opportunity, thus, is treated as a "bonus" consideration that can result in a higher evaluation for a wetland than its capacity alone would indicate but which will not lower a rating because of its absence.

Figure 1a. Structure of Spatial Wetland Assessment for Management and Planning Tidal Module.

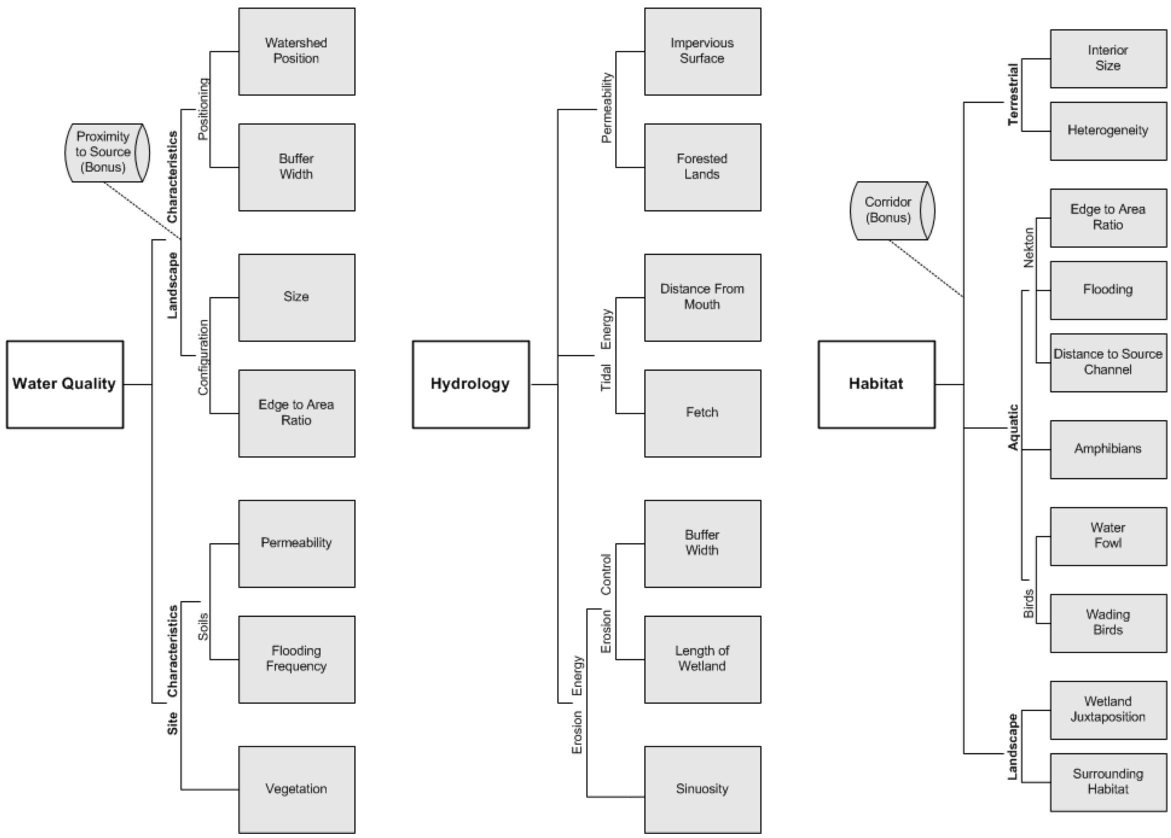
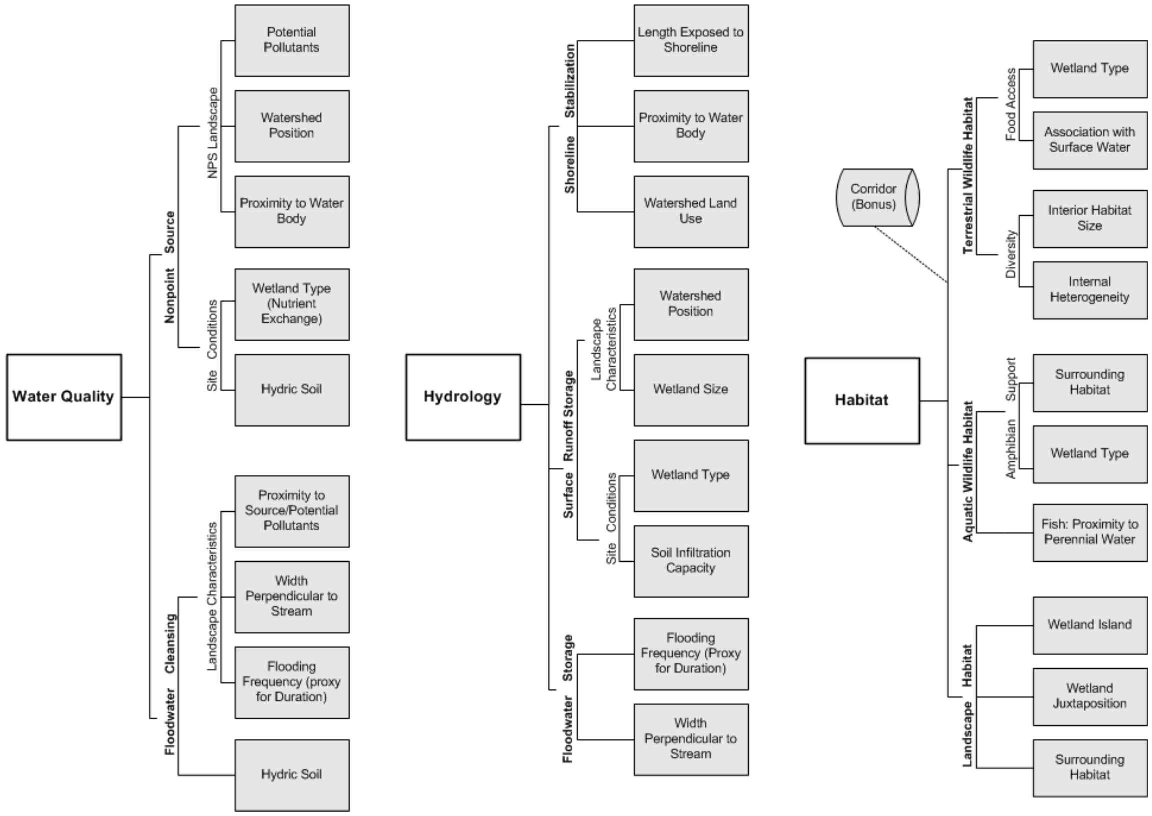


Figure 1b. Structure of Spatial Wetland Assessment for Management and Planning Riverine Module




## Model Verification

Careful attention was given throughout development of SWAMP to check and verify its validity. Parameter evaluations and combination procedures are based on the best wetland science available in the literature and extensive review by a team of wetland scientists. Accuracy of the GIS analyses used to apply the procedure have been verified to the greatest extent possible. When assumptions are made about wetland ecology, GIS data, or GIS analytical techniques, they are fully documented in this report.

## Parameter Descriptions: Ecological Basis and Assumptions

Most procedures for examining wetland functions are based on examinations of specific sites. Evaluations are derived from a static view of the site with little consideration of change over time or of position within the landscape (Gosselink and Lee 1986). SWAMP, in contrast, relies heavily on the spatial and temporal dynamics of wetlands. The majority of the parameters are derived from the landscape, and the inclusion of parameters that represent opportunity and capacity accounts for temporal changes in surrounding land use. Site conditions are determined by the biotic and physical structure typical of the wetland type and by the properties of the predominant underlying soil.

The underlying assumption of this approach is that wetland functions are not simply the product of particular wetland sites but of the relationships between a particular site and its surroundings (Patience and Klemas 1993). The occurrence and maintenance of wetlands and the processes that occur within them are a result of a combination of large-scale, long-term characteristics of watersheds, landscapes, and regional climatic regimes, and of more local processes (Winter 1988, Siegel 1988, O'Brien 1988). Local, site-specific characteristics of a wetland should be evaluated within the context of the landscape in which it exists to truly begin to understand the ecological significance of the wetland's functions. These functions are arguably more accurately viewed as landscape functions than as functions of individual wetlands (Leibowitz et al. 1992).

Wetland functions are commonly grouped into three general categories (Leibowitz et al. 1992) —water quality, hydrology, and habitat—and this grouping provides the basic structure of SWAMP. In SWAMP, the processing of pollutants, nutrient cycling, and water supply are the focal points for the examinations of the water quality function. Flood attenuation and moderation of hydrologic flow are the focal points for examining the hydrology function. Food, shelter, and breeding sites for fish and wildlife are the focus of the habitat examinations.

**Water Quality**

Wetlands significantly affect water quality within a watershed (Jones et al. 1976, Whigham et al. 1988, Detenbeck et al. 1988, Johnston et al. 1990). A variety of biogeochemical processes are involved (Hemond and Benoit 1988). Wetlands are sinks or transformers of suspended inorganic sediments, inorganic phosphorus, nitrate, sulfate, and toxins (Leibowitz et al. 1992, Adamus et al. 1991, Johnston 1991). By buffering surface and ground waters from these potentially damaging substances, wetlands can play a significant role in maintaining water quality within a watershed (Brinson 1988).

Water enters wetlands via overland runoff or overbank flow. Water that enters wetlands via overland runoff has not yet entered surface waters, while overbank flows come from channels. Because these water sources are distinct in riverine systems, the riverine module of SWAMP separately examines the effect these flows have on water quality. In contrast, this separation is not made in the tidal module because these flows are not distinct in tidal systems.

Wetlands remove particulates, nutrients, and toxins from surface runoff water before the water enters streams, lakes, or estuaries. Wetlands also remove sediments, nutrients, and toxins from water that enters a wetland by overbank flow from a flooding stream. During high-water periods in which water from streams enters channel floodplains, substances in the water (including sediments, nutrients, and toxins) are deposited in riparian wetlands removing them from surface waters (Mitsch et al. 1979, Kuenzler et al. 1980, Yarbro et al. 1984, Kuenzler and Craig 1986, Whigham et al. 1988). For tidal wetlands, the dominant hydrologic feature is daily or twice daily flooding. Several factors determine the extent to which this pollutant removal occurs. Many studies have documented this function of wetlands, including several performed specifically in the Carolina coastal plain (Cooper et al. 1986, Gilliam et al. 1986).

Eight parameters are used in the tidal module of SWAMP to examine how wetlands contribute to water quality (Table 2). To examine how tidal wetlands contribute to water quality, SWAMP analyzes both landscape and site-specific characteristics. Specifically, SWAMP uses the proximity of the wetland to pollutant sources, watershed position, width, edge to area ratio, and size of the wetland in conjunction with site conditions within the wetland, including characteristics of the plants and soils.

| **Table 2. Water Quality Parameters for the Tidal Module** | |
|---|---|
| **Landscape Parameters** | **Site Parameters** |
| Proximity of the wetland to pollutant sources | Vegetative cover |
| Position of the wetland within the watershed | Soil: Flooding frequency |
| Width of the wetland perpendicular to the stream | Soil: Permeability and texture |
| Edge to area ratio of the wetland | |
| Size of the wetland | |

The riverine module breaks water quality into two sub-functions, non-point source removal and floodwater cleansing (Table 3). The non-point source sub-function of riverine wetlands consists of the removal of particulates, nutrients, and toxins from surface runoff water before the water enters streams, lakes, or estuaries. Many studies have documented this function of wetlands, including several performed specifically in the Carolina coastal plain (Cooper et al. 1986, Gilliam et al. 1986). To examine how wetlands process non-point source pollutants, SWAMP uses proximity of the wetland to pollutant sources, proximity of the wetland to surface water bodies, watershed position of the wetland, and site conditions within the wetland.

| **Table 3. Water Quality Parameters for the Riverine Module** | |
|---|---|
| **Non-Point Source Removal** | **Floodwater Cleansing** |
| *Landscape Parameters* | *Landscape Parameters* |
| Proximity of the wetland to pollutant sources | Proximity of the wetland to pollutant sources |
| Proximity to water body | Width of the wetland perpendicular to the stream |
| Position of the wetland within the watershed | |
| | |
| *Site Parameters* | *Site Parameters* |
| Soil type | Soil type |
| Wetland type | Soil: Flooding frequency |

The floodwater cleansing sub-function of riverine wetlands consists of the removal of sediments, nutrients, and toxins from water that enters a wetland by overbank flow from a flooding stream. Only wetlands adjacent to channels should be expected to perform these functions, as they are the only ones normally in landscape positions to receive overbank flow (Brinson 1988, 1993). While riverine wetlands can also remove non-point source pollutants from upland runoff, overbank flow so dominates in floodplain wetlands along larger streams that floodwater cleansing is a key water quality function (Brinson 1988).

The dominant hydrologic feature of riverine wetlands is periodic flooding. During high-water periods in which water from streams enters riverine floodplains, substances in the water, including sediments, nutrients, and toxins, are deposited in riparian wetlands, removing them from surface waters (Mitsch et al. 1979, Kuenzler et al. 1980, Yarbro et al. 1984, Kuenzler and Craig 1986, Whigham et al. 1988). Several factors determine the extent to which this pollutant removal occurs.

Some parameters might be qualified by the presence or absence of channelization of the stream, a common situation in the coastal plain. Channelization has been performed to accelerate water movement downstream to alleviate flooding problems in areas bordering the stream. By so doing, channelization decreases the flow of floodwater into riverine wetlands and shortens the duration of flooding, decreasing the wetlands' effectiveness in removing sediments and nutrients from the water (Adamus et al. 1991). Watersheds with channelized streams and drainage ditches are significantly less effective for removing nutrients than those with natural drainage and undisturbed wetlands (Bedient et al. 1976, Chescheir et al. 1987). When the data reflect that channelization has occurred, the site often is lowered by one categorical rank.

Following is a detailed description of each of the parameters. Parameters shared by both modules are presented in a single discussion. Where differences occur, the module is listed by the parameter, and each is discussed separately.

*Landscape Parameters*

<u>Proximity to Sources/Potential Pollutants</u>

E Perimeter has more than 20% agriculture and developed land
S Perimeter has less than 20% agriculture, developed land, pine plantations, or impoundments
B Perimeter has no adjacent agriculture, developed land, pine plantations, or impoundments

This parameter considers the likelihood that polluted runoff water will enter a wetland based on predominant adjacent land uses. Agricultural land and developed land are considered the greatest potential contributors of pollutants. Areas that are not agricultural, developed, pine plantation, or impoundments are in natural vegetation, open water, and other classes. Of these, natural vegetation is assumed to contribute the least pollution. Managed pine plantations and impoundments are considered as greater contributors than natural vegetation but less than agricultural or developed lands.

Agriculture is a ground-disturbing activity that has a large potential as a sediment source. Use of fertilizers and pesticides and field applications of animal wastes increase the likelihood that runoff from agricultural fields will contain potentially harmful concentrations of nutrients, toxins, and bacteria that may pollute surface and groundwater (Stewart et al. 1976, Leonard 1980, Daniel et al. 1982, Canter 1987).

Land development and urbanization involve site clearing, grading, and increases in impervious surfaces and maintained landscapes (Schueler 1987). These landscape changes, together with increasing population density, result in increased runoff and pollutant loading. Major pollutants found in runoff from developed areas include sediment, nutrients, oxygen-demanding substances, road salts, heavy metals, petroleum hydrocarbons, bacteria, and viruses (U.S. Environmental Protection Agency 1993). While dense urban development occupies only a small proportion of the coastal area, population increases and tourism are resulting in increases in developed land with a corresponding increase in the significance of urban runoff as a pollutant source.

Intensive silviculture, particularly road construction, timber harvesting, and site preparation, can result in increased runoff with heavy sediment and nutrient loads (Pardo 1980, Coats and Miller 1981). Fertilization of forest stands during the rotation can also result in temporary increases in nitrogen and phosphorus in surface runoff (Campbell 1989). The impacts of forestry on surface runoff, however, are transient, and even intensively managed pine plantations have little impact on water quality during much of the rotation (Shepard 1994). While pine plantations currently occupy a large proportion of the coastal landscape, they are a relatively minor source of pollutants compared with agricultural and developed lands. While essentially none of the study area is truly undisturbed, naturally vegetated areas are minor sources of pollutants and are considered the baseline condition against which other land covers are compared.

<u>Watershed Position</u>
E Closest to the small tributaries furthest from the main water body
S Closest water body is not a small tributary, but a larger one that is not the main water body
B Closest water body is the watershed's main water body

Evaluation of this parameter is based on the assumption that headwater wetlands are more significant in removing non-point source pollutants than are wetlands further downstream in a watershed. The Strahler stream order nearest the wetland is used as an indicator of watershed position.

This assumption is quite well documented in the literature. As water runs off uplands, it first encounters wetlands in riparian areas associated with small streams (Whigham et al. 1988). These headwater areas are commonly bordered by agricultural fields, and wetlands immediately below the source of non-point pollution are the most effective filters (Cooper et al. 1986, Lowrance et al. 1983, Phillips 1989). Because of the much greater length of small tributary (lower order) streams than higher order main-stem streams in a watershed (Leopold et al. 1964), a higher proportion of runoff water flows through upstream riparian wetlands than through wetlands further downstream (Brinson 1988).

Evaluation of this parameter in the tidal module is based on the assumption that wetlands along small tributary rivulets are more significant in removing pollutants than are wetlands adjacent to large water bodies. Wetlands near the small rivulets eventually leading to an estuary are especially important to tidal water quality. The Strahler stream order nearest the wetland is used as an indicator of watershed position.

<u>Width of Wetland Perpendicular to Stream/Channel</u>
E Greater than 100 meters
S 50 to 100 meters
B Less than 50 meters

Evaluation of this parameter assumes that wider wetlands that allow floodwater to spread out over a larger area are more effective at removing pollutants from the water. The wider the area into which floodwaters flow, the greater is the reduction in flow velocity and the shallower is the water depth, both of which increase pollutant removal. The width values used are meant more to distinguish between narrow strips of riparian wetlands and more extensive wetland areas than to have absolute significance in and of themselves.

Wetlands exert their influence on in-stream water quality primarily through slowing the flow rate of water. Wider wetlands reduce flow rates more than narrow ones by decreasing channel restriction and by offering greater frictional resistance to flow. Most resistance to flow is provided by vegetation, and the wider the wetland the more vegetation is exposed to flowing water. Water depth will also be less in wider wetlands, and the shallower the water, the greater the frictional resistance provided by the vegetation (Adamus et al. 1991).

Flow velocity is the single most important factor affecting sediment trapping efficiency (Dendy 1974; Karr and Schlosser 1977). The slower the flow velocity, the more likely nutrients will be retained by sedimentation (Knight et al. 1984). Longer residence times resulting from lower flow rates also favor nutrient removing processes such as plant uptake and denitrification (Mulholland 1981). Yarbro et al.

(1984) determined that the wider the area of floodplain inundated, the greater the proportion of incoming phosphorus that was retained.

Edge to Area Ratio

- E  Highest 34% in watershed
- S  Middle 33% in watershed
- B  Lowest 33% in watershed

The ratio is calculated using this formula: *edge length/(2*(√ (π * area)))* (Winchester and Harris 1979).

The assumption is made that the edge of the wetland is a more active site for biogeochemical cycling, allowing pollutants, nutrients, and contaminants to be absorbed onto the sediment surface and removed from the water column. Literature describing an absolute value for this ratio was not found, so this parameter is measured in a relative fashion by comparing the results of the entire watershed.

Size of the Wetland

- E  Greater than 0.54% of the watershed
- S  0.05 to 0.54% of the watershed
- B  Less than 0.05% of the watershed

One of the primary determinants of a wetland's significance in influencing the water quality of a watershed is the wetland's size. In simplest terms, the larger a wetland is, the more water it can store, and the more sediment, nutrients, pollutants, and toxins it can process. Many studies have confirmed this assumption for the total area of wetlands in a watershed (Novitski 1979, Ogawa and Male 1983, Verry and Boelter 1979, Edgerton 1973). Kittelson (1988) extended the analysis to single wetland sites with the same conclusion.

Starting with the assumptions, then, that any wetland will store some water, and the larger a wetland is, the more water it can store and the more cycling that will occur, the question remains as to how large an individual wetland must be to have an appreciable effect on watershed hydrology and, therefore, water quality. The studies cited above all examined wetland size as a percentage of total watershed area, and it appears that this is a sound approach. Applicable values were not found in the literature on which to base a wetland size-significance relationship for the ACE Basin of South Carolina.

The current version of SWAMP assumes the same values appropriate for NC-CREWS. To determine these values for NC-CREWS, simulation modeling was used to determine the effect of wetland size on watershed peak discharge. Several models were explored for applicability and were tried on trial data sets, including AGNPS (Young et al. 1989), TR-55, ANSWERS (Beasley and Huggins 1981), SWRRB (Arnold et al. 1990), and HEC-1 (U.S. Army Corps of Engineers 1990). HEC-1 proved most useful for this purpose and was used to arrive at the wetland size figures used in this parameter.

Simulation results were used to develop a relationship between the percentage of watershed area converted from wetlands to agriculture and the percentage increase in watershed peak discharge. This relationship is shown in Figure 2. Cutoff points were selected at 0.1, 1.0, and 5.0 percent change in peak runoff. These correspond to wetland areas of 0.05, 0.54, and 2.7 percent of watershed area. An effect on watershed peak discharge of 0.1 percent or less is considered insignificant, while an effect of 1.0 percent or more is considered highly significant.

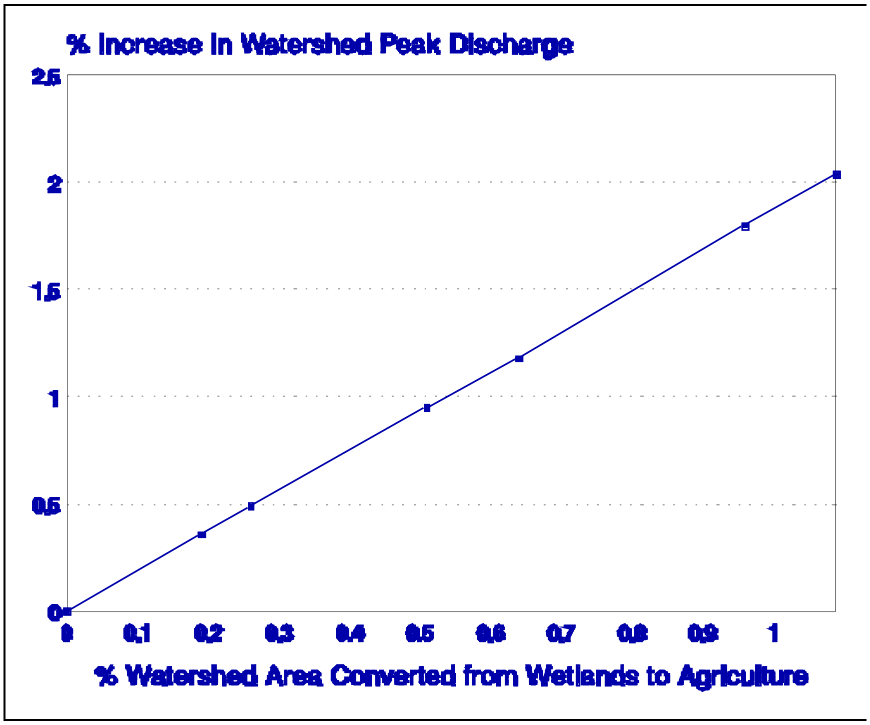



***Figure 2. Relationship between wetland area and change in watershed peak discharge as determined with HEC-1.***

*Site Parameters*

The internal characteristics of an individual wetland site are also important determinants of its ability to remove and retain non-point source pollutants. Biological and physical properties of vegetation and soils affect water flow-through rates and detention time, as well as a wetland's capacity for nutrient transformation and long-term storage of nutrients and toxins (Adamus et al. 1991). These factors are evaluated based on wetland type and predominant underlying soil.

Vegetative Cover Type *(Tidal Module*)

E Woody
S Emergent or herbaceous
B Aquatic bed

The grouping of wetland types by high, moderate, or low capacity is based on the amount of material available to trap sediments as they enter the wetland or the waterway. Wetland types with typically high vegetation density, organic matter accumulation, and long-term water storage capacity rate highest. Wetland types with generally high levels of disturbance and relatively little vegetation structure rate lowest. The approach taken in this parameter is to rate wetlands by the classification used in NWI's wetland mapping. It is based on the assumption that all wetlands of a given type are similar enough in structure and general characteristics that they will have the same capacity for removing non-point source pollutants.

Wetland Type (*Riverine Module*)

E Bottomland hardwood or other swamp
S Hardwood flat along river
B Pine flat along river

Wetland type characteristics relevant to floodwater cleansing include indicators of capacity for sediment capture, nutrient transformation, removal of dissolved materials, and retention of woody materials.

In the field sampling for NC-CREWS (Sutter et al. 1999), just two of the wetland types, bottomland hardwood and swamp forest, occupied 95 percent of the riverine sites capable of performing the floodwater cleansing function. Both of these types have similar characteristics in regard to their capacity for sediment, nutrient, and toxin removal, and both are included in the E category. No basis exists for further division of other wetland types between S and B categories. For those rare instances in which a wetland type other than bottomland hardwood or swamp forest occupies a site subject to overbank flooding from a stream, the wetland type rating for the site is B.

<u>Soil Characteristics: Flooding Frequency</u>

E Frequent
S Occasional or rare
B None or no entry

The original desire was to model flood duration, because the longer the water remains on a wetland surface, the more opportunities the soil and water have to interact for biogeochemical cycling; long duration facilitates nutrient and toxin retention. Also, the longer the period of flooding, the greater the settling time for suspended sediments and the more sediment deposition is likely to occur (Adamus et al. 1991, Jordan et al. 1986). Since phosphorus and toxins are normally associated with suspended particulates rather than being in solution (Froelich 1988), retention time can be significant in removal of these substances. Since denitrification occurs under anaerobic conditions, longer periods of flooding can also result in greater total nitrogen conversion by the wetland (Reddy and Patrick 1976). Unfortunately, the duration data were inconsistent; thus frequency is being used, assuming that these same functions will occur each time a wetland is flooded.

<u>Soil Characteristics: Permeability and Surface Texture</u> *(Tidal module)*

E Slow/very slow permeability or moderate/moderate-slow permeability with a mucky surface layer or rapid permeability with a sapric or hemic surface texture
S Moderate/moderate-slow permeability or slow/very slow with a mucky surface texture
B Rapid/moderately rapid permeability

Characteristics of the predominant soil series underlying the wetland are used to evaluate site suitability for pollutant removal. While vegetation and site structure as indicated by wetland type bear on the removal of both sediments and nonparticulates, soil characteristics have little bearing on a wetland's capacity for sediment removal. Soil characteristics can be very important, however, in determining a site's effectiveness in holding and transforming nutrients and toxins (Adamus et al. 1991).

Similar to flood duration, soil that is indicative of water retention or slow to percolate probably indicates a system where water is slowly drawn off into the channel or into groundwater. The presence of organic material on the surface is indicative of a longer residence time of water on the site as well.

Soils with high concentrations of organic matter absorb metals more effectively than do clays. Mercury, copper, lead, and cadmium have all been shown to be retained by wetland organic sediments (Hart 1982). Organochloride pesticides are also readily degraded in anaerobic, sulfide-rich, fine sediment organic soils typical of many wetlands (Adamus et al. 1991). Organic matter also is required for denitrification but is probably not limiting in most hydric soils (Brinson et al. 1984). Since denitrification, which occurs under anaerobic conditions, is coupled with nitrification, which occurs under aerobic conditions, the highest rates of denitrification occur with fluctuations between aerobic and anaerobic conditions (Reddy and Patrick 1976).

Soil Characteristics: Hydric Soil/Texture *(Riverine Module)*
E Infrequently flooded, low clay
S Infrequently flooded, high clay
B Frequently flooded

In addition to wetland type, characteristics of the predominant soil series underlying the wetland are used to evaluate site suitability. Soil characteristics can be very important in determining a site's effectiveness in holding and transforming nutrients and toxins (Adamus et al. 1991). The primary assumptions in evaluating soil characteristics in this context are that soils that developed under saturated conditions, or hydric soils, will contribute greater to the wetland capacity. Soils with high cation exchange capacity that are subject to frequent anaerobic conditions are the most effective in holding and transforming chemical compounds. Cation exchange capacity is a measure of a soil's ability to adsorb nutrients and is normally highest in soils with high organic matter or clay content. Alternating aerobic and anaerobic conditions lead to the most rapid rates of denitrification, the microbial conversion of nitrate to gaseous nitrogen.

Finely textured mineral soils, which normally have high concentrations of aluminum and iron, have high capacities to retain phosphorus (Richardson 1985). Finely textured soils also have high pore volume and surface area and, therefore, more contact between water and soil and higher cation exchange capacities than coarser textured soils.

Proximity to Surface Water Bodies *(Riverine Module)*
E Within 100 meters of permanent surface water
S Within 100 meters of intermittent stream
B Greater than 100 meters from permanent or intermittent surface water

This parameter is used only in the riverine module when examining non-point source pollution. Proximity to surface water is an indicator of the likelihood that polluted runoff entering a wetland would otherwise enter surface water. While wetlands anywhere in the landscape can remove pollutants from runoff water entering them, the significance of this function in maintaining water quality is greatest where the water would otherwise flow directly into a surface water body. In evaluation of this parameter, wetlands are considered to be of most significance if they are within 100 meters of permanent surface water and of lower significance if they are within 100 meters of an intermittent stream. Wetlands greater than 100 meters from any surface water are considered of lowest significance.

The assumption that wetlands closer to surface water are more significant in performing the non-point source removal function is based primarily on best professional judgment rather than scientific studies. The role of riparian areas in removing pollutants from runoff is, however, well documented (Cooper et al. 1986, 1987; DEHNR 1991). Riparian wetlands serve as natural buffers between uplands and adjacent water bodies, and loss of these systems allows for a more direct contribution of non-point source pollutants to receiving waters (U.S. Environmental Protection Agency 1993).

The distance, unfortunately, is arbitrary. There have been many studies on the effects of buffer width, but no conclusive results (DEHNR 1991). It should be noted that, in order to receive an E rating for this parameter, a wetland need only be within 100 meters of surface water, not necessarily a full 100 meters in width. This is a measure of proximity to water, not of wetland width, making the buffer width literature largely irrelevant. In coastal North Carolina, for example, a wetland within 100 meters of surface water is likely to be immediately adjacent to the water, i.e., to be a riverine, lacustrine, or fringe wetland (Brinson 1988). The objective of this parameter is to differentiate the role of riverine wetlands from that of depressional or flat wetlands that are likely to be a greater distance from surface water.

**Hydrology**

Wetlands help attenuate floods by absorbing some of the energy from tides and flood events. In addition, wetlands help maintain channels; vegetation alongside creeks and rivulets prevents mass sedimentation into these waterways. Hydrological functions are the result of many features, including geomorphology, size, and position on the landscape. Features of the watershed that increase energy (such as impervious surfaces and lack of forests) also affect the role wetlands play in attenuating flood flow.

The hydrology functions of wetlands are the result of water storage, in which peak flows from tides, runoff, surface flow, ground water discharge, and precipitation enter a wetland and are delayed in their movement (Adamus et al. 1991). This temporary storage of water in wetlands results in desynchronization of downstream or downtide flow which, under most circumstances, decreases flood peaks (Thomas and Benson 1970, Novitski 1979, Verry and Boelter 1979, Kittelson 1988). Comparisons of watersheds before and after wetland drainage (Brun et al. 1981) and of watersheds with drained versus undrained wetlands (Moore and Larson 1979) show the importance of wetlands in desynchronizing peak flows.

A significant aspect of the flow desynchronization resulting from wetland water storage in coastal areas is the prevention of freshwater dilution of brackish water in estuaries (Street and McClees 1981). If large areas of wetlands are drained or converted to other land uses, rapid influxes of freshwater can substantially dilute the salinity of estuarine areas (Daniel 1981), resulting in rapid fluctuations in salinity in nursery areas important for shellfish and finfish productivity. Salinity fluctuations have been shown to decrease productivity of shrimp (Pate and Jones 1981) and potentially of other important shellfish and finfish populations (Street and McClees 1981).

Water will flow into depressions anywhere they occur in the landscape. Wetlands not already filled to capacity with surface water are generally effective for water storage. In addition to water entering directly in precipitation, water may flow into wetlands as overland runoff or overbank flow. Since wetland and landscape characteristics determining the significance of storage of water entering from these two sources are different, they are evaluated independently.

Seven landscape parameters are used in the tidal SWAMP module to examine the hydrology function of tidal wetlands (Table 4). Note that no site parameters are included for this function. Existing data are not detailed enough to tease apart the characteristics of flood storage at the scale of SWAMP. While differentiation that can be determined with existing data can be useful for the other functions, the differences were viewed as insignificant for hydrological functions in this case. Information that is determined appropriate includes percent impervious surface, percent forested lands, distance of the wetland from the mouth of the estuary, fetch, width of the wetland perpendicular to the channel, length of the wetland along the channel, and the sinuosity of the channels within the wetland.

| Table 4. Hydrology Parameters for the Tidal Module | |
|---|---|
| **Landscape Parameters** | **Site Parameters** |
| Percent impervious surface in the watershed | None |
| Percent forested lands in the watershed | |
| Distance from the mouth | |
| Fetch | |
| Width of the wetland perpendicular to the channel | |
| Length of the wetland along the channel | |
| Sinuosity of the channels within each wetland | |

The riverine module breaks hydrology into three sub-functions, surface run-off storage, floodwater storage, and shoreline stabilization (Table 5). The surface runoff storage sub-function of riverine wetlands consists of watershed position, size, wetland type, and soil infiltration capacity. To examine how wetlands contribute to floodwater storage, SWAMP uses watershed position, size, width of the wetland perpendicular to the stream, and flooding frequency. To evaluate the contribution of the wetland to shoreline stabilization, SWAMP measures the proximity to surface water body, length of wetland border exposed to open water, and land use of the watershed (as a proxy for watershed energy).

| Table 5. Hydrology Parameters for the Riverine Module | | |
|---|---|---|
| **Surface Runoff Storage** | **Floodwater Storage** | **Shoreline Stabilization** |
| *Landscape Parameters* | *Landscape Parameters* | *Landscape Parameters* |
| Position within the watershed | Position within the watershed | Proximity to water body |
| Size of the wetland | Size of the wetland | Length of border exposed to open water |
| | Width of the wetland perpendicular to the stream | Watershed land use |
| | | |
| *Site Parameters* | *Site Parameters* | *Site Parameters* |
| Wetland type | Soil: Flooding frequency | None |
| Soil infiltration capacity | | |

Because the hydrology of tidal wetlands differs significantly from that of riverine wetlands, discussion of the parameters will be completely separate.

*Tidal Wetlands*

Impervious Surface

E Less than 7.5% impervious surface
S 7.5 to 30% impervious surface
B Greater than 30% impervious surface

This parameter is based on the assumption that the flow rate and erosive force of a stream will be greater when watershed runoff is more rapid. The larger the amount of cleared land and the larger the proportion of impervious surface in a watershed, the more runoff there is and the faster it will reach streams.

Impervious surfaces cause surface runoff to increase, thereby increasing runoff velocity and volume, leading to general hydrologic disruption. An increase in impervious surfaces has been shown to degrade stream quality and wetland health (Arnold and Gibbons 1996). Adamus et al. (1987) use 10 percent impervious surface as the threshold for significance for this function. Studies by others have provided similar results. Those studies conducted by the South Carolina Department of Natural Resources suggest that the thresholds of 7.5% and 30% indicate the break points of a healthy watershed (Fred Holland, SCDNR, personal communication.). The overall watershed impervious surface percentages are obtained by calculating an area-weighted average of the land use coefficients. Table 6 lists the coefficients that SWAMP uses for impervious surface by land use.

| **Table 6. Impervious Surface by Land Use** | | | |
|---|---|---|---|
| **Land Use** | **Impervious Surface Coefficient** | **Land Use** | **Impervious Surface Coefficient** |
| Natural areas | 0.00 | Other urban | 0.80 |
| Residential | 0.30 | Industrial/commercial | 0.95 |
| Transportation/utilities | 0.90 | Mixed urban | 0.50 |
| Commercial/services | 0.50 | Mines/quarries/pits | 0.80 |
| Industrial | 0.90 | Commercial | 0.50 |

Forested Lands
E Greater than 50% forests in the watershed
S 25 to 50% forests in the watershed
B Less than 25% forests in the watershed

Forest cover provides shade and cooling to streams. As forest cover is removed, temperature fluctuations increase, further disturbing the hydrologic cycle by influencing the microclimate of that stream (Arnold and Gibbons 1996, Galli 1991). Thresholds were provided by the South Carolina Department of Natural Resources (Holland, pers. comm.)

Distance from Mouth
E Farthest
S Moderate
B Nearest

The tidal energy associated with lunar tides is greatest nearest its source. This "push" has the greatest opportunity to affect a wetland nearest the source of the energy, or near the mouth. Although geomorphology may cause a tributary far from the mouth to have a great range (and therefore energy), most of the energy will be dissipated to wetlands nearest the mouth. These wetlands attenuate the flood energy and also provide vegetative protection for reduced sedimentation. A more direct measure of flood energy would be preferable, but distance from mouth remains the current proxy in SWAMP.

Fetch
E Adjacent to the mouth of a large body of open water (e.g., an estuary)
S Adjacent to open water other than the mouth of the system
B Not adjacent to any open water

The erosive force of wave action is greatest where the fetch exceeds three miles (Knutson et al. 1982), but a one-half mile fetch is sufficient to generate waves capable of resuspending sediments (Carper and Bachmann 1984). Obviously, the higher the current velocity of flowing water, the greater is its erosive potential (Karr and Schlosser 1977). Because SWAMP's analyses are limited to watersheds, a true measure of fetch is not possible. The proximity to open water, as used here, serves as a proxy to identify the relative likelihood of having any effects of energy from the waters immediately adjacent to a wetland.

Buffer/Width Perpendicular to Channel

E  Greater than 100 meters
S  50 to 100 meters
B  Less than 50 meters

This parameter and the next one, length of tidal wetland, are related measures of a wetland's size. The critical factor is the size of the floodplain, since that is the area in which floodwater is actually stored. In the absence of digital floodplain maps, however, these two parameters are used as indirect measures of available water storage area.

Width is important not only as a measure of area, but also as an indicator of frictional resistance to flow, which slows flood velocity and increases storage time. Frictional resistance is provided by wetland vegetation, ground structure such as logs and hummocks, and by the soil surface itself. The frictional drag provided by vegetation is proportional to stem density (Marble 1992), with at least 70 percent coverage by vegetation required for most effective flow resistance (Adamus et al. 1987). Woody debris underlying floodplain forests also increases surface roughness and decreases flood flow (Burkham 1976, Taylor and Barclay 1985). In all cases, the wider the wetland, the more these factors come into play.

Evaluation of this parameter assumes that wider wetlands that allow floodwater to spread out over a larger area are more effective at reducing the energy from the water. The wider the area into which floodwater flows, the greater is the reduction in flow velocity and the shallower is the water depth. The width values used are meant more to distinguish between narrow strips of estuarine wetlands and more extensive wetland areas than to have absolute significance in and of themselves.

Wider wetlands reduce flow rates more than narrow ones by decreasing channel restriction and by offering greater frictional resistance to flow. Most resistance to flow is provided by vegetation, and the wider the wetland, the more vegetation is exposed to flowing water. Water depth will also be less in wider wetlands and the shallower the water, the greater the frictional resistance provided by the vegetation (Adamus et al. 1991).

Length of Tidal Wetland

E  Greater than 1000 meters
S  300 to 1000 meters
B  Less than 300 meters

One of the primary determinants of a wetland's significance in influencing the hydrology of a watershed is the wetland's size. In simplest terms, the larger a wetland is, the more water it can store. Many studies have confirmed this assumption for the total area of wetlands in a watershed (Novitski 1979, Ogawa and Male 1983, Verry and Boelter 1979, Edgerton 1973). Kittelson (1988) extended the analysis to single wetland sites with the same conclusion. Because the ACE Basin study deals with tidal systems that receive their tide from a channel, the pure measure of size has been replaced with length (and combined with the previous parameter, width) to evaluate not only size, but the shape that is most relevant in a tidal system as well.

If exposure to open or flowing surface water is a prerequisite for a wetland to perform shoreline stabilization, then the greater the extent of exposure, the higher is the wetland's potential significance. The length values used are arbitrary, based simply on conditions recommended by expert reviewers.

Sinuosity
E Top 34% in the watershed
S Middle 33% in the watershed
B Lowest 33% in the watershed

As stated previously, flow velocity is an important factor for water quality improvement. Similar to hydrology, the slower the flow velocity, the more likely energy will be absorbed by the wetland, preventing sedimentation and other undesired impacts. The greater the sinuosity, the lower the energy. Lower flow rates also suggest longer residence times (Mulholland 1981).

*Riverine Wetlands - Surface Runoff Storage*
As noted previously, the riverine module breaks hydrology into three sub-functions: surface runoff storage, floodwater storage, and shoreline stabilization (Table 5).

Surface runoff storage includes storage of water that enters a wetland as precipitation or as runoff from adjacent areas. SWAMP examines the wetland's capacity to slow or stop the rate at which water enters a stream network. Since much of the water entering wetlands from these sources never enters a stream at all, but infiltrates to the groundwater or is returned to the atmosphere through evapotranspiration, this sub-function can have great impact on downstream flow rates (Adamus et al. 1991).

Watershed Position
E Intermittent or first order stream
S Second or third order stream
B Greater than a third order stream

The order of the stream nearest the wetland is used as an indicator of the effective position of the wetland in the hydrologic unit. Strahler stream order is used, which numbers the smallest streams as first order. The assumption used in ranking is that wetlands further upstream in a watershed have greater significance in storing surface runoff than do downstream wetlands.

The first phenomenon on which this assumption is based is the fact that precipitation and surface flow are the predominant water sources for upstream wetlands, while hydrology of downstream wetlands is dominated by overbank flow (Brinson 1988). The percentage of total overland runoff that enters wetlands decreases as stream order increases (Whigham et al. 1988). This fact, together with the greater length of low order than high order streams in a watershed (Leopold et al. 1964) gives wetlands along low order streams a greater significance in storing runoff water.

The second phenomenon involved in the importance of upstream wetlands in surface runoff storage is their role in desynchronizing flood flows. Water storage in wetlands located in headwaters desynchronizes peak flows in tributaries, resulting in lower peak flows downstream (Carter et al. 1979). A study by Novitski (1979) found that 50 percent of the reduction in flood peaks results from the first five percent of wetland area in a watershed, and Flores et al. (1981) determined by simulation that detention basins are most effective if located in the upper portion of a watershed. Wetlands located in the uppermost portions of a watershed, where the total acreage of wetlands and surface waters upstream is less than seven percent of total wetland and surface water acreage of the watershed, are the most effective (Ogawa and Male 1983).

Wetland Size
E  Greater than 0.54% of the watershed area
S  0.05 to 0.54% of the watershed area
B  Less than 0.05% of the watershed area

As discussed previously, size is a key determinant of a wetland's influence on hydrology. Starting with the assumption, then, that any wetland will store some water, and the larger a wetland is the more water it can store, the question remains as to how large an individual wetland must be to have an appreciable effect on watershed hydrology. Studies have measured wetland size as a percentage of total watershed area, and it is obvious that this is a sound approach. Applicable values were not found in the literature on which to base a wetland size-hydrologic significance relationship for the ACE Basin of South Carolina.

We accepted the method employed in NC-CREWS where simulation modeling was used to determine the effect of wetland size on watershed peak discharge. Several models were explored for applicability and were tried on trial data sets, including AGNPS (Young et al. 1989), TR-55, ANSWERS (Beasley and Huggins 1981), SWRRB (Arnold et al. 1990), and HEC-1 (U.S. Army Corps of Engineers 1990). HEC-1 proved most useful for this purpose and was used to arrive at the wetland size figures used in this parameter.

Simulation results were used to develop a relationship between the percentage of watershed area converted from wetlands to agriculture and the percentage increase in watershed peak discharge. This relationship is shown in Figure 2. Cutoff points were selected at 0.1, 1.0, and 5.0 percent change in peak runoff. These correspond to wetland areas of 0.05, 0.54, and 2.7 percent of watershed area. An effect on watershed peak discharge of 0.1 percent or less is considered insignificant, while an effect of 1.0 percent or more is considered highly significant. If a wetland occupies such a proportion of its watershed that its loss would result in a 5 percent or greater increase in peak discharge, the wetland is rated at least S for this sub-function, regardless of its rating for each parameter.

Wetland Type
E  Bottomland hardwood or other swamp
S  Hardwood flat along river
B  Pine flat along river

Complexity of vegetative structure, surface roughness, and internal ponding increase a wetland's capacity to store water (Adamus et al. 1991). The bottomland hardwood, swamp forest, and headwater swamp types in the E category have maximum values for these characteristics. Freshwater marsh is included in the E group because marshes typically act as ponds to hold and retain water. Wetland types in the S and B categories have a lower degree of surface roughness and internal ponding. Although pine communities, both natural and managed, have high rates of evapotranspiration, they have low internal roughness and vegetative structure.

Soil Infiltration Capacity
E  Soil hydrologic group A, B, or A/D
S  Soil hydrologic group C or B/D
B  Soil hydrologic group D

Wetlands continue to store runoff water until they become filled to capacity with surface water. Since wetlands normally occur in depressions, surface ponding stores water until the depression fills (Carter et al. 1979, Adamus et al. 1991). Surface runoff normally enters a wetland relatively slowly compared with floodwater from a stream, allowing time for infiltration into the soil. The faster the soil infiltration rate, the more runoff water can be stored before a wetland fills with surface water and begins to overflow.

Soil series are categorized into hydrologic groups according to the soil's capacity for water intake when the soil is wet and receives additional water from long-duration storms. The hydrologic groups are defined as follows (Goodwin 1987).

> Group A: Soils having a high infiltration rate when thoroughly wet. These consist mainly of deep, well-drained to excessively drained sands or gravelly sands.
>
> Group B: Soils having a moderate infiltration rate when thoroughly wet. These consist chiefly of moderately deep or deep, moderately well-drained or well-drained soils that have moderately fine texture to moderately coarse texture.
>
> Group C : Soils having a slow infiltration rate when thoroughly wet. These consist chiefly of soils having a layer that impedes the downward movement of water or soils of moderately fine texture.
>
> Group D: Soils having a very slow infiltration rate when thoroughly wet. These consist chiefly of clays that have high shrink-swell potential, soils that have a permanent high-water table, soils that have a clay pan or clay layer at or near the surface, and some organic soils.
>
> Group A/D: A dual hydrologic group is given for certain wet, sandy soils that have a thin infiltration rate if drained. The first letter applies to the drained condition, and the second letter applies to the undrained condition.
>
> Group B/D: A dual hydrologic group is given for certain wet soils that can be adequately drained. The first letter applies to the drained condition, and the second letter applies to the undrained condition.

*Riverine Wetlands - Floodwater Storage*
Riverine wetlands, particularly those on higher order streams, receive most of their water from overbank flow when stream flow exceeds channel capacity (Brinson 1988). The process of overbank flow into these wetlands spreads floodwater over larger areas and slows its flow, resulting in less severe flooding downstream. Since floodwater storage, by definition, occurs only in riverine wetlands that receive overbank flow, headwater and depressional wetlands are assigned an automatic B rating for this sub-function.

<u>Watershed Position</u>
E Greater than third order stream
S Second or third order stream
B Intermittent or first order stream

As with the other watershed position parameters, Strahler stream order is used as an indicator. In this case, however, higher significance is assigned to wetlands further downstream in a watershed. In the coastal area, these often are the bottomland hardwoods and extensive swamp forests that occupy the broad floodplains of major coastal rivers.

These downstream floodplains are of great significance in floodwater storage for several reasons. They occupy large areas and, at least under natural conditions, are usually quite broad, allowing them to store large amounts of water. Since these wetlands occur along major rivers, their significance in floodwater storage is greatest during major flood events. The simulation studies of Ogawa and Male (1983) indicated that wetlands low in a watershed reduced flooding over a greater downstream area than did upstream wetlands and that these downstream wetlands were important regardless of the total amount of other storage available in the watershed.

<u>Wetland Size</u>
E Wetland is greater than 0.54% of watershed area
S Wetland is 0.05 to 0.54% of watershed area
B Wetland is less than 0.05% of watershed area

The ability of a wetland to alter flood flows depends on its storage capacity and hydraulic length (Adamus et al. 1991), which are functions of wetland area, depth, and surface roughness. This size parameter, combined with width perpendicular to the stream, is used as an indicator of those direct characteristics that determine wetland significance in flood attenuation. This parameter also recognizes the flood storage potential of even narrow strips of riparian wetlands if they extend for long distances along a stream. The size breakdowns are the same as those used in the size parameter for runoff storage and are based on the results of simulation modeling as previously explained.

<u>Width of Wetland Perpendicular to Stream</u>
E Greater than 100 meters
S 50 to 100 meters
B Less than 50 meters

This parameter is a measure of a wetland's size. The critical factor is the size of the floodplain, since that is the area in which floodwater is actually stored. In the absence of digital floodplain maps, however, this parameter is used as indirect measures of available water storage area.

Width is important not only as a measure of area, but also as an indicator of frictional resistance to flow, which slows flood velocity and increases storage time. Frictional resistance is provided by wetland vegetation, ground structure such as logs and hummocks, and by the soil surface itself. The frictional drag provided by vegetation is proportional to stem density (Marble 1992), with at least 70 percent vegetational coverage required for most effective flow resistance (Adamus et al. 1987). Woody debris underlying floodplain forests also increases surface roughness and decreases flood flow (Burkham 1976; Taylor and Barclay 1985). In all cases, the wider the wetland, the more these factors come into play.

<u>Flooding Frequency</u>
E Frequent
S Occasional or rare
B None or no entry

Evaluation of this parameter is based on the assumption that the longer the period of time floodwater is retained in a wetland, the greater is the significance of the wetland in desynchronizing and lessening the severity of downstream flood peaks. Long water residence times are more likely to occur in watersheds with gradual topography, such as those of the southeastern coastal plain, than in steeper watersheds (Adamus et al. 1991), but, in either case, is a valid measure of flood storage effectiveness.

Values used to determine parameter ratings are the frequency-of-flooding ratings (as a proxy for the more desirable duration of flooding) for the predominant underlying soil series taken from the pertinent soil survey. Duration of flooding is an indicator of the length of time the soil surface is covered by flowing water from overflowing streams, determined by examination of the soil profile and consideration of local information about the extent and levels of flooding in that soil. This measure does not include shallow standing water after intense rainfall or semi-permanent ponding, but is based on actual flood events (Goodwin 1987).

Using this soil series measure as the basis of parameter evaluation has some shortcomings. Characteristics of the soil profile are the result of a soil's history, and may not reflect current flooding conditions, especially if land cover or hydrologic conditions in the watershed have substantially changed from their historic condition. It is also impossible to clearly distinguish between water remaining for long periods after a single flood event and frequent, short-lived flooding from repeated flood events. In either case, however, floodwater storage could be significant. In the absence of specific, site-level measurements of flood duration, this soil characteristic is the most appropriate measure for evaluating this parameter.

*Riverine Wetlands - Shoreline Stabilization*

Shoreline stabilization could be viewed as a sub-function under either water quality or the hydrology since it includes both sediment stabilization and dissipation of erosive forces (Adamus et al. 1991). In SWAMP it is included as a hydrology sub-function.

Wetland plants bind soil with their root systems and help hold the soil in place in the face of erosive forces from waves and currents (Allen 1979, Benner et al. 1982). Wetlands also reduce wave and current energies through frictional resistance and by allowing space for energy dissipation before water hits upland soils (Wayne 1976). This effect can reduce erosion elsewhere in the watershed. Although the shoreline stabilization function is perhaps of greatest significance in marshes along estuarine or large lake shorelines, wetlands can also be important in stabilizing stream banks.

<u>Proximity to Surface Water Body</u>

E Less than 20 meters from shoreline of a second or higher order stream or of an estuary or lake shoreline

S Less than 20 meters from first order stream or between 20 and 100 meters from an estuary shoreline

B At least 20 meters from any stream or lake or more than 100 meters from an estuary shoreline

This parameter indicates whether a wetland is in an appropriate landscape position to perform shoreline stabilization. Obviously, if it is not located on a shoreline, a wetland cannot perform this function. If the wetland is on a shoreline, its stabilizing significance depends on the erosive force of the water body. Estuaries and lakes, with large fetch, and higher order streams have greater erosive forces than small streams.

The erosive force of wave action is greatest where the fetch exceeds three miles (Knutson et al. 1982), but a one-half mile fetch is sufficient to generate waves capable of resuspending sediments (Carper and Bachmann 1984). Obviously, the higher the current velocity of flowing water, the greater is its erosive potential (Karr and Schlosser 1977).

<u>Length of Border Exposed to Open Water</u>

E Greater than 175 meters of wetland perimeter borders open water

S 30 to 175 meters of perimeter borders open water

B Less than 30 meters of perimeter borders open water

If exposure to open or flowing surface water is a prerequisite for a wetland to perform shoreline stabilization, then the greater the extent of exposure, the higher is the wetland's potential significance.

The length values used are arbitrary, based simply on conditions typical of the North Carolina coastal area.

<u>Watershed Land Use</u>

E Greater than or equal to 1% developed or greater than 20% developed and agriculture lands
B Less than 1% developed and less than 20% developed and agriculture lands

This is an opportunity parameter based on the assumption that the flow rate and erosive force of a stream will be greater when watershed runoff is more rapid. The larger the amount of cleared land and the larger the proportion of impervious surface in a watershed, the more runoff there is and the faster it will reach streams. Adamus et al. (1987) uses 10 percent impervious surface as the threshold for significance for this function. The numbers in SWAMP were derived from NC-CREWS (Sutter et al. 1999) based on an analyses of natural breaks in the data.

**Habitat**

The role of wetlands in providing habitat for both terrestrial and aquatic animal species is well known. Wetlands function as feeding, roosting and staging sites, dispersal corridors, shelters, and refuges for many different species. Some of these species are dependent on wetlands to meet one or more life cycle requirements and would not exist in a landscape without wetlands. Other species use wetlands for water, food, or shelter, but could exist just as well in natural upland habitat.

In either case, wetlands are attractive to many wildlife species. The high productivity of many wetlands provides nutrients and other resources used by diverse wildlife populations (Tiner 1984), and the structural diversity of wetlands and wetland-upland habitat complexes provides unique habitats necessary for many species (Weller 1988). In many regions, more species are restricted to wetlands than to any other habitat (Williams and Dodd 1978). Nationwide, about one-third of the species listed as threatened or endangered are dependent on wetlands, and more than 50 percent of the species of protected migratory birds depend upon or frequent wetland habitats (U.S. Fish and Wildlife Service 1990). Among various types of undeveloped lands, wetlands often make the largest contribution to regional biodiversity (Brinson et al. 1981).

In the coastal area, wetlands are particularly significant to wildlife populations because the wetlands are the primary remaining large areas of natural or semi-natural habitat. Fertile upland areas were long ago converted to agricultural use, and many of them have subsequently been developed. Forested wetlands where drainage was impractical or the soils were too wet or highly organic to farm remain as refuges for wetland and upland wildlife populations. Some coastal area wetlands, particularly those that hold floodwaters from streams, also provide significant spawning habitat for fish.

The habitat function of wetlands is particularly difficult to assess, since good habitat for one species may be poor habitat for another. Nearly any vegetated area can provide habitat for some species of animal life, and picking a particular species or group of species is a matter of management objectives or personal preference.

In the SWAMP assessment of wetland wildlife habitat, two principles are considered most important. Overall habitat quality is highest where biodiversity is highest, i.e., the more habitat requirements a wetland fills for the greatest number of species, the higher is its habitat significance. In a landscape where remaining habitat is highly fragmented, internal habitat is more ecologically significant than edge habitat.

These two principles may conflict in some cases, since there are normally more edge-dwelling species than interior-dwelling species. The first principle comes into play in parameters such as association with surface water and wetland type, while the second principle predominates in consideration of wetland size. In cases where the two principles may conflict, the predominant assumption used is that the coastal landscape provides plenty of edge habitat exclusive of wetlands. Thus, the primary habitat value of wetlands is for those species that require either the specific habitat characteristics provided by wetlands or relatively large unbroken habitat areas.

The tidal module of SWAMP examines habitat from five perspectives, which equate to the sub-functions discussed under water quality and hydrology (Table 7). Those perspectives are general terrestrial animals, nekton, amphibians, birds, and general benefits derived from the landscape. The parameters contained within each of these perspectives can also be seen in Table 7.

**Table 7. Habitat Parameters for the Tidal Module**

| Terrestrial | Nekton | Amphibians | Birds | Landscape |
|---|---|---|---|---|
| Interior size of the wetland | Edge to area ratio | Proximity to open water | Available freshwater | Wetland juxtaposition |
| Heterogeneity of habitat complex | Flooding frequency | | Edge to area ratio | Surrounding habitat |
| | Proximity to source channel | | | Corridor potential |

The riverine module examines habitat from four perspectives (Table 8). Those perspectives are general terrestrial animals, amphibians and invertebrates, fish, and general benefits derived from the landscape. The parameters contained within each of these perspectives can also be seen in Table 8.

**Table 8. Habitat Parameters for the Riverine Module**

| Terrestrial | Amphibians and Invertebrates | Fish | Landscape |
|---|---|---|---|
| Interior size of habitat complex | Wetland type | Proximity to perennial stream | Wetland juxtaposition |
| Heterogeneity of habitat complex | Surrounding habitat | | Surrounding habitat |
| Association with surface water | | | Wetland islands |
| Wetland type | | | Corridor potential |

The habitat parameters are presented in the following text in the general order they can be found in the SWAMP model. Because some parameters are present in more than one sub-function, however, the order of presentation does not exactly match the model (see Figure 1 and Appendix I). Parameters included in both the tidal and riverine module are listed with notation reflecting this, and those parameters found within only one of the modules are so noted.

*Terrestrial Wildlife Habitat*

The first habitat sub-function assessed is the significance of the wetland in providing habitat for terrestrial wildlife species. The quality of terrestrial habitat is determined by characteristics internal to the habitat.

This series of parameters assesses the quality of habitat provided internal to the "habitat complex." The basic unit of assessment, i.e., the "habitat complex," includes not only the wetland itself, but also all contiguous unbroken areas of unmodified wetlands, drained wetlands, and intact upland areas.

This represents the total area available for terrestrial wildlife activity provided by natural vegetation. Most terrestrial species utilize more than the interior of a wetland itself for parts of their life cycles, and this approach assesses the total available habitat, of which the wetland is a part.

Interior Size of Habitat Complex (*Both Tidal and Riverine Wetlands*)
E Greater than 30 hectares (74 acres)
S 0 to 30 hectares (0 to 74 acres)
B No interior habitat

In determining the extent of the habitat complex, primary and secondary roads are assumed to be effective breaks in habitat. Areas not fragmented by roads are reduced inward 100 meters from the boundaries to compensate for edge effects. If any of the complex area remains after these reductions, it is assumed that the complex provides some interior habitat.

The significance of interior habitat is well documented. When compared to forest interiors, forest edges typically have an altered plant species composition and community structure, higher temperature, more light, and lower humidity (Fraver 1993). In general, habitat fragmentation leads to loss of wide-ranging species, loss of interior or area sensitive species, erosion of genetic diversity in rare species, and increased abundance of species that prosper in human-dominated landscapes (Harris 1988, 1989). Many species of rare plants and animals depend on forest interiors beyond the influence of edge for essential habitat. Nest predation and brood parasitism of interior dwelling songbirds increases with proximity to edge (Wilcove 1985).

The 100-meter inward reduction and the habitat complex size breakdowns are based on several studies reported in the literature. The zone of negative influence associated with openings and edges has been quantified in several different regions and is known to extend at least 100 meters into the forest. Climatic and more subtle species composition effects may extend 1000 meters (Brittingham and Temple 1983, Wilcove 1985, Lovejoy et al. 1986). Even if they occur in a forested landscape, individual forest tracts need to be at least 30 to 40 hectares (74 to 99 acres) in size in order to abate the negative consequences of edge effects (Harris 1989). Bird species diversity has been shown to decrease rapidly with stand sizes less than 30 to 40 hectares.

Heterogeneity of Habitat Complex (*Both Tidal and Riverine Wetlands*)
E More than eight vegetation types within complex
S Five to eight vegetation types within complex
B One to four vegetation types make up entire complex

Areas with numerous interspersed vegetation forms normally support higher wildlife diversity and abundance than homogeneous areas because of the increased number of ecological niches available (Landers et al. 1977, Flake 1979). Continuous unbroken habitat containing a mixture of vegetation types can fulfill habitat requirements for both interior-dwelling and edge species. In forested areas, bird use in particular is strongly related to diversity of vegetation forms and tree species (Tramer and Suhrweir 1975, Swift et al. 1984).

Habitat heterogeneity is assessed in SWAMP by determining the number of vegetation types (based on NWI classes) included within the habitat complex associated with each wetland. Vegetation types are identified using the Cowardin classes on the underlying NWI data and different classes in the satellite-based land cover data layer.

Association with Surface Water (*Riverine Wetlands*)
E Adjacent to permanent surface water

S Adjacent to intermittent stream
B Not adjacent to surface water

Availability of surface water is important to many species and limiting to some. For example, surface water availability, at least during critical periods of the year, determines whether a wetland will be frequented by waterfowl. While wide-ranging terrestrial species may travel long distances to reach water, the presence of surface water tends to concentrate use. Even if species live elsewhere and merely visit the wetland to drink, the presence of surface water increases an area's use by wildlife and, thus, its habitat significance. Water-vegetation transition zones also provide habitat for both open-water species and those inhabiting adjacent vegetation (Weller and Spatcher 1965, Willard 1977).

The nature of tidal systems suggests that they will always be associated with surface water, so this parameter is not considered in tidal systems.

<u>Wetland Type</u> (*Riverine Wetlands*)
E Bottomland hardwood or other swamp
S Hardwood flat along river
B Pine flat along river

As with other wetland type evaluations, these groupings are based on analysis of field data on the presence of habitat-related indicators in wetlands of various types. Indicators measured such factors as food supply, vertical habitat structure, and maintenance of food web support.
In general, the greater the internal structural diversity of a plant community, the more animal species it can support. Forested and shrub-scrub vegetation provide habitat structure through vertical layering and patchiness resulting from horizontal overlap of layers (Roth 1976). The presence of several vertical vegetative strata is particularly significant to breeding-bird use (Kantrud and Stewart 1984), and bird species diversity has been shown to increase as the number and density of foliage layers increase (MacArthur et al. 1964, Karr and Roth 1971). The presence of standing dead trees further increases habitat provision for cavity-nesting birds and mammals (Porter 1981).

The availability of food supplies, particularly fruit and mast, is also an important determinant of habitat quality and use (Robinson and Bolen 1984). Although these food supplies are often supplied by adjacent uplands, wetlands with fruit and mast-bearing trees and shrubs are rated higher than those without them.

Data reviewed during the development of SWAMP rarely discriminate between tidal wetland types in enough detail to discriminate between tidal wetland types for this purpose. For this reason, this parameter is not considered when evaluating tidal wetlands.

*Nekton, Amphibians, Invertebrates, and Fish*
While wetlands provide significant habitat for terrestrial wildlife, naturally vegetated uplands often provide as good or better habitat and can substitute for wetland habitats for many species. For species that are mainly confined to water or saturated soils or that require shallow, slow-moving water during part of their life cycles, however, wetlands provide essential habitat. Aquatic organisms that are wetland-dependent include many species of fish, amphibians, reptiles, and invertebrates.

Nearly all freshwater and many saltwater fish require shallow water such as that provided by wetlands at some stage of their lives. Fish use wetlands for spawning, predator avoidance, shelter from extreme conditions, and feeding (Adamus et al. 1991). Except for large freshwater marshes and swamps, which may support a permanent fish population of their own, a wetland must be connected to surface water to perform these functions.

Amphibians and invertebrates, on the other hand, are more successful when they are not subject to predation by fish. Consequently, ephemeral wetlands with no connection to permanent surface water provide better habitat for these life forms (Bradshaw 1991). Since the habitat requirements for these two groups of aquatic organisms are so different, wetlands are evaluated separately for fish and other aquatic life.

<u>Edge to Area Ratio</u> (*Tidal Wetlands: Nekton*)
E Highest 34% in watershed
S Middle 33% in watershed
B Lowest 33% in watershed

The greater edge occurrence on a wetland provides suitable habitat for nekton to feed. Vegetation protruding from the edge into the waterway also provides cover.

<u>Flooding Frequency</u> (*Tidal Wetlands: Nekton*)
E Frequently
S Occasional or rare
B None or no entry

Seasonally flooded wetlands adjacent to southeastern streams are used by nearly all species of fish present in the stream for feeding, spawning, and protection during juvenile periods (Larson et al. 1981). Wetlands along higher order streams are most significant, since both large fish populations and annual flooding are more likely to occur in streams further down a watershed (Adamus et al. 1991). Invertebrate species richness and fish productivity are generally higher in third and higher order streams (Minshall et al. 1985, Lotrich 1973). In tidal systems, frequent inundation introduces juveniles into higher areas of the marsh where they may escape some predation, and the tidal flow then facilitates their eventual return to the water.

<u>Proximity to Source Channel</u> (*Tidal Wetlands: Nekton*)
E Close distance
S Moderate distance
B Far distance

Wetlands that are in closer proximity to the main channel of water have a greater opportunity for nekton immigration and emigration. These areas also offer more regular flushing, which potentially could offer more nutrients for the nekton to feed on or more oxygen for their health.

This parameter will also be one measured in true relative fashion, both because of the limitations of the hydrography actually showing the meanders in the streams and in finding a valid value to insert.

<u>Proximity to Perennial Stream</u> (*Riverine Wetlands: Fish*)
E Less than 100 meters from a perennial stream
S Less than 100 meters from an intermittent stream
B Greater than 100 meters from surface water

Seasonally flooded wetlands adjacent to southeastern streams are used by nearly all species of fish present in the stream for feeding, spawning, and protection during juvenile periods (Larson et al. 1981). Wetlands along higher order streams are most significant, since both large fish populations and annual flooding are more likely to occur in streams further down a watershed (Adamus et al.

1991). Invertebrate species richness and fish productivity are generally higher in third and higher order streams (Minshall et al. 1985, Lotrich 1973).

Data specific to anadromous or other types of concerns would be a good addition to SWAMP. Several species of anadromous fish are commercially important in mid-Atlantic fisheries. Because of their importance, wetlands that provide potential anadromous fish habitat could be evaluated as having higher significance than those that do not. While anadromous species live their adult lives in saltwater, they move up freshwater rivers and streams to spawn in shallow water. Flooded wetlands along these streams provide ideal spawning habitat. For a wetland to provide this function, it must be along a stream used by anadromous fish, and it must be flooded during the early spring spawning season. Virtually all streams in the coastal area flood into adjacent floodplains during late winter and early spring of years with normal precipitation. Channelization, however, can lessen or prevent this flooding and lowers wetland significance for fish habitat.

<u>Proximity to Open Water</u> (*Tidal Wetland: Amphibians*)
E Permanent impoundments or ponds within 0.8 kilometers (0.5 miles)
B No nearby ponds or impoundments within 0.8 kilometers (0.5 miles)

This breakdown is based on the likelihood of standing water presence. Wetlands receiving an E include those in which shallow water habitat is most likely to exist without connection to surface waters with fish populations. Those in group B are not likely to have standing water long enough to allow amphibian reproduction. Many species of amphibians are dependent on ephemeral wetlands for reproduction (Bradshaw 1991). Wetlands with isolated pools of standing water for a few months in spring and early summer followed by dry conditions in late summer provide ideal amphibian habitat. Because this type of habitat is relatively uncommon outside of wetlands, and several species of wetland-dwelling amphibians are rare, this is an important parameter.

While amphibians require water for reproduction and larval development, mature animals require terrestrial habitat. Wetlands that are flooded most or all of the time do not provide satisfactory amphibian habitat unless drier areas are available within the movement range of these animals. There is no S rating for this parameter, since the habitat requirements are either met or not met, with no meaningful inbetween condition.

This parameter might also be extended to invertebrate fauna, including insects, nematodes, mollusks, etc., important processors of organic material and sources of food for higher-level consumers (Brinson et al. 1995). While invertebrates are common in all natural ecosystems, some species require the saturated soils and ponded water of wetlands. Invertebrates are also subject to fish predation, making their optimal habitat similar to that of amphibians.

This parameter is only used in the tidal module. In the riverine module, SWAMP uses a combination of wetland type and surrounding habitat (explained elsewhere) because of a lack of pond and impoundment data inland from the nearshore area.

<u>Wetland Type</u> (*Riverine Wetlands: Amphibians and Invertebrates*)
E Bottomland hardwood or other swamp
S Hardwood flat along river
B Pine flat along river

The wetland type breakdown is based on field evidence form NC-CREWS.

Surrounding Habitat (*Riverine Wetland: Amphibians and Invertebrates*)
E Greater than 50% of adjacent land cover composed of natural vegetation
S Greater than 50% of adjacent land cover composed of a combination of natural vegetation, pine plantations, and agriculture
B less than 50% of adjacent land cover developed OR less than 10% natural vegetation

The parameter measures the availability of non-aquatic habitat within a feasible movement range for adult amphibians.

*Birds*
Weber and Haig (1996) suggest that diked wetlands and other artificial ponds may help migrating and wintering shorebirds face reductions that have occurred in their historical "stopover" sites. Besides providing a location when all natural sites have been removed, these sites can offer additional habitat at high tide and can be preferential to natural areas during low tide.

Available Fresh Water (*Tidal Wetlands: Waterfowl*)
E Emergent wetland with adjacent permanent impoundments or ponds
S Nonemergent wetland with adjacent permanent impoundments or ponds
B No adjacent permanent impoundments or ponds

Waterfowl are dependent upon the ponds and impoundments for insects and nesting areas. This parameter is measured only in the tidal module.

Edge to Area Ratio (*Tidal Wetlands: Wading Birds*)
E Highest 34% in watershed
S Middle 33% in watershed
B Lowest 33% in watershed

Wading birds feed largely on the nekton that occupy these spaces (Weber and Haig 1996). The edge to area ratio is calculated using this formula: $edge\ length/(2*(\sqrt{(\pi * area)}))$ (Winchester and Harris 1979).

*Landscape Habitat*
Although the life-support needs of sedentary species may be met within a single wetland, many species are mobile and require a mix of wetland types or wetland and upland habitat for optimum success (Weller 1988). The relationship of a wetland to habitat conditions in adjacent areas may be more significant in determining habitat value than conditions within the wetland itself (Leibowitz et al. 1992). Both the juxtaposition of other wetlands and the availability of nearby naturally vegetated habitat are used to evaluate this characteristic.

Wetland Juxtaposition (*Both Tidal and Riverine Wetlands*)
E Greater than 50% bordered by other wetlands
S 0.1% to 50% bordered by other wetlands
B Isolated from other wetlands

For many animal species, no single wetland can provide all of their needs over their entire life cycle. For these species' success, several wetlands of various types must exist in the same area (Leibowitz et al. 1992). Since many wetlands exhibit considerable temporal variability in water depth and general "wetness," adjacent wetlands with different hydrologic regimes provide alternative habitat when the primary habitat becomes too dry or too wet. The proximity of different wetland types also increases overall habitat diversity, leading to increases in wildlife species richness (Brown and Dinsmore

1986).

Surrounding Habitat (*Both Tidal and Riverine Wetlands*)
E Greater than 50% of adjacent land cover composed of natural vegetation
S Greater than 50% of adjacent land cover composed of a combination of natural vegetation, pine plantations, and agriculture
B less than 50% of adjacent land cover developed OR less than 10% natural vegetation

Naturally vegetated areas in the near vicinity of a wetland can provide additional food sources and refuge that enhance the habitat value of the wetland (Weller 1988). Natural vegetation, pine plantation, agricultural land, and developed areas make up a descending hierarchy of habitat values. The more of the former and the less of the latter in the area surrounding a wetland, the higher is its potential habitat significance. It would be preferable for SWAMP to evaluate the percentage of various wetland types based on a buffered area around these wetlands. Unfortunately, programming difficulties prevented this and adjacency is used as an alternative measure.

Wetland Island (*Riverine Wetlands*)
E Isolated wetland greater than 2 hectares (5 acres) in size within 0.8 kilometers (0.5 miles) of the same
S Isolated wetland less than 2 hectares (5 acres) within 0.8 kilometers (0.5 miles)
B Wetland less than 0.4 hectare (1 acre) in size OR greater than 0.8 kilometers (0.5 miles) from nearest wetland

Provided that intervening areas are not effectively impassable, many wildlife species do not require continuous cover for movement and dispersal. A series of isolated wetland "islands" can enable animals to move so long as the wetlands are large enough to provide temporary cover and close enough to be within the range of reasonable movement for a species. Obviously, both of these metrics will differ for different species. The sizes and distances used are typical values for small mammals and most amphibians. This parameter is used only for riverine systems.

Potential Corridor Value (*Both Tidal and Riverine Wetlands*)
E Corridor greater than 200 meters wide connected to contiguous natural vegetation
S Corridor less than 200 meters wide connected to contiguous natural vegetation
B Isolated from other natural vegetation

Some wetlands that are of relatively low significance as primary habitat may still perform important functions as movement or dispersal pathways between more favorable habitat areas. Continuous corridors through areas of otherwise unsuitable habitat, such as agricultural or developed land, may provide regularly used movement pathways.

While small wetland patches or narrow alluvial strips may provide only limited permanent habitat, they can often be quite significant in providing temporary cover for moving animals. The absence of significance as a movement pathway does not lower the overall habitat significance of a wetland if its internal and landscape habitat significance is high. This assessment is applied to a wetland to determine if it is, in effect, a corridor through otherwise inhospitable habitat that connects two or more areas of natural vegetation. Corridor width values are based on studies of habitat buffers and riparian buffer strips (Brinson et al. 1981, Brown et al. 1990).

## Conclusion

SWAMP provides an approach to systematically view various elements that contribute to different aspects of watershed function, specifically water quality, hydrology, and habitat. This report detailed the parameters and the underlying assumptions. The interface, including instructions for combining these parameters is provided in the “SWAMP: Tutorial” document contained on the SWAMP CD-ROM. Using these tools, resource managers can examine the contribution of wetlands to a watershed in order to make more informed management decisions.

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## Appendix I: Parameter Summary and Organization

| ***Tidal Wetlands Evaluation Module*** **Water Quality** | |
|---|---|
| **Parameter Evaluation** | **Brief Explanations** |
| ***Landscape Characteristics*** | |
| **Proximity to Sources/Potential Pollutants**<br>E Perimeter has more than 20% agriculture and developed<br>S Perimeter has less than 20% agriculture, developed land, pine plantations, or impoundments<br>B Perimeter has no adjacent agriculture, developed land, pine plantations, or impoundments | This is an opportunity feature. Wetlands that are not in close proximity to pollutants will not be penalized for a lack of opportunity. Any site near a current source of pollution will receive an added benefit within SWAMP's scoring opportunity because the wetland is likely acting as a sink or transformer for those nutrients and/or pollutants. Presumably, wetlands nearest a source delivering particulates (agriculture & developed land) will be relatively more active in improving water quality. |
| **Watershed Position**<br>E Closest to the small tributaries furthest from the main water body<br>S Closest water body is not a small tributary, but a larger one that is not the main water body<br>B Closest water body is the watershed's main water body | Wetlands higher in the landscape and closer to smaller tidal channels are recipients of a greater percentage of sediments from a land-based source, thereby contributing more to the water quality of a watershed than those that are closer to the main body of the estuary. |
| **Width of Wetland Perpendicular to Stream/Channel**<br>E Greater than 100 meters<br>S 50 to 100 meters<br>B Less than 50 meters or not adjacent to channel | Wide wetlands adjacent to channels provide more surfaces for soil exchange, thereby removing the nutrients that would otherwise be transported into the water. Wider wetlands are assumed to provide more surfaces. |
| **Edge/Area Ratio**<br>E Highest 34% in watershed<br>S Middle 33% in watershed<br>B Lowest third 33% in watershed | Pollutant removal is greatest at the interface between soil and water. An elongated system allows more edge per given area. Wetlands that have the greatest edge per unit area contribute more significantly to water quality. |
| **Size**<br>E Greater than 0.54% of the watershed<br>S 0.05 to 0.54% of the watershed<br>B Less than 0.05% of the watershed | The larger a wetland, the more micro-sites can potentially be available to facilitate soils exchange. |

| Parameter Evaluation | Brief Explanations |
|---|---|
| ***Site Conditions*** | |
| **Vegetative Cover Type**<br>E Woody<br>S Emergent, herbaceous<br>B Aquatic bed | Vegetation helps to slow water flow, thereby trapping sediments and other particulates. Woody vegetation is accepted as having the greatest trapping efficiency for particulates. Emergent, herbaceous vegetation is less significant for trapping sediments, and submerged plants can be helpful in this function, but rarely play a significant role. |
| **Flooding frequency**<br>E Frequent<br>S Occasional or rare<br>B None or no entry | Chemical transformations occur in the fluctuation between aerobic and anaerobic conditions in a wetland. When soils are flooded longer, they potentially remain anaerobic longer, thus allowing these chemical reactions to occur. Duration is a better indicator than frequency, but the data are poorly represented in this field. Frequency is being used to approximate the results, using the assumption that frequently flooded soils provide a greater opportunity for anaerobic processing. |
| **Permeability and Surface Texture**<br>E Slow/very slow permeability or moderate/moderate-slow permeability with a mucky surface layer or rapid permeability with a sapric or hemic surface texture<br>S Moderate/moderate-slow permeability or slow/very slow with a mucky surface texture<br>B Rapid/moderately rapid permeability | Soils that allow water to filtrate quickly do not develop anaerobiosis and process nutrients to the same extent that those that are wetter for longer times, and, thus, anaerobic. The presence of large organic material in more permeable soils indicates that another property is present that allows water to remain on-site for a period of time; thus, those soils can be rated higher. |

| ***Tidal Wetlands Evaluation Module*** **Hydrology** | |
|---|---|
| **Parameter Evaluation** | **Brief Explanations** |
| | ***Landscape Parameters*** |
| **Impervious Surface**<br>E Less than 7.5% impervious surface<br>S 7.5 to 30% impervious surface<br>B Greater than 30% impervious surface | Increased impervious surface leads to greater energy as water moves, and thus greater erosion. Coefficients were assigned to each land cover category, and an impervious surface percentage was calculated for the watershed. |
| **Forested Lands**<br>E Greater than 50% forests in the watershed<br>S 25 to 50% forests<br>B Less than 25% forests | Amount of forested areas in watershed allows water to permeate the ground better. According to Holland (pers. comm.), this percent of land use is a critical parameter. |
| **Distance from Mouth**<br>E Farthest<br>S Moderate<br>B Nearest | Wetlands nearest the mouth, in general, are subjected to tides at their strongest. Although geomorphology may be a cause for an increase in tidal range at some distance from the mouth, the energy from tides (not wave driven) is greatest nearest the source, or the mouth. |
| **Fetch**<br>E Adjacent to the mouth of a large body of open water (e.g., an estuary)<br>S Adjacent to open water other than the mouth of the system<br>B Not adjacent to any open water | Wind-driven waves increase in size and energy with greater fetch, the distance wind blows over open water. Wetlands adjacent to areas with the greatest fetch serve an important role in maintaining the shoreline and defending against sedimentation. |
| **Buffer/Width Perpendicular to Channel**<br>E Greater than 100 meters<br>S 50 to 100 meters<br>B Less than 50 meters | The broader the expanse of a wetland perpendicular to a channel, rivulet, or shoreline, the more opportunity to attenuate any flood events. |
| **Length of Tidal Wetland**<br>E Greater than 1000 meters<br>S 300 to 1000 meters<br>B Less than 300 meters | A longer interface between land and water allows a greater opportunity to ameliorate any tidal energy. |
| **Sinuosity**<br>E Top 34% in the watershed<br>S Middle 33% in the watershed<br>B Lowest 33% in the watershed | The straighter the channel, the easier water flows up the marsh surface. Stronger water flows can cause erosion, hence a greater sinuosity decreases the energy deflected to the wetland and adjacent upland areas. |

| *Tidal Wetlands Evaluation Module*<br>**Habitat** | |
|---|---|
| **Parameter Evaluation** | **Brief Explanations** |
| | ***Terrestrial*** |
| **Interior Size of Habitat Complex**<br>E Greater than 30 hectares (74 acres)<br>S 0 to 30 hectares (0 to 74 acres)<br>B No interior habitat | The habitat complex (wetlands plus naturally vegetated uplands) is buffered inward for 100 meters to eliminate edge effects. The remaining area is evaluated to determine if adequate area exists for interior (non 'edge') species. Roads are considered breaks in the habitat. |
| **Heterogeneity of Habitat Complex**<br>E More than 8 vegetation classes within complex<br>S 5 to 8 vegetation classes within complex<br>B 1 to 4 vegetation classes within complex | More classes in an area provide a more diverse landscape. Cowardin classes are used in SWAMP as a substitute for a true heterogeneity measure as a pure measure of heterogeneity is most difficult to obtain at an appropriate scale. |
| | ***Aquatic - Nekton*** |
| **Edge/Area Ratio**<br>E Highest 34% in watershed<br>S Middle 33% in watershed<br>B Lowest 33% in watershed | Greater edge provides greater food source and more hiding locations for nekton. |
| **Flooding Frequency**<br>E Frequent<br>S Occasional or rare<br>B None or no entry | Frequent flooding episodes allow small fish to move into the floodplain and feed while predators remain in the open channel. Frequent reflooding allows the juveniles to return to the channel. |
| **Proximity to Source Channel**<br>E Close distance<br>S Moderate distance<br>B Far distance | Wetlands closer to the main body of water within a watershed offer greater opportunities for fish to reach both the wetland and the subtidal refuges. It also suggests more frequent flushing to add oxygen to the water. |

| **Parameter Evaluation** | **Brief Explanations** |
|---|---|
| ***Amphibians*** | |
| **Amphibians: Open Water**<br>E Permanent impoundments or open water within 0.8 kilometers (0.5 mile)<br>B No nearby ponds or impoundments within 0.8 kilometers (0.5 mile) | Amphibians need a nearby source of water for breeding. Travel can extend to approximately one-half mile. Water sources removed from a channel also remove the threat of predation by fish. |
| ***Birds*** | |
| **Waterfowl: Available Fresh Water**<br>E Emergent wetland with adjacent permanent impoundments or ponds<br>S Nonemergent wetland with adjacent permanent impoundments or ponds<br>B No adjacent permanent impoundments or pond | Waterfowl make active use of both natural and managed open water areas. The presence of these sites increases the value of the wetland being evaluated for waterfowl. |
| **Wading Birds: Edge/Area Ratio**<br>E Highest 34% in watershed<br>S Middle 33% in watershed<br>B Lowest 33% in watershed | Greater edge allows more nekton per unit area, and the nekton are prey for wading birds. |
| ***Landscape characteristics*** | |
| **Wetland Juxtaposition**<br>E Greater than 50% of perimeter bounded by other wetlands<br>S 0.1% to greater than 50% of perimeter bounded by other wetlands<br>B Isolated from other wetlands | This is an examination of the quality of habitat reflecting the significance of connected wetland complexes in providing habitat. |
| **Surrounding Habitat**<br>E Greater than 50% of adjacent land cover composed of natural vegetation<br>S Greater than 50% of adjacent land cover composed of a combination of natural vegetation, pine plantations, and agriculture<br>B less than 50% of adjacent land cover developed <u>OR</u> less than 10% natural vegetation | This is an examination of the landscape setting. It evaluates how many uplands are nearby (within a one-half mile radius) for the terrestrial wildlife to use for sleep and foraging. |
| **Potential Corridors Value**<br>E Corridor greater than 200 meters wide connected to contiguous natural vegetation<br>S Corridor less than 200 meters wide connected to contiguous natural vegetation<br>B Isolated from other natural vegetation | A wildlife corridor is a potential movement pathway through areas of unsuitable habitat such as agricultural or developed land. The corridor can include natural upland vegetation as well as wetlands. When all parameters rate "low" for a given wetland, the site will then be evaluated to determine if it acts as a corridor for wildlife. If it does serve a corridor function, it will be further evaluated for width, assuming wider corridors are safer travel and refuge areas for a broader range of animals. |

| ***Riverine Wetlands Evaluation Module***<br>**Water Quality Functions** | |
|---|---|
| **Parameter Evaluation** | **Brief Explanations** |
| | ***Non-point Source Function*** |
| **Proximity to Sources/Potential Pollutants**<br>E Perimeter has more than 20% agriculture and developed<br>S Perimeter has less than 20% agriculture, developed land, pine plantations, or impoundments<br>B Perimeter has no adjacent agriculture, developed land, pine plantations, or impoundments | This is an opportunity parameter. It considers the likelihood of polluted runoff entering the wetland based on predominant adjacent land uses. The more of the perimeter of the wetland surrounded by nonpoint source pollution producing land uses, the higher the rating. |
| **Watershed Position**<br>E Closest to the small tributaries furthest from the main water body<br>S Closest water body is not a small tributary, but a larger one that is not the main water body<br>B Closest water body is the watershed's main water body | The higher in its watershed a wetland lies, the greater is the potential effect of non-point source removal on overall watershed water quality. The Strahler stream order of the nearest stream is an indicator of watershed position. |
| **Proximity to Surface Water Body**<br>E Within 100 meters of permanent surface water<br>S Within 100 meters of intermittent stream<br>B Greater than 100 meters from permanent or intermittent surface water | Proximity to surface water body is an indicator of the likelihood that polluted runoff entering the wetland would otherwise enter surface water. Wetlands close to permanent surface water are rated higher than those close to intermittent streams, and those not close to any surface water are rated lowest. |
| **Wetland Type**<br>E Bottomland hardwood or other swamp<br>S Hardwood flat along river<br>B Pine flat along river | Wetland type breakdowns are based on NC-CREWS field data on indicators of wetland capacity for nutrient transformation and processing and removal of sediments and dissolved materials. |
| **Hydric Soil/Texture**<br>E Infrequently flooded, low clay<br>S Infrequently flooded, high clay<br>B Frequently flooded | The presence of fine mineral soils or organic material indicates that the hydrologic influence slows to a degree to release these sediments, which are held in suspension longer than coarse particles. The presence of fine particles suggests a longer residence time of the water, thus allowing time for biogeochemical activity in the soil. The higher the organic matter content of the soil, the higher is its cation exchange capacity and the more effective it is in retaining and transforming nutrients. |

| Parameter Evaluation | Brief Explanations |
|---|---|
| | ***Floodwater Cleansing Function*** |
| **Proximity to Sources/Potential Pollutants**<br>E Perimeter has more than 20% agriculture and developed<br>S Perimeter has less than 20% agriculture, developed land, pine plantations, or impoundments<br>B Perimeter has no adjacent agriculture, developed land, pine plantations, or impoundments | This is an "opportunity" parameter. It considers the likelihood of polluted runoff entering the wetland based on predominant adjacent land uses. The more of the perimeter of the wetland surrounded by non-point source pollution producing land uses, the higher the rating since the site will already be closer to capacity of its sediment/nutrient retention/translation when the floodwater expels the banks. |
| **Width of Wetland Perpendicular to Stream/Channel**<br>E Greater than 100 meters<br>S 50 to 100 meters<br>B Less than 50 meters or not adjacent to channel | The wider a wetland is along a stream, the more area there is available for water retention and pollutant removal. |
| **Flooding Frequency**<br>E Frequent<br>S Occasional or rare<br>B None or no entry | This is a proxy for duration of flooding, as duration data were not available. The longer that floodwaters remain in a wetland, the greater is the level of pollutant removal that occurs. Parameters are based on the flooding duration typical of the predominant underlying soil as reported in the appropriate soil survey. |

| *Riverine Wetlands Evaluation Module*<br>**Hydrology Functions** | |
|---|---|
| **Parameter Evaluation** | **Brief Explanations** |
| ***Surface Runoff Storage*** | |
| **Watershed Position**<br>E Intermittent or first order stream<br>S Second or third order stream<br>B Greater than a third order stream | Wetlands along headwater streams receive proportionately more overland runoff than downstream wetlands, and their position high in the watershed results in their water storage capacity having greater impact on overall watershed hydrology. Stream order breakdowns are by the Strahler system, which numbers the smallest streams as first order. |
| **Wetland Size**<br>E Wetland is greater than 0.54% of the watershed area<br>S Wetland is 0.05 to 0.54% of the watershed area<br>B Wetland is less than 0.05% of the watershed area | Based on hydrologic modeling, the water storage capacity of a wetland equal in size to 0.54% of total watershed area will result in a decrease in peak discharge of 1%. Water storage in a wetland less than 0.05% of the watershed area will result in a decrease in peak discharge of less than 0.1%. |
| **Wetland Type**<br>E Bottomland hardwood or other swamp<br>S Hardwood flat along river<br>B Pine flat along river | Wetland type breakdowns are based on NC-CREWS field data on such indicators of surface water storage capacity as microtopographic complexity, evidence of soil reduction, and evidence of standing water. |
| **Soil Infiltration Capacity**<br>E Soil hydrologic group A, B, or A/D<br>S Soil hydrologic group C or B/D<br>B Soil hydrologic group D | The infiltration capacity of the underlying soil determines the amount of water the soil can receive and store before additional water will run off. Hydrologic groups are used in soil surveys to indicate a soil's capacity for water intake when the soils are wet and receive precipitation from long-duration storms. |

| Parameter Evaluation | Brief Explanations |
|---|---|
| | ***Floodwater Storage*** |
| **Watershed Position**<br>E Greater than a third order stream<br>S Second or third order stream<br>B Intermittent or first order stream | Wetlands along large streams further downstream in a watershed are the most significant in receiving and holding in-stream floodwaters. |
| **Wetland Size**<br>E Greater than 0.54% of the watershed area<br>S 0.05 to 0.54% of the watershed area<br>B Less than 0.05% of the watershed area | Even if a wetland is relatively narrow along a stream, if it is of considerable length and thus of large size, it can store significant amounts of water. |
| **Width of Wetland Perpendicular to Stream**<br>E Greater than 100 meters<br>S 50 to 100 meters<br>B Less than 50 meters | The wider a wetland is along a stream, the more area subject to flooding, thus increasing the available area over which floodwaters can flow. |
| **Flooding Frequency**<br>E Frequent<br>S Occasional or rare<br>B None or no entry | This is a proxy for duration of flooding, as duration data were not available. The longer that floodwaters remain in a wetland, the greater is the level of pollutant removal that occurs. Parameters are based on the flooding duration typical of the predominant underlying soil as reported in the appropriate soil survey. |

| Parameter Evaluation | Brief Explanations |
|---|---|
| ***Shoreline Stabilization Function*** | |
| **Proximity to Surface Water Body**<br>E Less than 20 meters from shoreline of a second or higher order stream or of an estuary or lake shoreline<br>S Less than 20 meters from first order stream or between 20 and 100 meters from an estuary shoreline<br>B At least 20 meters from any stream or lake or more than 100 meters from an estuary shoreline | If a wetland is not located on a shoreline, it cannot perform this function. If the wetland does occupy a shoreline, the larger the stream or the greater the fetch of open water the more erosive force that is likely to be present. |
| **Length of Border Exposed to Open Water**<br>E Greater than 175 meters of wetland perimeter borders open water<br>S 30 to 175 meters of perimeter borders open water<br>B Less than 30 meters of perimeter borders open water | The longer the length of shoreline that the wetland occupies, the more significant is this function in relation to other wetland functions. |
| **Watershed Land Use**<br>E Greater than or equal to 1% developed or greater than 20% developed and agriculture lands<br>B Less than 1% developed and less than 20% developed and agriculture lands | This is an "opportunity" parameter. The assumption is that the flow rate and erosive force of a stream are increased by more rapid runoff of storm water from cleared and developed land than from forested land. |

| *Riverine Wetlands Evaluation Module*<br>**Habitat Functions** | |
|---|---|
| **Parameter Evaluation** | **Brief Explanations** |
| ***Internal Terrestrial Habitat*** | |
| **Interior Size of Habitat Complex**<br>E Greater than 30 hectares (74 acres)<br>S 0 to 30 hectares (0 to 74 acres)<br>B No interior habitat | For interior-dwelling species, as opposed to edge species, the larger the area of unbroken habitat the better. Evaluation of this parameter is based on the internal area of contiguous, unbroken wetlands and intact upland forests. Internal area is calculated as the area remaining after the total size of the habitat complex is reduced inward 100 meters from its boundaries to compensate for edge effects. |
| **Internal Heterogeneity of Habitat Complex**<br>E Greater than 8 vegetation types within complex<br>S 5 to 8 vegetation types within complex<br>B 1 to 4 vegetation types make up entire complex | Areas with higher internal heterogeneity generally provide suitable habitat for more species and often better habitat for individual species due to greater food sources, nesting sites, and cover. Internal heterogeneity is measured by the number of vegetation types present in the habitat complex |
| **Association with Surface Water**<br>E Adjacent to permanent surface water<br>S Adjacent to intermittent stream<br>B Not adjacent to surface water | Availability of surface water is important to many species and limiting to some. Even if species live elsewhere and visit the wetland to drink, the presence of water results in the area being more heavily used and having high habitat significance. |
| **Wetland Type**<br>E Bottomland hardwood or other swamp<br>S Hardwood flat along river<br>B Pine flat along river | The wetland type breakdown is based on analysis of field data for food and cover values typical of different wetland environments and on available literature on the habitat value of different wetland types. |

| Parameter Evaluation | Brief Explanations |
| --- | --- |
| | ***Amphibians and Invertebrates*** |
| **Wetland Type**<br>E Bottomland hardwood or other swamp<br>S Hardwood flat along river<br>B Pine flat along river | The wetland type breakdown is based on field data on existence from NC-CREWS. |
| **Surrounding Habitat**<br>E Greater than 50% of adjacent land cover composed of natural vegetation<br>S Greater than 50% of adjacent land cover composed of a combination of natural vegetation, pine plantations, and agriculture<br>B less than 50% of adjacent land cover developed <u>OR</u> less than 10% natural vegetation | The availability of non-aquatic habitat within a feasible movement range allows adequate life cycle habitat for more adult amphibians. |
| | ***Fish*** |
| **Fish Species: Proximity to Perennial Stream**<br>E Less than 100 meters from a perennial stream<br>S Less than 100 meters from an intermittent stream<br>B Greater than 100 meters from surface water | Many stream-dwelling fish species utilize flooded wetlands for food, cover, and breeding. The larger the stream, the more significant is this function due to the greater numbers of fish and longer periods of flooding. |

| Parameter Evaluation | Brief Explanations |
|---|---|
| ***Landscape Habitat*** | |
| **Wetland Juxtaposition**<br>E Greater than 50% bordered by other wetlands<br>S 0.1% to 50% bordered by other wetlands<br>B Isolated from other wetlands | Connected wetland complexes are useful in providing habitat and meeting many species' needs. |
| **Surrounding Habitat**<br>E Greater than 50% of adjacent land cover composed of natural vegetation<br>S Greater than 50% of adjacent land cover composed of a combination of natural vegetation, pine plantations, and agriculture<br>B less than 50% of adjacent land cover developed <u>OR</u> less than 10% natural vegetation | Upland, nearby habitats are examined as sleep and foraging areas for terrestrial wildlife. |
| **Wetland Island Function**<br>E Isolated wetland greater than 2 hectares (5 acres) in size within 0.8 kilometers (0.5 miles) of the same<br>S Isolated wetland less than 2 hectares (5 acres) within 0.8 kilometers (0.5 miles)<br>B Wetland less than 0.4 hectare (1 acre) in size <u>OR</u> greater than 0.8 kilometers (0.5 miles) from nearest wetland | Noncontinuous islands of habitat can also provide movement pathways for wildlife, provided that these islands are of sufficient size and within reasonable travel distance of one another. |
| **Potential Corridor Value**<br>E Corridor greater than 200 meters wide connected to contiguous natural vegetation<br>S Corridor less than 200 meters wide connected to contiguous natural vegetation<br>B Isolated from other natural vegetation | A wildlife corridor is a potential movement pathway through areas of unsuitable habitat such as agricultural or developed land. The corridor can include natural upland vegetation as well as wetlands. When all parameters rate "low" for a given wetland, the site will then be evaluated to determine if it acts as a corridor for wildlife. If it does serve a corridor function, it will be further evaluated for width, assuming wider corridors are safer travel and refuge areas for a broader range of animals. |