Assessing the ecological condition of wetlands at the catchment scale

Hydrogeomorphic
Upscaling
Wetland assessment
Catchment
Chesapeake bay

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Rapid assessment methods for evaluating the functioning and biodiversity status of wetlands are mostly carried out at the scale of individual wetlands. There is an increasing need for evaluating the condition of wetlands at the watershed scale. We used statistical procedures to determine the relationships between data compiled in field-based assessments of individual wetlands and spatial data from remote sensing or other mapping efforts. The goal was to determine if available geographic data could be used to assess individual wetlands or the overall condition of wetlands in the watershed without having to do site-specific assessments based on field sampling.

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The movement of water through landscapes is most effectively managed at the level of individual catchments (hereafter referred to as watersheds), and wetlands are important components of watersheds because of their ability to retain, store, and transform nutrients, toxics, water, and sediments that originate from both diffuse and point sources (Whigham *et al.*, 1988; Johnston *et al.*, 1990; Dorioz & Ferhi, 1994; Weller *et al.*, 1996; Greiner & Hershner, 1998; Kuusemets & Mander, 1999; Crumpton, 2001; Reed & Carpenter, 2002). Effective watershed management thus requires knowledge about the abundance, location, and ecological condition of wetlands within the watershed.

Most assessments of wetland condition occur at the level of individual wetlands (Bartoldus, 1999), and few approaches are available to assess the condition of wetlands at the scale of an entire watershed. Wetlands have been considered as elements of watersheds for purposes of risk assessment (Lemly, 1997; Detenbeck *et al.*, 2000; Cormier *et al.*, 2000; Leibowitz *et al.*, 2000.), but this approach does not result in any characterization of wetland ecological condition. Geographic analysis of digital maps has been used to determine the importance of wetlands in reducing nutrient runoff from watersheds (e.g., Weller *et al.*, 1996) and to identify the location of significant wetlands in watersheds (Cedfeld *et al.*, 2000; Crumpton, 2001). While Weller and colleagues were successful in demonstrating the importance of riparian wetlands in reducing phosphorus in surface water, Cedfeld and colleagues had limited success in identifying potentially important wetlands in a watershed because of difficulties in correlating results of the geographic analysis with results from field-based assessments.

If wetland management and restoration are to be successful at the watershed scale, we need analytical methods to evaluate wetland condition, identify important wetlands in watersheds, and determine where wetland restoration efforts should be concentrated (O'Neill *et al.*, 1997). In this paper, we describe an approach that we used to evaluate the ecological condition of two types of wetlands individually and at the scale of an entire watershed. We describe two of the primary goals of the study. The first is to evaluate the condition of wetlands within the watershed by using a field-based assessment approach in combination with a probability-based method for selecting a spatially representative sample. The second goal is to determine if geographic analysis of mapped data can be used separately or in combination with the field-based assessment approach to characterize the condition of individual wetlands or the populations of wetlands in a watershed. In this paper we focus on issues related to selection of assessment sites, the range of assessment scores for both wetland classes at the scale of the entire watershed, and the suitability of using geographic data to conduct site assessments.

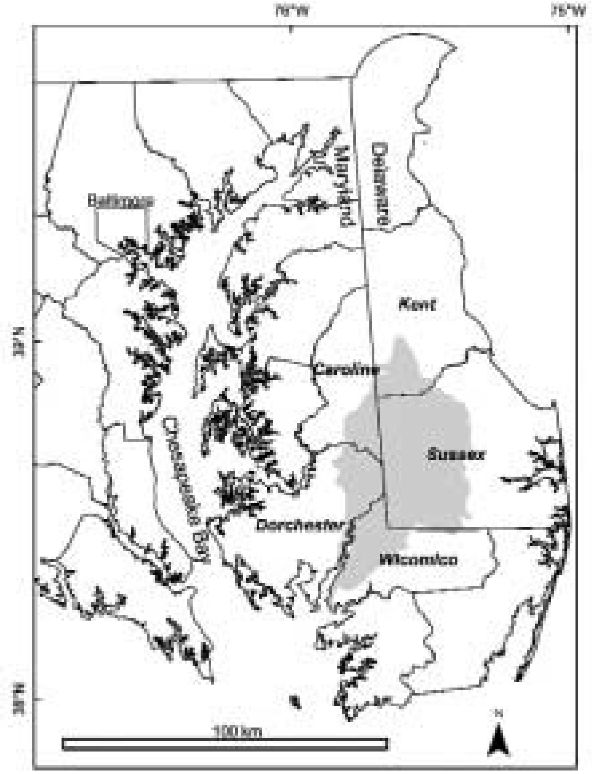


Figure 1. Map of the Chesapeake Bay region showing location of Nanticoke River watershed (shaded area).

Nanticoke River watershed and its wetlands

The Nanticoke River drains approximately 283,000 ha of three counties in Maryland and two counties in Delaware (Figure 1). Agriculture occurs on more than 40% of the watershed and less than 2% has been characterized as urban and suburban development (The Nature Conservancy, 1994). Forests cover approximately 45% of the watershed but many are intensively managed and harvested (Bohlen & Friday, 1997). Agriculture and forest management have been supported by extensive drainage and most nontidal wetland losses in the watershed have been the result of drainage by channelization (Tiner, 1985). Water quality problems are common within the watershed and are mostly related to surface and subsurface runoff from intensive agriculture (e.g., Phillips *et al.*, 1993; Jordan *et al.*, 1997). About 27% of the watershed contains both tidal and non-tidal wetlands (Tiner, 1985; The Nature Conservancy, 1994; Tiner & Burke, 1995). Non-tidal wetlands, the focus of this project, account for almost 85% of all wetland area and are mostly associated with streams (riverine wetlands), poorly drained depressions (depressional wetlands), and poorly drained sites that are relatively flat (flats wetlands).

The Nanticoke watershed is of interest to conservation organizations such as The Nature Convervancy because of the presence of almost 200 plant species and 70 animal species that have been listed as rare, threatened or endangered by the states of Maryland and Delaware (The Nature Conservancy, 1994).

Project Design

The project design integrated three components (Figure 2). First, the hydrogeomorphic (HGM) method for wetland assessment was used to assess the ecological conditions of individual wetlands. Second, the selection of sites for conducting HGM assessments was accomplished by applying methods developed by the U.S. Environmental Protection Agency Environmental Monitoring and Assessment Program (EMAP). Third, GIS procedures were used for two purposes. Selected spatial data were used to assist in the HGM assessments of individual wetlands and a separate effort focused on the potential use of spatial data to assess wetland condition from mapped information.

The hydrogeomorphic (HGM) method (Brinson *et al.*, 1995; Smith *et al.*, 1995; Brinson & Rheinhardt, 1996; Whigham *et al.*, 1999) is one of more than 40 approaches that have been developed in the U.S. to assess wetland conditions

(Bartoldus, 1999). In brief, the method produces Functional Capacity Index (FCI) scores for specific wetland functions. FCI scores range from 0.0 to 1.0 and they are calculated from equations that combine scores for individual variables. Individual variable scores also range from 0.0 to 1.0 and they are quantified by evaluating data collected at the assessment site. Variable scores are determined based on reference sites; the higher the score the more similar a variable is to a site with minimal disturbance. Once models are developed, the HGM procedure is intended to be a fairly rapid assessment, requiring 0.5 to 1.0 day of data collection. Details of the HGM procedures can be found in the references cited above and a list of HGM publications found on a web site maintained by the U.S. Army Corps of Engineers (*http://www.wes.army.mil/el/wetlands/wlpubs.html*).

HGM models specific to the Nanticoke watershed were developed in two phases. The *Developmental Phase* took approximately one year to complete. First, an interdisciplinary team of biologists, soil scientists, and wetland ecologists identified the dominant wetland classes and selected potential variables (Table 1) for use in the HGM models (Table 2). The selection of variables was based on existing knowledge about wetlands in the study area and information available from efforts to develop HGM models for similar classes of wetlands (e.g., Brinson *et al.*, 1995; Whigham *et al.*, 1999; Rheinhardt *et al.*, 2002). The interdisciplinary team then selected a series of Reference Wetlands (Figure 3) to represent the full range of altered and unaltered conditions. These wetlands were sampled using protocols based on the experiences of the interdisciplinary team and procedures published by other groups who had developed HGM models. For riverine wetlands, sampling procedures relied on methods developed by Whigham and colleagues (Whigham *et al.*, 1999) for riverine wetlands in the same region. For flat wetlands, sam-

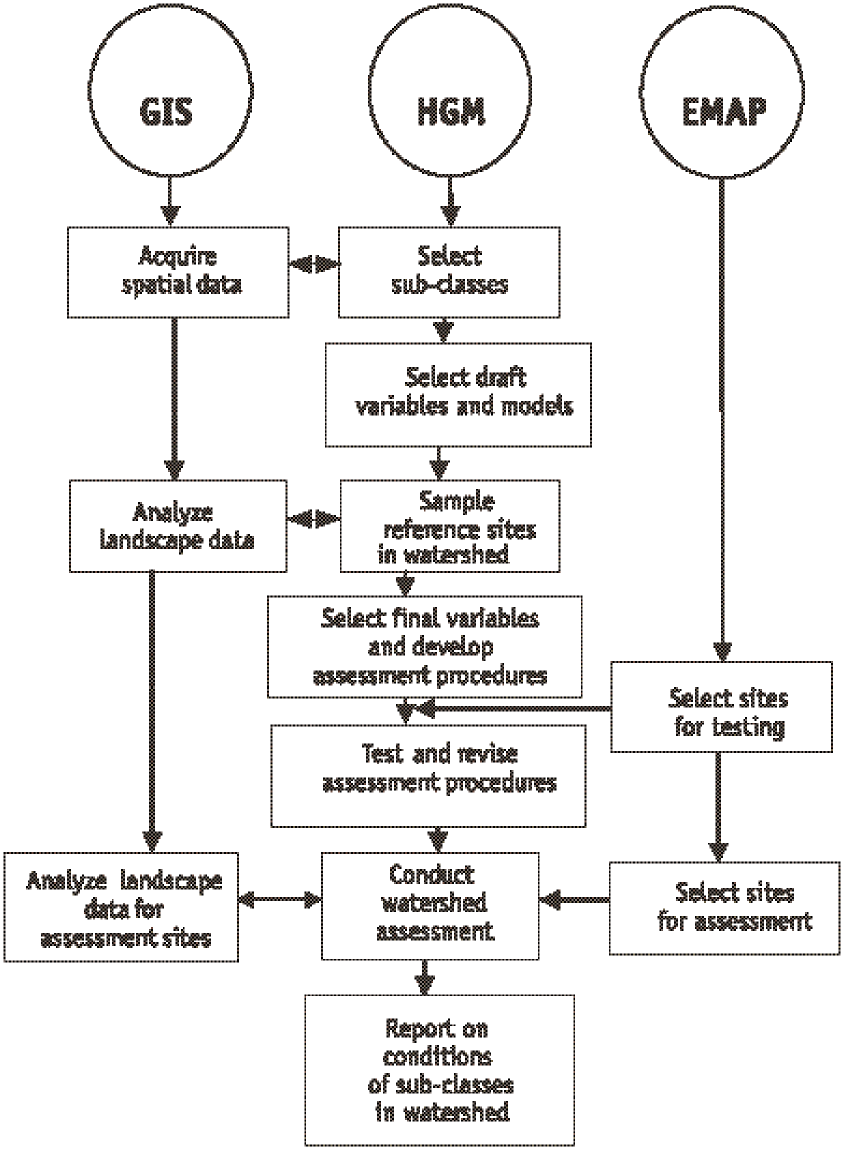


Figure 2. Box and arrow diagram showing the organizational structure of the project. The three elements of the project described in this paper included the development and application of field-based hydrogeomorphic (HGM) assessments, the use of mapped geographic data (GIS), and the sample design provided by the Environmental Monitoring and Assessment Program (EMAP).

Flats Class		Riverine Class	
V_{ANIMAL}	Number of vertebrate species	V_{CANOPY}	Percent tree canopy cover
V_{CANOPY}	Percent tree canopy cover	V_{CWD}	Density of coarse woody debris
$\mathbf{V}_{\mathbf{DISTURB}}$	**Evidence of vegetation disturbance**	V_{DITCH}	Presence of ditches on floodplain
$\mathbf{V}_{\mathbf{DRAIN}}$	**Percent of assessment area affected by drainage**	$\mathbf{V}_{\mathbf{FARBUFFER}}$	**Condition of buffer within 20-100 m**
$\mathbf{V}_{\mathbf{FILL}}$	**Presence of anthropogenic derived sediment**	$\mathbf{V}_{\mathbf{FLOODPLAIN}}$	**Floodplain condition**
$\mathbf{V}_{\mathbf{HERB}}$	**Species of herbs present**	$\mathbf{V}_{\mathbf{HERB}}$	**Species of herbs present**
V_{ANTHRO}	Number of anthropogenic features	$\mathbf{V}_{\mathbf{INVASIVE}}$	**Presence of invasive species**
V_{LANDUSE}	Land-use of adjacent upland habitats	V_{LANDUSE}	Land-use within 1 km of wetland
V_{LITTER}	Percent litter cover	V_{MICRO}	Presence of microtopographic features
$V_{\mathrm{LITTDEPTH}}$	Litter depth	$\mathbf{V}_{\mathbf{NEARBUFFER}}$	**Condition of vegetation buffer within 0-20 m**
V_{LOG}	Density of downed logs	V_{ROOT}	Root abundance
$\mathbf{V}_{\mathbf{MICRO}}$	**Presence of microtopographic features**	$\mathbf{V}_{\mathbf{SAPLING}}$	**Sapling species composition**
$\mathbf{V}_{\mathbf{RUBUS}}$	**Presence of *Rubus* sp.**	V_{SEEDLING}	Seedling density
V_{SAPLING}	Sapling density	$\mathbf{V}_{\mathbf{SHRUB}}$	**Shrub density**
$\mathbf{V}_{\mathbf{SHRUB}}$	**Shrub density**	V_{STRATA}	Number of vegetation strata
$\mathbf{V}_{\mathbf{SNAG}}$	**Density of standing of standing dead trees**	$\mathbf{V}_{\mathbf{STREAMIN}}$	**Stream condition inside assessment area**
V_{STRATA}	Number of vegetation strata	$\mathbf{V}_{\mathbf{STREAMOUT}}$	**Stream condition outside assessment area**
$\mathbf{V}_{\mathbf{TREE}}$	**Tree species composition**	$\mathbf{V}_{\mathbf{TBA}}$	**Basal area of trees**
$\mathbf{V}_{\mathbf{TBA}}$	**Basal area of trees**	$\mathbf{V}_{\mathbf{TDEN}}$	**Tree density**
$\mathbf{V}_{\mathbf{TDEN}}$	**Tree density**	$\mathbf{V}_{\mathbf{TREE}}$	**Tree species composition**
V_{TREESEED}	Number of tree seedling species	V_{TREESEED}	Number of tree seedling species
V_{VINE}	Number of vine species	$\mathbf{V}_{\mathbf{VINE}}$	**Number of vine species**

Table 1. Variables considered for inclusion in HGM models for riverine and flats classes in the Nanticoke River watershed. Variables that were chosen for use in the models shown in Table 2 are shown in bold.

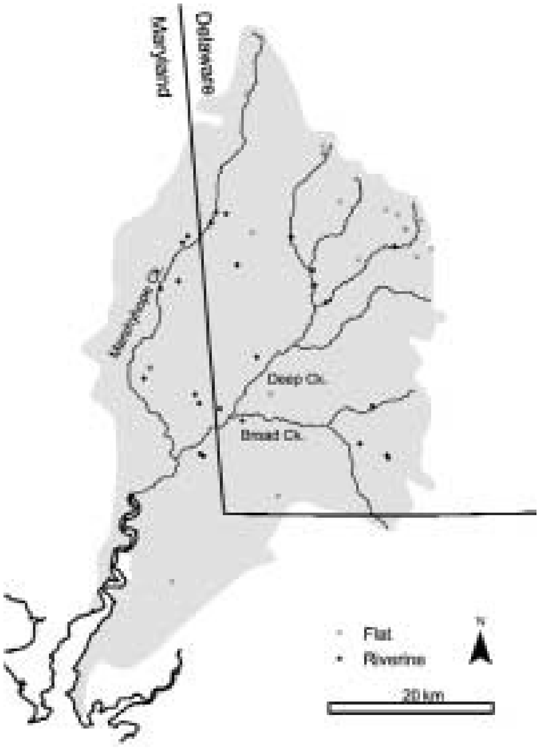


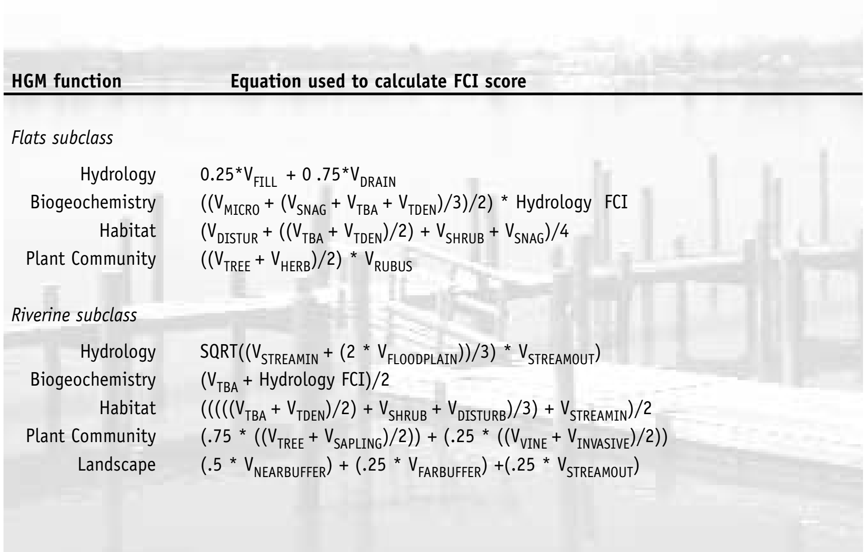
Figure 3. Location of Reference Wetlands within Nanticoke River watershed for riverine and flats subclasses.

pling procedures were based mostly on methods developed by Rheinhardt *et al.* (2002) for similar wetlands along the Atlantic and Gulf of Mexico Coastal Plains.

After Reference Wetland sampling was completed, the Principal Investigators as well as local, regional, and national experts in hydrology, soil sciences, ecology, and biology evaluated the data at workshops. The primary objective of the workshops was to select and scale variables for use in field assessments of wetlands in the second phase of the project, the *Assessment Phase*. Variables listed in bold in Table 1 are the variables that were selected for use in calculating FCI scores for the HGM models listed in Table 2. Table 2 shows how variables were combined to calculate Functional Capacity Scores (FCI) for five HGM models for the riverine wetland class and four HGM models for the flats wetland class.

The HGM models are chosen to represent broad categories of ecological processes in wetland ecosystems. The hydrology function is found in all HGM models because of the importance of hydrologic conditions in wetlands. The variables that are used to evaluate the hydrology function typically are chosen to represent physical features (e.g., stream condition, the presence of absence of human alterations to the stream, the presence of drainage features in the wetland) that would result in alterations of the site water balance. The biogeochemical function is representative of nutrient cycling processes that occur in wetlands. Because it is not possible to measure rates of nutrient cycling in short-term wetland assessments, the biogeochemistry models incorporates structural features of the wetland system that are important elements of nutrient cycling (e.g., the presence of mature vegetation that includes both living and dead biomass). The plant community and habitat functions are representative of the biodiversity and structural features of wetlands. The models typically include variables that quantify features of the vegetation including biomass and species composition. The habitat model usually represents features of the vegetation that provide habitat for animals. The landscape function is usually chosen to represent the condition of the landscape adjacent to the assessment site. This model is important because the characteristics of the adjacent landscape determine the degree to which the assessment site may be impacted by human activities.

As indicated, variables were scaled from 0.0 to 1.0 and HGM models were mathematically organized to calculate FCI scores, that ranged from 0.0 to 1.0. A score of 1.0 means that the function at a site is in a condition equivalent to a reference standard site (i.e., the least altered functionality). As the FCI score declines, the condition of the wetland function degrades until the function is absent at a score of 0.0. Brinson *et al.* (1995), Smith *et al.* (1995), Whigham *et al.* (1999) and Rheinhardt *et al.* (2002) provide more detailed description of procedures used to scale HGM variables and develop HGM models to calculate FCI scores.



HGM function	Equation used to calculate FCI score
Flats subclass	
Hydrology	$0.25*V_{FILL} + 0 .75*V_{DRAIN}$
Biogeochemistry	$((V_{MICRO} + (V_{SNAG} + V_{TBA} + V_{TDEN})/3)/2) * \text{Hydrology FCI}$
Habitat	$(V_{DISTUR} + ((V_{TBA} + V_{TDEN})/2) + V_{SHRUB} + V_{SNAG})/4$
Plant Community	$((V_{TREE} + V_{HERB})/2) * V_{RUBUS}$
Riverine subclass	
Hydrology	$SQRT((V_{STREAMIN} + (2 * V_{FLOODPLAIN}))/3) * V_{STREAMOUT})$
Biogeochemistry	$(V_{TBA} + \text{Hydrology FCI})/2$
Habitat	$(((((V_{TBA} + V_{TDEN})/2) + V_{SHRUB} + V_{DISTURB})/3) + V_{STREAMIN})/2$
Plant Community	$(.75 * ((V_{TREE} + V_{SAPLING})/2)) + (.25 * ((V_{VINE} + V_{INVASIVE})/2))$
Landscape	$(.5 * V_{NEARBUFFER}) + (.25 * V_{FARBUFFER}) +(.25 * V_{STREAMOUT})$

Table 2. HGM models used to calculate functional capacity index (FCI) scores for riverine and flats wetland classes. Variables are listed and described in Table 1.

During the *Assessment Phase* of the project, sites were chosen using protocols developed by the U.S. Environmental Protection Agency's Environmental Monitoring and Assessment Program (EMAP). One of the PIs (DEW) provided EMAP staff with the most recent digital wetland maps for the Nanticoke River watershed. A Generalized Random Tessellation Stratified (GRTS) design (Stevens and Olsen 1999, 2000) was used to draw the sample from the maps and generate potential sample sites identified by latitude and longitude. The basic concept of GRTS design is to construct a random spatial stratification using equal-sized tessellation cells, and then to select a point at random within each cell. A spatial address is constructed using the pattern of subdivision so that the result is a spatially well-distributed sample. The final set of assessment sites is well-dispersed over the accessible portion of the population (Stevens and Olsen, in review, 2002) and each point will have a known probability of being selected.

Potential sites were chosen for inclusion in the set of assessment sites only when it had been determined that they were actually wetlands of the targeted class (flat or river-

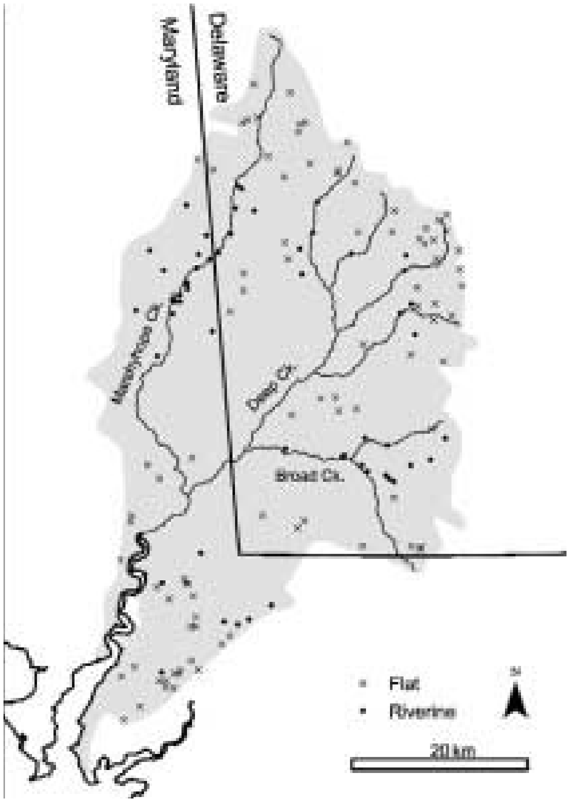


Figure 4. Location of assessment sites in the Nanticoke River watershed for riverine and flats subclasses.

ine) and permission for access had been obtained. Figure 4 shows the distribution of assessment sites for both classes of wetlands. The first 17 flats and 15 riverine sites that met our criteria and to which we were allowed access were used as sites for testing the final protocols and models. Following the field testing, final versions of the data sheets and variable scaling procedures were prepared for use in the *Assessment Phase*.

Field-assessments were conducted by teams under the supervision of one of the authors (ADJ). The field teams received training from two of the authors (DFW, ADJ) and they followed formal quality assurance and quality control procedures (The Nature Conservancy, 2000; Whigham *et al.*, 2000). Assessment teams consisted of individuals hired for the project and volunteers, mostly provided through contacts with The Nature Conservancy.

Data compiled during the assessment phase of the project were scanned from the field datasheets to create computer files using procedures developed by EMAP under the supervision of one of the authors (MEK). Electronic data files were checked with field data sheets and corrected.

Comparison of assessment data with remotely sensed spatial data

One of our objectives was to determine if it would be possible to use remotely acquired spatial data to produce site assessments with an acceptable degree of accuracy. We evaluated a variety of mapped spatial data (Table 3) for their potential to predict wetland conditions as assessed by HGM field-based assessments. In this paper, we focus on preliminary results using land cover data (Table 3) and metrics of stream disturbance status (natural, channelized, or artificial ditch; Tiner *et al.*, 2000, 2001). For each wetland, land cover proportions and lengths of excavated and natural stream channels were determined for radial distances of 100, 500 and 1000 meters from the sampling point provided by EMAP. Step-wise multiple regression analysis was used to determine the relationship between the independent variables and the measured HGM variables (Table 1) and FCI scores (Table 2) for riverine and flats subclasses.

Results

Selection of assessment sites

Digital wetland maps were used to evaluate up to 1050 potential assessment sites from a list of 1,992 random points provided by EMAP. Based on an interpretation of digital maps of the 1050 potential sites, we selected a subset of 455 sites to which we sought access. Sites were examined

Table 3. Spatial data sets with sources or contacts.

Data set	Source
Orthophotography for Maryland	http://www.dnr.state.md.us/MSGIC/techtool/samples/metadata/doqq.htm
Orthophotography for Delaware	http://bluehen.ags.udel.edu/spatlab/doqs/_doq.html
EPA EMAP land cover	U.S. EPA., 1994
NLCD land cover	Vogelman *et al.*, 2001SSURAGO NRCS county soils data
	http://www.ftw.nrcs.usda.gov/ssur_data.html
	ftp://ftp.ftw.nrcs.usda.gov/pub/ssurgo/online98/data/
	http://bluehen.ags.udel.edu/spatlab/soils/
EPA Reach File 3 stream maps	http://www.epa.gov/r02earth/gis/atlas/rf3_t.htm
US Census TIGER road files	http://www.census.gov/geo/www/tiger/index.html
Stream maps classified by disturbance	Tiner *et al.*, 2000; Ralph Tiner (unpublished data)

in the order provided by EMAP. The coding associated with existing digital wetland maps could not be used to determine the hydrogeomorphic classification of individual wetlands. Subsequently, each potential wetland assessment site identified by EMAP had to be visited to evaluate the following criteria, which all had to be met in order for a site to be selected:

- Point was in the respective testing or assessment group specified by EMAP
- Point was in the Nanticoke River watershed
- Point was a wetland
- Point was in a non-tidal wetland
- Point was in a wetland in the flats or riverine HGM subclass
- Point was not in a farmed wetland
- Landowner permission had been granted to conduct the assessment

One of the most time consuming aspects of this part of the project was the process of obtaining permission from private landowners to visit potential assessment sites. First, landowners were identified through the use of public ownership documents. We then examined the lists of owners and identified individuals who would be willing to attempt to communicate with the landowner by calling or scheduling a meeting. We received no response from 38% of the contacts and 17% of the contacts denied access. We gained permission to sample 201 sites. Once contact had been made with landowners, we obtained access to all of the publicly owned sites and 67% of the privately owned sites. Contacting landowners, follow-up contacts with landowners, and examination of the sites to determine if they would be included in the study took approximately 168 person-days (1,200 hours). For comparison, two other major components of the study took less time. Site selection and forming and training field crews took 97 person-days (776 hours). Sampling assessment sites required 145 person days (1160 hours).

Assessment sites for both wetland classes were distributed across the entire watershed (Figure 4) but there was a bias toward public sites in the riverine subclass (D. Stevens, personal communication). The bias was most likely the result of a lower level of accessibility to privately owned riverine sites. EMAP staff will be conducting further tests to determine if adjustments need to be made in the final interpretation of the assessment data.

Range of variability of FCI scores

A goal of any HGM protocol is to select variables that quantitatively express the range of natural variation

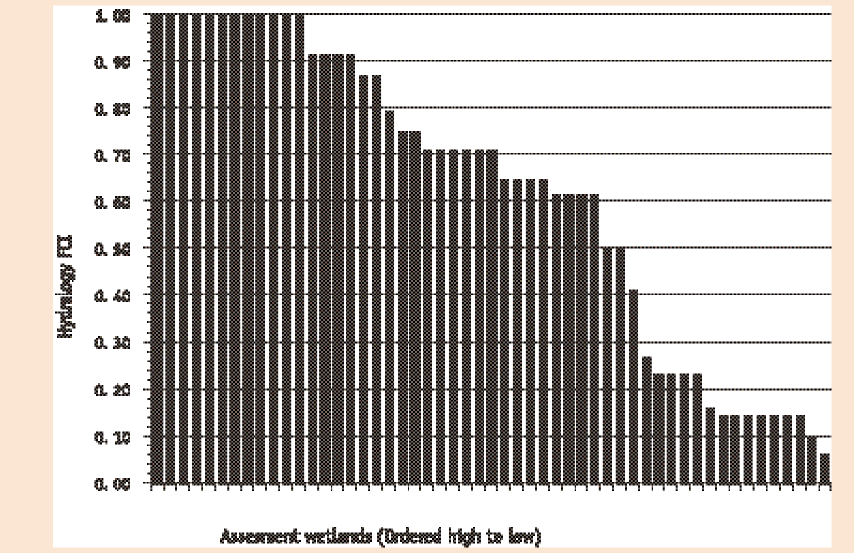


Figure 5. Distribution of FCI scores for the hydrology function for the riverine subclass sampled in the Nanticoke River watershed. Sites are aligned so that FCI scores vary from high (left) to low (right). The hydrology model for the subclass is provided in Table 2.

across the set of reference sites (Brinson & Rheinhardt, 1996; Wakeley & Smith, 2001). In this project, approximately half of the variables that were initially chosen were eventually used in the HGM models (Tables 1 and 2). FCI scores shown in Figure 5 are typical of scores for all of the models in both hydrogeomorphic subclasses. FCI scores varied from 1.0 (reference standard conditions with no detectable impacts) to 0.1 (function present but at a very low level). These results suggest that the majority of the wetlands in the two classes have been degraded from reference standard conditions. Only a small percentage of un-impacted wetlands remain (e.g., sites with FCI scores > 0.90 for all functions), suggesting that there is a high potential for restoration of wetland functions within the watershed. Further analysis of the FCI scores and variable scores will be conducted to determine which variables were most responsible for lower FCI scores at impacted sites and which wetland features need to be considered in the development of restoration goals.

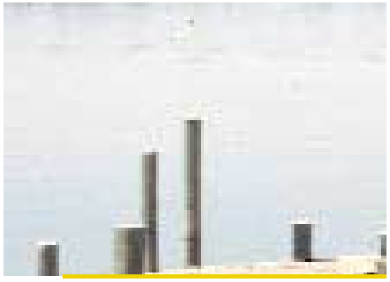
In addition, we will be conducting further analyses to evaluate how wetland condition varies spatially throughout the watershed. Locations of streams (Marshyhope Creek, Deep Creek, Broad Creek) that drain three subwatersheds are shown on Figure 3. Table 4 shows mean FCI scores for the five riverine functions for Marshyhope Creek, Deep Creek and Broad Creek subwatersheds. Mean FCI scores were significantly lower for four of the functions (hydrology, biogeochemistry, habitat, and landscape) in the Deep Creek subwatershed (Table 4). Spatial information of this type can potentially be used to identify problem areas within the watershed as well as targeting areas within the watershed for restoration. Analysis of spatial information will also allow us to further evaluate the adequacy of the site selection process. The ratio of public to privately owned assessment sites was lower in the Deep Creek subwatershed, potentially resulting in a bias toward lower quality private sites with lower FCI scores.

Suitability of using geographic data to assess individual wetland sites

Use of the mapped digital data to predict HGM functions produced variable results. For the flats subclass, there were significant stepwise multiple regressions for each of the HGM functions (data not shown) and the regressions

Table 4. Mean FCI scores for five HGM functions for the riverine subclass for the three large subwatersheds in the Nanticoke River system. The number of riverine assessment sites in each subwatersheds were: Marshyhope = 24, Deep Creek = 10, and Broad Creek = 13. For each function, means that differ for the subwatersheds have different superscripts.

Subwatershed	Hydrology	Biogeochemistry	PlantCommunity	Habitat	Landscape
Marshyhope Creek	.701^a	.772^a	.947^a	.859^a	.788^a
Deep Creek	.236^b	.495^b	.807^a	.431^b	.584^b
Broad Creek	.683^a	.759^a	.809^a	.727^a	.770^a



HGM Function	No. of Variables	Variables	R2
Biogeochemistry	3	-ex100 + nat1000 – DEV100	0.51
Habitat	2	-ex100 + nat1000	0.42
Hydrology	5	-ex100 + nat1000 +FOREST100 +FOREST1000 –FORDEC100	0.70
Landscape	6	-ex100 –ex1000 +nat1000 –CROP100 –DEV1000 +FOREVER1000	0.70
Plant Community	2	-ex500 –DEV100	0.31

Variable names are:

ex100	Length of excavated stream channel (ditches and channelized) in 100 m circle around the sample point.
ex500	Length of excavated stream channel (ditches and channelized) in 500 m circle around the sample point.
ex1000	Length of excavated stream channel (ditches and channelized) in 1000 m circle around the sample point.
nat1000	Length of natural stream channel in 1000 m circle around sample point.
DEV100	Proportion of total developed land (low + high intensity development in 100 m circle around the sample point).
DEV1000	Proportion of total developed land (low + high intensity development in 1000 m circle around the sample point).
FOREST100	Total amount of forest within 100 m of the sample point.
FOREST1000	Total amount of forest within 1000 m of the sample point.
FORDEC100	Total amount of deciduous forest within 100 m of the sample point.
FOREVER1000	Total amount of evergreen forest within 1000 m of the sample point.
CROP100	Total amount of crop within 100 m of the sample point.

Table 5. Stepwise multiple regression results for riverine HGM functions (dependent variables) and landscape cover data (independent variables). All models shown in the Table were significant at $p < 0.0001$. The sign (+/-) in front indicates whether the variable is positively or negatively related to the HGM function.

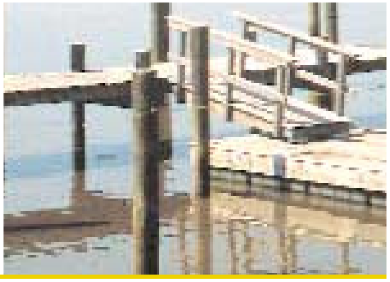
explained between 17 and 44% of the variability. Multiple regressions were more successful in predicting FCI scores for the riverine class than the flats class (Table 5). All of the multiple regressions in Table 5 were significant at $p < 0.0001$ and they accounted for between 31% and 70% of the variation in the FCI scores. One variable (length of excavated stream channel within 100 or 500 meters of the site where the assessment was conducted) had a negative relationship to the FCI scores for all models. This result clearly suggests that channelization results in effective drainage of sites and has a negative impact on wetland function as measured by HGM scores. Land-use categories were also important. Increasing amounts of developed land and crop land near the assessment site had a negative influence on FCI scores and the greater the amount of forested land near the site, the higher the FCI score. These results suggest that individual wetlands have important linkages to adjacent land uses and that degradation of areas adjacent to wetlands results in negative impacts of ecological functions in the wetlands.

Discussion

As described earlier, the project was divided into a *Development Phase* and an *Assessment Phase*, with each phase taking approximately one year to complete. We believe that the two phases are equally important to overall success of a project. The *Development Phase* is essential if site-specific assessments are to be conducted in the second phase. The selection and sampling of reference sites and the selection and scaling of variables are essential elements of any field-based HGM assessment. The necessity of selecting reference sites that represent the range of condition for a given wetland class has been described by Brinson and Rheinhardt (1996). Data from reference sites are essential in the selection of HGM variables that can be used to quantify differences between assessment sites. Both selection and sampling of sites during the *Development Phase* require adequate training of field teams (Whigham *et al.* 1999), implementation of procedures to assure accuracy of data gathering and reporting, and development of standard methods for collecting field data (Wakeley & Smith, 2001). The reader can refer to several HGM guidebooks to learn more about the procedures that have been suggested for selecting HGM variables and for selecting and sampling reference wetland sites using HGM procedures (Adamus & Field, 2001; Hauer *et al.*, 2002; Rheinhardt *et al.*, 2002). The *Development Phase* is time consuming and costly; thus it is often cited as one reason why the HGM approach to wetland assessment has not been used more widely. While it is unfortunate that there are no faster ways to complete the

Development Phase, the results are worth the effort because field-assessments can be done in less than one day when field-tested protocols have been developed. In addition, once the procedures have been developed and verified, methods can be applied in many locations. Thus, the product of the investment in the *Development Phase* has applications beyond the initial assessment and the potential for continued use in a monitoring and assessment program that supports decision making.

While we have not reached any final conclusions regarding the ecological condition of wetlands in the watershed, the approach that we have used clearly suggests that there is a wide range of conditions in the watershed and that most wetlands in the watershed have been degraded at some level. Preliminary data further suggest that wetland condition differs among wetlands in different subwatersheds of the Nanticoke basin. Finally, the use of spatial geographic data can be important in assessing wetland condition at the scale of entire watersheds for several reasons. First, spatial data can be effectively used to identify and conduct preliminary interpretations of potential assessment sites. Second, spatial data at appropriate levels of resolution can provide input variables to HGM models. Third, mapped spatial data has the potential to be used as a surrogate for field-based assessments when properly calibrated with field assessments. This study will provide useful information for designing future watershed-based assessments that employ a combination of field-based sampling and assessment based on spatial data.



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Abstract

Ecological processes in wetlands result in important societal values, whether one is considering an individual wetland or all of the wetlands within a catchment (watershed). In addition to providing habitats for numerous species, wetlands typically intercept surface and groundwater and improve water quality by removing nutrients, contaminants, and sediments. A variety of approaches have been developed to assess the ecological condition of individual wetlands, but less progress has been made in developing approaches to evaluating the ecological condition of wetlands at the scale of entire watersheds. In this paper we describe an approach to assessing the ecological condition of two classes of wetlands in the Nanticoke River watershed, a subwatershed in the Chesapeake Bay drainage of North America. We used the hydrogeomorphic (HGM) approach to assess the ecological condition of wetlands along nontidal streams (riverine class) and wetlands associated with poorly drained soils on interfluves (flats class). Sampling protocols developed by the U.S. Environmental Protection Agency's Environmental Assessment and Monitoring Program were used to select a spatially unbiased sample of sites for field-based assessments. Statistical procedures were used to determine the relationships between data compiled in the field-based assessments and spatial data from remote sensing or other mapping efforts. We wanted to determine if available geographic data could be used to assess individual wetlands or the overall condition of wetlands in the watershed without having to do site-specific assessments based on field sampling. The HGM approach to wetlands assessment appears to be a useful methodology when it is applied in combination with a spatially unbiased method for selecting sampling sites. There were significant relationships between results of HGM assessments and mapped geographic data, but the strengths of the relationships were variable, demonstrating potential limitations to the use of mapped geographic data to assess wetlands condition in relatively flat landscapes such as those present in the Nanticoke River watershed. Future improvements in the resolution of GIS data, however, should result in better correlations between GIS-based assessments and field-based assessments of wetlands.

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