EXPLORING THE UTILITY OF HIGH RESOLUTION IMAGERY FOR DETERMIMING WETLAND SIGNATURES

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Table of Contents

List of Tables

List of Figures

1. Introduction

Wetland habitats are characterized by periodic inundation and saturation by water creating anaerobic conditions that generate hydric soils and support hydrophytic vegetation. Wetland habitats provide important ecological functions including breeding grounds for fish, other wildlife, water purification, reduction in flooding, species diversity, recreation, food production, aesthetic value, and transformation of nutrients (Tiner, 1999). The multiple benefits of wetlands make them an important resource to monitor.

A literature review suggests a combination of geospatial variables and methods should be tested for appropriateness in wetland delineation within local settings. Advancements in geospatial data technology and ease of accessing new, higher resolution geospatial data make study at local levels easier and more feasible (Barrette et al, 2000).

The purpose of the current study is to evaluate new sources of geospatial data as potential variables to improve wetland identification and delineation. The study includes forested wetlands as a dependent variable given that they are among the most difficult wetland types to delineate (Kudray & Gale, 2000; Sader, Ahl, & Liou, 1995; Stolt & Baker, 1995) and account for 51% of all freshwater wetland types in the US (Dahl, 2006). High resolution multispectral digital imagery, topographic data, and soils information are used to derive and evaluate independent variables. Regression analysis was used to analyze the data.

2. Historical Perspectives

Surveys generated by the Land Ordinance Act of 1785 are some of the earliest sources of information about the historical location and distribution of wetlands. These and earlier surveys have been used to estimate the acreage of wetlands present during the early history of settlement in the US. The westward migration of settlers along with agriculture and development were the most prominent causes of early wetland loss in the United States. The industrial revolution of the early 1900's increased the anthropogenic stresses on wetland resources (Dahl, 1990). Estimates indicate that of the 221 million acres of wetlands in the conterminous US in existence prior to European settlement, only 103 million acres remained by the mid 1980's, a loss of 53% (Dahl & Johnson, 1991).

The Fish and Wildlife Service (FWS) first surveyed wetlands on a national scale in 1954. The initial survey was not comprehensive and focused only on wetlands important for waterfowl. The survey brought about public awareness of wetland conservation for waterfowl habitats. Increased understanding and knowledge of wetlands as a natural resource led to the National Wetlands Inventory (NWI) Project. The Emergency Wetlands Resources Act of 1986 made the NWI an ongoing effort to produce hard copy and digital maps for the conterminous US for better natural resource management. An amendment of this act in 1989 mandated an estimate of the acres of wetland habitats present in each state in the 1780's, the estimated total acres in each state in the 1980's, and the percentage of wetland losses (Wilen & Bates, 1995).

Conventional aerial-photographic interpretation was used to conduct a statistical survey of the US wetlands in the 1950's and the 1970's. Comparison between these estimates indicates a net loss of 9 million acres. Eighty seven percent of wetland losses were due to agricultural conversion. The other wetland losses were attributed to development (Wilen & Bates, 1995). Between mid-1970s and mid-1980s an estimated 2.6 million acres of wetlands were lost in the conterminous United States, 98% of which were freshwater wetlands. Indiana had lost an estimated 87% of its wetlands over the same time period (Dahl & Johnson, 1991).

The FWS reports there were 43.6 million Ha of wetlands in the conterminous United States in 2004. The vast majority of these wetlands (95%) are freshwater wetland types. Just over half of the freshwater wetlands (51%) are forested. The rest of the freshwater wetlands consist of emergent wetlands (25.5%) and ponds (6.5%) (Dahl, 2006).

Historically, wetlands were thought of as swamps that bred diseases and hindered more productive uses of the land. Settlers, developers, and governments approved mass destruction of wetlands (USGS, 1996). The value of wetland resources have since begun to be recognized (Dahl, 1990). New views of the relationship between human society and nature are emerging in the concept of ecosystem services. Ecosystem services are the services or benefits humans gain from ecosystems (Alcamo et al, 2005). The economic, social and ecological values provided by wetlands make it necessary to preserve, enhance, and restore this important habitat component. To do so means knowing where wetlands have existed, currently exist, and should exist.

3. Monitoring and Assessing Wetlands

Wetland habitats are increasingly threatened by a variety of anthropogenic processes including water pollution, destruction, degradation, exotic species invasion, and land use modifications (Dudgeon et al, 2005). These anthropogenic stresses create the need for more current wetland information and for more efficient methods to monitor temporal changes in wetland resources. Methods used to monitor wetland changes over time should take advantage of recent technological advancements.

3.1 National Wetlands Inventory

The NWI was created in 1974 by the U.S. Fish and Wildlife Service (USFWS) to map the wetlands of the United States (USFWS, 2005). From 1975 to the early 1980's NWI mapping relied on visual interpretation of aerial photography using 1:80,000 black and white panchromatic imagery and supporting ancillary data. Early in the 1980's, stereoscopic photo interpretation of 1:58,000-scale color-infrared photography combined with field verification became the standard for wetland delineation used by the NWI. This method produced the NWI maps currently used as reference for resource management.

The goals of the NWI for the 21st century include digitizing and updating wetland maps, many of which are now more than 20 years old (USFWS, 2005). New digital geospatial data resources, including high resolution imagery, topographic data, and GIS layers, have the potential to contribute to the process of updating and improving wetland mapping methods. For example, multispectral, multi-temporal imagery is now collected at resolutions ranging from less than 1 meter to 4 meters from commercial satellites such as Ikonos and Quickbird as well as the new GeoEye-1 sensor launched in September 2008 with a resolution of .41 to 1.65 meters. These advances in sensor technology make it more practical to acquire high resolution data and imagery for wetland resource management.

Recent internal evaluations of the NWI mapping methodology propose monitoring be done at a state, regional, and local level and the ten year monitoring and reporting interval of the NWI be shortened to five years, a major undertaking. The USFWS suggests more aggressive conservation and outreach programs can be designed to protect the nation's natural resources as newer technology becomes more readily available (USFWS, 2005).

3.2 Evaluating the NWI

Several studies have evaluated the accuracy of existing NWI maps. Tiner (1990), citing a study by Swartwout et al (1981), reported wetlands were distinguished from uplands with 95% accuracy by the NWI in Massachusetts. The high accuracy was attributed to a labor intensive multi-stage draft review process. Wetland map production began by reviewing aerial photographs to determine which sites were problematic and needed field verification of land cover types. Data were collected on site to answer questions related to photo interpretation. Further evaluation of stereoscopic photography correlated the ancillary data to photo interpretation with more site visits if necessary. After the large scale drafts were prepared, state and local agencies reviewed draft maps and conducted even more site visits for verification where needed to produce a final edited map.

Stolt and Baker (1995) evaluated NWI mapping accuracy in the southern Blue Ridge of Virginia. This study used field verification of hydric soils, identification of hydrophytic vegetation, and hydrology to determine how well jurisdictional wetlands were delineated on NWI maps given that this was not an intended use of the NWI maps. Stolt and Baker (1995) mention the NWI relies on soil survey data and reports for locating hydric soils instead of using more labor intensive field truthing (as cited in Dahl, 1993). Wetlands missed by the NWI occurred primarily in woodland areas covered by tree canopy. Some wetlands were missed due to the scale of the imagery used and would be smaller than the width of the pencil line on NWI maps.

Kudray and Gale (2000) evaluated the accuracy of NWI maps of the Hiawatha National Forest in the Great Lakes Region. Field data from an extensive ecological classification and inventory (ECI) program conducted during 1994 was marked on color infrared photographs of the study area then compared to NWI maps of the same area. The study found the NWI identified nonforested wetlands, jurisdictional wetlands and uplands with the highest accuracy. The NWI was least accurate when identifying forested wetlands, especially those occurring on the AuGres soil series. This soil series typically occurs as a poorly drained upland soil as well as in combination with other wetland soils found within the region. Better mapping of hydric-nonhydric soil complexes by area soil surveys could increase the accuracy of NWI maps. Citing other studies, Kudray and Gale (2000) mention the many uses and the wide availability of the maps generated by the NWI. These uses have led to controversy and interest in the NWI map accuracy. One difficulty with estimating NWI accuracy is the unintended use of the NWI maps for regulatory purposes. Kudray and Gale (2000) suggest a better question to ask is the accuracy of the NWI within its technological limits.

3.3 Wetland Models Using GIS and Remote Sensing

Researchers have tested GIS models designed for wetland delineation using remotely sensed data. Sader et al (1995) used Landsat Thematic Mapper (TM) with 30 meter resolution, panchromatic and color infrared photography, NWI maps, soils maps, DEM's and USGS topographic maps to develop a rule-based model for land use classification that identified wetlands, urban areas, open areas and uplands at two sites in Maine. Four classification methods were compared to a manual approach using visual photo interpretation: 1) unsupervised classification (to establish a baseline), 2) a tasseled-cap transformation, 3) a hybrid method combining unsupervised cluster statistics with supervised forested wetland training sites, and 4) a GIS rule-based model. Results indicated hydric soils maps, NWI maps and slope were the most important variables in the rule-based GIS model for their study area. The study concluded that a combination of methods was most promising for further exploration of remotely sensed wetland delineation.

A study by Lunetta and Balogh (1999) using Landsat 5 TM imagery found that multi-temporal imagery improved classification accuracy by capturing the dynamic nature of wetland habitats, especially those wetlands characterized by seasonal inundation. The study area was limited to the Millington 7.5 minute quadrangle, which bisects the

Maryland – Delaware state border. The goal of this study was to improve the accuracy of mapping potential jurisdictional wetlands. The imagery used coincided with what was determined by meteorological records to be the seasonally wet period. This study suggested multi-temporal imagery could supplement the NWI maps that currently exist.

Ramsey and Laine (1997) concluded that spatial scale was the most important factor in pre- and post-hurricane classifications of water, emergent vegetation, floating vegetation and mud flats in complex coastal wetlands. The area studied was in the southern coastal region of Louisiana impacted by Hurricane Andrew in 1992. High resolution color infrared aerial photographic transparencies covering a portion of the study area were also evaluated. Identification of emergent and floating vegetation was improved by using multi-temporal TM imagery. Using higher resolution imagery made clearer the problems associated with lower resolution TM imagery, especially misclassification due to mixed pixels. Change detection among similar wetland vegetation types was more difficult with lower resolution TM imagery (Jensen et al, 1987).

McCauley and Jenkins (2005) evaluated the use of hydric soils maps along with digital raster graphics (DRG), digital elevation models (DEM) and digital orthophotography quarter quadrangles (DOQ) to devise a model of former wetlands in Champaign County, Illinois. Digital versions of topographic maps from 1960 to 1975 were used along with digital hydric soils maps obtained from the Natural Resource Conservation Service (NRCS) Soil Survey Geographic Database (SSURGO). Former depressional wetlands were assumed to have occurred where depressions depicted on the topographic maps intersected the hydric soils identified on the SSURGO maps. Field verification of the DOQ model revealed low accuracy results attributed to the difficulty of manual interpretation. Former and current depressional wetlands were more accurately predicted when DRG or DEM models were applied. The study also evaluated a model combining the DRG and DEM model. The DRG model estimated a loss of 846 Ha of depressional wetlands. The DEM model estimated a loss of 1777 Ha and the combined DEM/DRG model estimated a loss of 2504 Ha of depressional wetlands. These results suggest the intersection of depressions and hydric soils as a possible parameter to include in a wetland model.

Li and Chen (2005) developed a rule-based method for mapping Canada's wetlands using Landsat-7/ETM+, two-season Radarsat-l/SAR images and DEM data. The ground survey methods used by the NWI for national mapping and regular updating of the NWI maps are impractical in Canada where a large number of wetlands are found in remote areas. Tree canopies also limit optical remote sensing for some of these wetlands. Synthetic aperture radar (SAR) sensors can penetrate vegetative canopies elucidating hydrology and ground conditions invisible to optical remote sensing. Li and Chen, (2005) tested their model at three sites in eastern Canada. While the authors concluded that the integration of optical, radar and DEM data with knowledge-based decision rules was a promising technique, they also mention more study is needed in other eco-regions due to variability and complexity among wetlands from one ecoregion to another.

3.4 Soils and Terrain Data

Researchers have shown that soil data are important in wetland delineation. Soil survey reports and data from the USDA Soil Conservation Service can be an inexpensive way to develop soil attribute maps within desired boundaries. However, soils maps can imply existence of greater uniformity within soil types than actually exists and, as with the NWI, uses can go beyond their original intent (Moore et al, 1993). Moore et al (1993) hypothesized terrain features could be associated with systematic variations in soil development and be used to predict soil attributes including soil moisture. Primary topographic attributes, including slope, aspect, flow path length, profile curvature and plan curvature were calculated directly from the DEM. The study area was located in northeastern Colorado. This study found the terrain attributes most closely correlated with soil attributes were slope and wetness index. The wetness index used was $w = \left(\frac{A}{\tan\beta}\right)$ where A was the specific catchment's area and $\tan\beta$ was the slope angle. The attributes calculated using DEM data augmented the soil survey data.

Günter, Siebert, and Uhlenbrool (2004) evaluated several terrain indices to predict patterns of saturation in the Black Forest Mountains of southwestern Germany. Field surveys were used to locate and map saturated areas for comparison to saturated areas predicted by terrain indices. The terrain indices used included: curvature, concavity/convexity, a radiation index to measure spatial variance of evapotranspiration, the upslope contributing watershed area to measure the area that could contribute to lateral flow pathways, a topography-based wetness index and a soil-topographic index. Results indicated the upslope contributing area index was the most predictive of saturation for the mountainous terrain. The degree of success was dependant on the algorithm used for calculating flow accumulation using a grid based elevation model.

3.5 New Technology

The NWI strategy for the 21st century acknowledges that manual interpretation of aerial photography used to develop the first generation of maps did not take advantage of advances in geospatial data acquisition. Innovative technologies with shorter processing times are needed by resource managers to continually monitor the status and trends of wetland loss or gain (USFWS, 2002).

While previous studies have shown promise in wetland delineation with moderate resolution remote sensing imagery (e.g., Landsat TM and ETM+), the spatial resolution of these data prohibit their application to more precise wetland delineation required at regional or local scales (Li & Chen, 2005). Small or linear wetlands can be missed by remotely sensed data with lower spatial resolution. In addition, wetlands with cover types similar to surrounding uplands are difficult to detect with remote sensing, as are drier-end wetlands and cropped wetlands (Kudray & Gale, 2000).

New geospatial data resources have emerged in recent years that make it an opportune time to revisit the wetland delineation process. Digital orthophotography lacks distortions from scale, tilt and relief found in traditional photography. Fewer distortions make wetland delineation easier and faster when using digital orthophotography than when using traditional aerial photography (Barrette et al, 2000). Improvements in computer technology and associated software give remotely sensed methods the potential to be less labor intensive, quicker and cheaper for wetland mapping within local and regional contexts.

4. Data and Methods

The current study concentrates on discerning uplands from wetlands. The dependent variable was whether or not a grid cell in the analysis was classified as a wetland. This section describes the study area and independent variables examined. The independent variables examined were NDVI, wetness index, degree slope, and profile curvature, hydric and non-hydric soils.

4.1 Study Area

The study region analyzed in the current research is the sub watershed Little Eagle Branch-Woodruff Branch (Woodruff Branch) and lies within the Eagle Creek Watershed located in Central Indiana, approximately 16 Km northwest of Indianapolis. Figure 1 shows the location of the study area.

The Eagle Creek Watershed lies within the Central Till Plain Region. The watershed contains some of the most rapidly developing areas in the state. Pressure from development in this area threatens current wetlands and their ecosystem services (http://www.cees.iupui.edu/). Eagle Creek Watershed as well as the Woodruff Branch sub-watershed encompasses portions of Boone and Hamilton counties. (Figure 1).

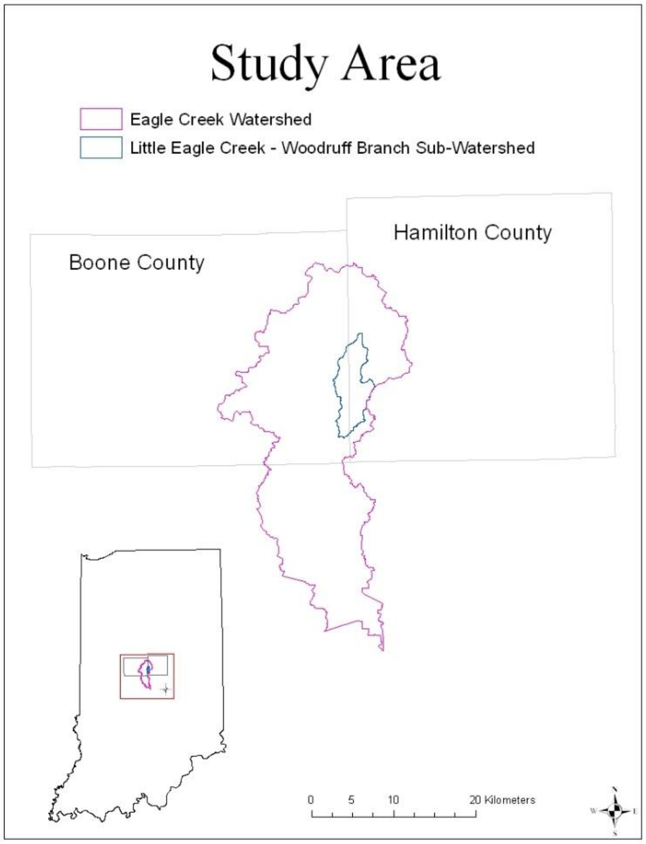

Figure 1: Study Area Location

The NWI has identified 121 Ha of wetlands within Woodruff Branch. Of this 16 Ha (13%) are considered lakes, freshwater ponds, and riverine; 13 Ha (11%) are classified as freshwater emergent wetlands and scrub brush wetlands with the remaining 92 Ha (76%) classified as freshwater forested wetlands.

4.2 Sampling

A polygon grid was created and the edges edited to follow the boundary of the study area. The polygon grid was then converted to a point file using the grid cell centroids. Each cell centroid represented an area of $15m^2$ (.0015 Ha). All layers used for analysis included the entire Woodruff Branch sub-watershed boundary with a buffer extending 100m beyond the boundary to ensure complete coverage by the grid layer. Individual environmental variables were summarized within grid cells to create the final data base used in the analysis.

Grid cells representing roads, developed areas and NWI features designated as ponds were excluded from the analysis. The remaining 141,496 grid cells (212.244 Ha) were used for analysis.

4.3 Variables

The wetlands evaluated in this study area are part of the palustrine system as determined by the NWI. For this study the models used predicted whether or not a grid cell represented wetlands or non-wetlands. Statistical analysis needed to distinguish between forested wetlands and non-forested wetlands goes beyond the scope of this analysis. Descriptive statistics are summarized in Table 1.

The independent variables analyzed in this study consisted of continuous and dichotomous variables. The continuous variables were wetness index (WI), normalized difference vegetation index (NDVI), profile curvature, and degree slope. The soils were classified as either hydric or non-hydric and analyzed as a dichotomous variable.

Calculations for WI, NDVI, profile curvature, and degree slope were made using high resolution color infrared imagery and topographic data obtained from IndianaMap Framework Data from the Indiana 2005 Orthophotography Project. The imagery was collected during the month of April 2005 and was cloud free for the study area.

Table 1: Descriptive Statistics Areas of Coverage

Variable	Boone County	Hamilton County	Woodruff Branch
Wetlands	2.56 Ha	3.17 Ha	5.823 Ha
Percent	3.25%	2.38%	2.74%
Number Centroid Points	1709	2113	3882
Total Area	78.97 Ha	133.27 Ha	212.24 Ha
Total Centroid Points	52648	88848	141496

4.3.1 Wetness Index

WI was calculated as a simple band ratio represented by the formula: WI = $\left(\frac{Green}{NIR}\right)$.

There was little difference between the means for each county and the mean for the entire study area. Grid cells representing forested wetlands in the Hamilton County portion of the study area showed the highest mean WI while grid cells representing non wetlands also in the Hamilton County portion of the study area showed the lowest mean WI. (Table 2)

Table 2: Means of Continuous Variable Wetness Index

Variable	Boone County	Hamilton County	Woodruff Branch
Wetlands	1.10	1.26	1.18
Non-wetlands	1.03	1.02	1.03

4.3.2 Normalized Difference Vegetation Index (NDVI)

The NDVI is an indicator of vegetation derived from remotely sensed data. Values range between -1.0 and +1.0, were lower values are indicative of the absence of vegetation and higher values indicate dense, health vegetation cover. NDVI is represented by the formula:

$$\text{NDVI} = \left(\frac{NIR - RED}{NIR + RED}\right)$$

The NDVI data used in this study were calculated using the high resolution color infrared imagery. NDVI values were stretched to an 8 bit range (0 to 255) prior to analysis. Grid cells representing forested wetlands in the Boone County portion of the study area had the highest mean NDVI while the grid cells representing mean NDVI in the Hamilton County portion of the study area had the lowest mean NDVI. (Table 3)

Table 3: Means of Continuous Variable NDVI

Variable	Boone County	Hamilton County	Woodruff Branch
Wetlands	138.36	130.85	134.45
Non-wetlands	136.35	139.11	138.09
Study Area	136.42	139.00	138.04

4.3.3 Profile Curvature

Profile curvature is a measure of surface morphology. It is the slope of the slope and is calculated on a cell by cell basis. Profile curvature is in the direction of the maximum slope. Zero curvature indicates flat surface morphology. A negative value indicates the surface is convex, while a positive value indicates a surface morphology that is concave.

The means of the profile curvature, while negative, were near zero indicating a relatively flat surface morphology throughout the study region. Overall the Boone County portion of the study area had a slightly convex profile while the Hamilton county portion had a slightly concave profile (Table 4).

Table 4: Means of Continuous Variable Profile Curvature

Area	Boone County	Hamilton County	Woodruff Branch
Wetlands	-.01821	-.01423	-.01614
Non-wetlands	-.00082	.00189	.00089
Study Area	-.00131	.00161	.00052

4.3.4 Degree Slope

Degree slope expresses the rate of the maximum change in elevation between each cell and its eight neighbors with values potentially ranging from 0 – 90. Lower values indicate flatter surfaces, while higher values indicate steeper surfaces. The means of the degree slope for the study area are summarized in Table 5.

Table 5: Means of Continuous Variable Degree Slope

Variable	Boone County	Hamilton County	Woodruff Branch
Wetlands	1.61	1.52	1.56
Non-wetlands	1.46	1.17	1.28
Study Area	1.47	1.18	1.28

4.3.5 Soils

Soils were divided into hydric and non-hydric categories. The list of hydric soils is determined by each county and provided by the Natural Resource Conservation Service. What at first seemed to be a simple means of classification became more complex when examining the map of hydric soils. The western portion of Woodruff Branch that lies within Boone County jurisdiction has a more extensive list of hydric soils (Table 14[1]) than does the eastern portion that lies within Hamilton County. (Table 13[2])

In the Hamilton County portion of the study area only 17.5% of grid cells representing NWI wetlands were associated with grid cells representing hydric soils as defined by Hamilton County. In the Boone County portion of the study area 80.3% of the cells representing NWI wetlands were associated with cells representing hydric soils as defined by Boone County.

The difference in hydric soils definitions had significant implications with regards to the final analysis. For this reason a "hydric by association" approach was also used for further analysis. Soils were considered hydric if they were associated with a soil polygon designated hydric in the neighboring county.

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[1] Found in the Appendix, page 29.

[2] Found in the Appendix, page 29.

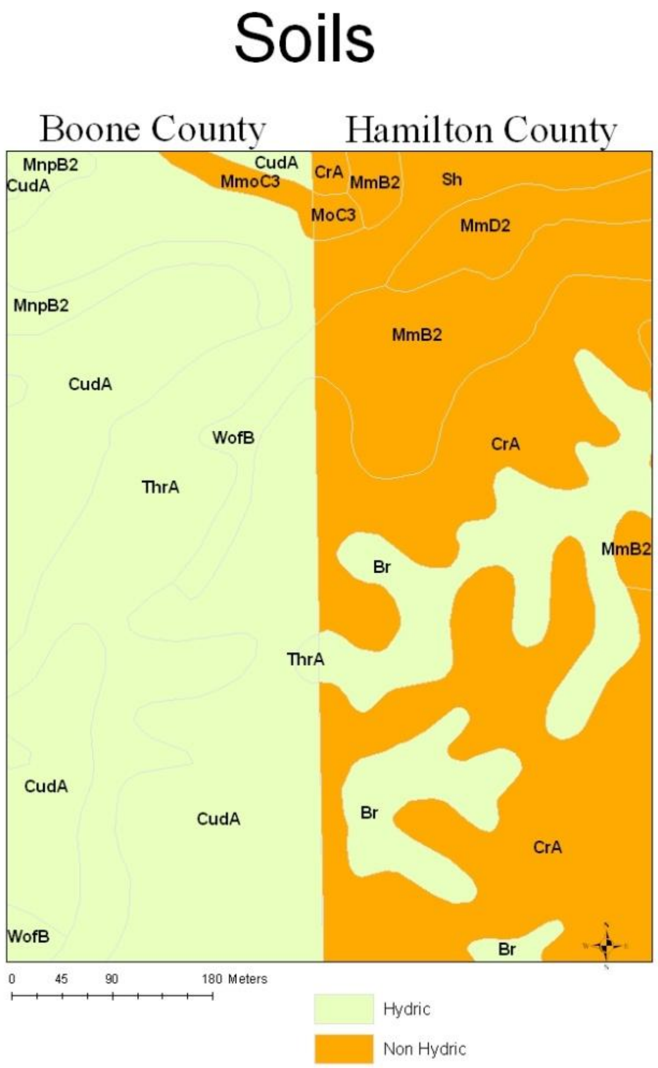

Figure 2: Determining soil associations

This significantly changed the number of soil polygons designated hydric in the Hamilton County portion of the study area. The Hamilton County jurisdiction comprised 62.8% of the study area while the Boone County jurisdiction comprised the other 37.2%. The hydric by association approach also had significant implications with regards to the final analysis for the entire Woodruff Branch study area.

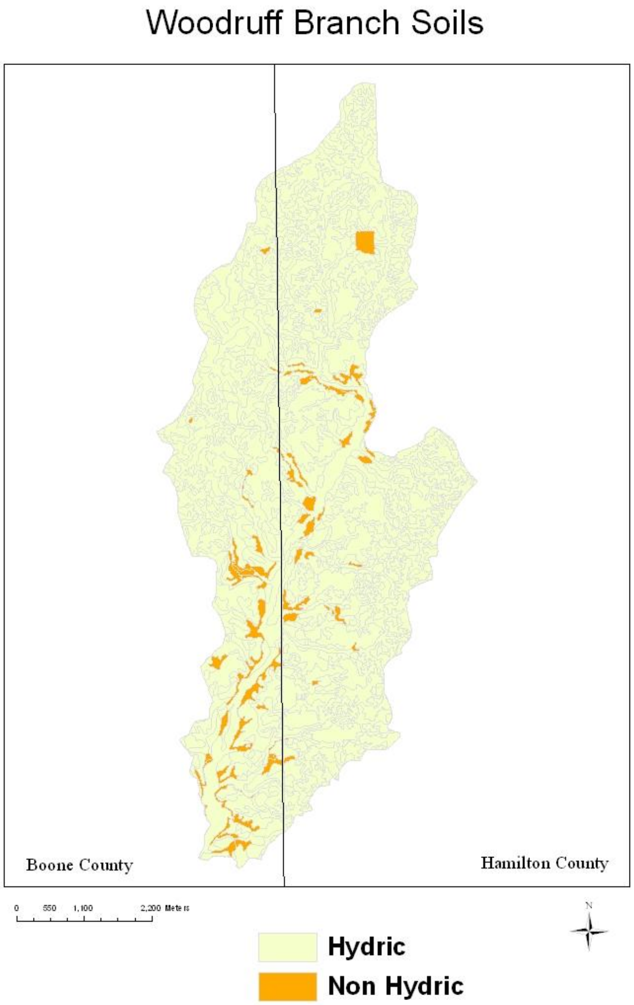

Figure 3: Soils as determined by Association

When using the hydric by association approach, the percentage of grid cells representing NWI wetlands associated with hydric soils increased from 17.5% to 68.3% in the Hamilton County portion of the study area, while grid cells representing NWI wetlands associated with non hydric soils decreased from 82.4% to 31.7%. In the Boone County portion of the study area the percentage of grid cells representing NWI wetlands associated with hydric soils increased from 80.5 to 80.7% using the hydric by association reasoning. Those grid cells in the Boone County portion of the study area representing NWI wetlands and associated with grid cells representing non hydric soils decreased from 19.5% to 19.3%.

Table 6: Soils Associations

Hectares (Percent)

Soils	Boone County	Hamilton County	Woodruff Branch
Hydric Soils by Definition	2.06 (80.3)	0.555 (17.5)	2.619(45.7)
Hydric Soils by Association	2.07 (80.7)	2.166 (68.3)	4.263(74.4)
Non Hydric Soils by Definition	.5 (19.5)	2.613(82.4)	3.114 (54.3)
Non Hydric Soils by Association	.494 (19.3)	1.004(31.7)	1.497(26.1)
N	2.564	3.17	5.733

5. Analysis

Regression analysis using SPSS software explored the relationships between independent and dependent variables. Grid cells associated with roads, developed areas and ponds were excluded from analyses.

The independent variables analyzed were profile curvature, degree slope, NDVI, wetness index and hydric soils. The dependent variable in this study was whether or not a grid cell was identified as a wetland. Table 7 summarizes the results of the three logistic regression models used and includes regression coefficients (β) along with the exponential of the regression coefficients (EXP (β)). The standard errors are in parentheses. Table 7 also includes summary measures on how well the models performed.

The Chi-squared tests indicated the models were statistically significant at the 0.001 level. Nagelkerke pseudo-R-squared values range from 0 to 1 where 0 indicates no relationship between independent and dependent variables and 1 indicates a perfect relationship. The Nagelkerke pseudo-R-squared values for the analysis in this study ranged from 0.07 to 0.13 indicating the models accounted for only a small portion of the variation in the dependent variable.

The models did not improve the classifications of grid cells as wetlands, 92.5% of the grid cells were correctly classified as wetlands in the Hamilton County jurisdictional area, 96.9% in the Boone County jurisdictional area and 95.6% in the entire study area. The models did not improve the ability to predict grid cells as wetlands. When the models were used to predict the grid cells as wetlands there was a slight decline in accurateness. More non-wetland cells were classified as wetlands than were wetland cells.

For the independent variables NDVI, wetness index, degree slope and profile curvature, the magnitude of the effect of the variable on the odds depends on the range of the variable.

Table 7: Logistic Regression Predicting Wetlands

(Standard errors in parentheses)

	Boone County		Hamilton County		Woodruff Branch	
	β	Exp(β)	β	Exp(β)	β	Exp(β)
NDVI	0.0026 (0.0011)	1.0026	-0.0153 (0.0013)	0.9848	-0.0036 (0.0008)	0.9964
Wetness Index	0.4622 (0.0497)	1.5875	1.5041 (0.0744)	4.5003	0.8022 (0.0402)	2.2305
Degree Slope	0.0108 (0.0115)	1.0109	-0.0581 (0.0157)	0.9435	-0.0133 (0.0089)	0.9868
Profile Curvature	-0.3782 0.1330	0.6851	-0.3073 (0.1564)	0.7354	-0.3709* (0.0990)	0.6901
Hydric by Association	0.8228 (0.1132)	2.2769	1.3162 (0.0634)	3.7292	1.6934 (0.0524)	5.4381
Hydric by Definition	1.0939 (0.1131)	2.9860	-0.7205 (0.0692)	0.4865	-0.6082 (0.0418)	0.5444
Constant	-5.7435 (0.1812)	0.0032	-2.6733 (0.2062)	0.069	-4.3048 (0.1302)	0.0135
Chi-square	889.1588		1297.9647		1685.6612	
Nagelkerke R Square	0.0711		0.1327		0.0732	
Percent correctly classified without model	96.9987		92.5865		95.64769	
Percent correctly classified with model	96.991		92.4182		95.5909	
Classification improvement	-0.0077		-0.1683		-0.0568	

For the Boone County portion of the study area the NDVI value had a positive, but statistically insignificant relationship. Both the Hamilton County portion of the study area and the entire Woodruff Branch study area had a slight negative but statistically significant relationship with the NDVI.

5.1 NDVI

As the NDVI value increased (or decreased) by *n*, the odds of a grid cell being classified as a wetland increased (or decreased) by $(\text{Exp}\beta)^n$. For an increase of 5 in the NDVI value in the Boone County portion of the study area, the odds increased 1.0026^5. The odds of wetlands in the Boone County portion of the study area increased about 1.01 for a 5 unit increase in the NDVI value.

In the Hamilton County portion of the study area, the odds of a grid cell being classified as a wetland decreased slightly as did the odds of a grid cell being classified as a wetland for the entire Woodruff Branch study area. The odds of a grid cell being classified as a wetland in the Hamilton County portion of the study area decreased 0.9848^5, or about 0.93 for a 5 unit increase in the NDVI value. For the entire Woodruff Branch Study area the odds of a grid cell being classified as a wetland decreased by $.9964^5$ or about 0.98 for a 5 unit increase in the NDVI value.

The values for the NDVI had the greatest range for the continuous variables. The larger range for the NDVI variable resulted in a reduction of a grid cell being classified as a wetland the magnitude of the effect on the odds for the NDVI compared to all other continuous variables analyzed. The magnitude of the effect is slightly greater for Boone County than for Hamilton or the entire study area.

Table 8: Logistic Regression Predicting Wetlands using NDVI
(Standard errors in parentheses)

	Boone County		Hamilton County		Woodruff Branch	
	β	Exp(β)	β	Exp(β)	β	Exp(β)
NDVI	0.0026 (0.0011)	1.0026	-0.0153 (0.0013)	0.9848	0.0026 (0.0011)	1.0026
Range	145.85		159.36		165.17	

5.2 Wetness Index

The wetness index had positive relationships in the Boone County and Hamilton County portions of the study area as well as in the entire Woodruff Branch study area. The (Exp)β is large in all three cases indicating a 1 unit change in the wetness index value has a substantial effect on the odds. For a 1 unit change in the wetness index the odds of a cell being a wetland increased by 1.59 for the Boone County portion of the study area, 4.5 for the Hamilton County portion of the study area and 2.2 for the entire Woodruff Branch study area.

The range for the means of the wetness index was narrower than that of the means of the NDVI so the magnitude of the effect on the odds was greater for the wetness index than for the NDVI. The range for the means of the wetness index was only slightly smaller than that for the means of degree slope, therefore the effect was similar for wetness index and degree slope. The range of the means for the wetness index was greater than the range for the means of the profile curvature as a result the magnitude of the effect on the wetness index is less than the magnitude of the effect on the means of the profile curvature.

Table 9: Logistic Regression Predicting Wetlands using Wetness Index

(Standard errors in parentheses)

	Boone County		Hamilton County		Woodruff Branch	
	β	Exp(β)	β	Exp(β)	β	Exp(β)
Wetness Index	0.4622 (0.0497)	1.5875	1.5041 (0.0744)	4.5003	0.8022 (0.0402)	2.2305
Range	2.18		6.29		6.32	

5.3 Profile Curvature

Profile curvature is not significant for either county jurisdiction, but it is significant for the entire study area. The logistic regression coefficients are similar for both the Hamilton and Boone County portions of the study area as well as the entire study area. An increase in the profile curvature in this case indicates a reduction in the odds of the grid cells being classified as wetlands since the relationship is negative. A one unit change in the profile curvature signifies a reduction in the odds of a grid cell being classified as wetlands ranging from 0.68 in the Boone county portion of the study area to 0.74 in the Hamilton County portion of the study area.

The range for the means of the profile curvature was narrower than that of the means of all other continuous variables analyzed so the magnitude of the effect on the odds for the means of the profile curvature was greater than the magnitude of effects for all other continuous variables analyzed.

Table 10: Logistic Regression Predicting Wetlands using Profile Curvature
(Standard errors in parentheses)

	Boone County		Hamilton County		Woodruff Branch	
	β	Exp(β)	β	Exp(β)	β	Exp(β)
Profile Curvature	-0.3782	0.6851	-0.3073	0.7354	-0.3709	0.6901
	(0.1330)		(0.1564)		(0.0990)	
Range	3.21		2.10		3.32	

5.4 Degree Slope

Degree slope has a positive relationship for the Boone County portion of the study area and a negative relationship for the Hamilton County portion of the study area. When analyzing the entire study area, the relationship is negative.

For Boone County an increase of 5 units in the degree slope increases the odds by about 1.06. For Hamilton County the decrease in odds would be 0.75. For the entire study area the odds decrease by 0.94 for a 5 unit change in the degree slope.

Since the range for the means of the degree slope was similar to that of the wetness index, the magnitudes of the effects on the odds for the two continuous variables were similar as well. As with the means of the wetness index, the magnitude of the effects on the odds for the degree slope were more than the magnitude of effect on the odds of the NDVI, but less than the magnitude of the effects on the odds for the profile curvature.

Table 11: Logistic Regression Predicting Wetlands using Degree Slope
(Standard errors in parentheses)

	Boone County		Hamilton County			Woodruff Branch
	β	Exp(β)	β		Exp(β)	β
Degree Slope	0.0108 (0.0115)	1.0109	-0.0581 (0.0157)	0.9435	-0.0133 (0.0089)	0.9868
Range	17.00		19.69			19.69

5.5 Soils

The relationship between hydric soils and the designation of a grid cell as wetlands was analyzed using a dummy variable. There is also a difference between the two jurisdictions as to how soils are classified as hydric.

Table 13 and Table 14 list names and characteristics of the soils found within the study area that are designated hydric by the two county jurisdictions. The tables illustrate not only do the nomenclatures differ, but that the number of soils designated hydric differs between the two jurisdictions as well. For this reason the “hydric by association” method was added to the analysis. Soils were considered hydric if they were associated with a soil polygon designated hydric in the neighboring county.

The analysis indicates that when looking at the soils as defined a negative relationship exists in the Hamilton County portion of the study area. This may be due to adding hydric by association to the analysis. In the Hamilton County portion of the study area, hydric soils as defined are not a good indication of cells being designated as wetlands. Using hydric by association logic, the odds of a grid cell being designated as wetlands in Hamilton County increase from 0.49 to 3.73.

In the Boone County portion of the study area soils that are hydric by definition are good indications of a grid cell being designated as wetlands. The hydric by association logic enhances the odds of designating a cell as wetlands.

6. Conclusions

In the Boone County portion of the study area the results indicated the wetness index was significant as were the two approaches for determining hydric soils. Thus having both a good measure of hydric soils along with a wetness index seemed to predict wetlands for this portion of the study area.

For the Hamilton County portion of the study area the results for the hydric by definition approach to defining hydric soils gave a negative sign, while the hydric by association approach was significantly more predictive. When the hydric by definition approach was used NDVI and slope became significant predictors. For the entire study area similar results were found.

The results show ambiguities due to the difference in definitions for hydric soils between county jurisdictions which pointed toward a need for more consistent method for defining hydric soils. A consistent method for defining hydric soils along with a wetness index could possibly be a good measure for predicting wetlands.

The model used in the analysis did not have the power to accurately predict the locations of wetlands. Nor could the model accurately classify the cells representing wetlands. The model was unable to classify cells as wetlands using a standard classification cutoff with a predicted probability of 0.5. Changing the classification cutoff with a predicted probability of 0.4, 0.3, 0.2 and 0.1 did not improve the models ability to classify cells as wetlands.

Table 12: Changing Classification Cutoff Values

Cutoff Value	Cells correctly predicted to be wetlands(hectares)	Cells incorrectly predicted to be wetlands(hectares)
0.5	5 (0.0075)	49 (0.0735)
0.4	8 (0.012)	70 (0.105)
0.3	15 (0.0225)	95 (0.1425)

0.2	23 (0.0345	165 (0.2475)
0.1	145 (0.2175)	837 (1.2555)

Overall, the model results indicate using hydric soils (accurately defined) along with a wetness index could indicate areas that have a higher probability of being wetlands. Minus an accurate definition for hydric soils, using NDVI and slope could indicate areas with a higher probability for being a wetland. This could provide a basis for focusing field studies more efficiently. The most efficient methods for doing this would require additional study and analysis.

APPENDIX

Table 13: Hydric Soils for Hamilton County

Map Unit Symbol	Map Unit Name	Component Name and Phase	Landforms
Br	Brookston silty clay loam	Brookston	Depressions, Till plains
Ho	Houghton muck	Houghton	Depressions, Outwash plains
Pa	Palms muck	Palms	Depressions, Terraces
Pn	Patton silty clay loam	Patton	Depressions, Terraces
Ps	Patton silty clay loam, limestone substratum	Patton	Depressions, Terraces
Sx	Sloan silty clay loam, sandy substratum	Sloan	Flood plains
We	Westland silty clay loam	Westland	Depressions, Outwash plains

Table 14: Hydric Soils for Boone County

Map Unit Symbol	Map Unit Name	Component Name and Phase	Landforms
CxdA	Crosby silt loam, 0 to 2 percent slopes	Typic Argiaquolls	Depressions, Swales, Till plains
EdeAW	Cyclone silty clay loam, 0 to 1 percent slopes	Cyclone	Depressions, Swales, Till plains
FdbA	Cyclone silty clay loam, 0 to 1 percent slopes	Mahalasville	Depressions, Swales, Till plains
FdhA	Eel and Beckville soils, 0 to 2 percent slopes, occasionally	Sloan	Backswamps, Flood plains, Meander scars

	flooded, very brief duration		
MamA	Fincastle silt loam, 0 to 2 percent slopes	Typic Argiaquolls	Depressions, Swales, Till plains
MamA	Fincastle-Crosby silt loams, 0 to 2 percent slopes	Typic Argiaquolls	Depressions, Till plains
MamA	Mahalasville silty clay loam, 0 to 1 percent slopes	Pella	Depressions
MamA	Mahalasville silty clay loam, 0 to 1 percent slopes	Mahalasville	Depressions, Flats, Outwash plains, Swales
MaoA	Mahalasville silty clay loam, 0 to 1 percent slopes	Mahalaland	Depressions, Flats, Outwash plains, Swales
MjkAH	Mahalasville silty clay loam, 0 to 1 percent slopes	Treaty	Outwash plains, Swales
MnpB2	Mahalaland silty clay loam, 0 to 1 percent slopes	Mahalaland	Outwash plains, Swales
MnpC2	Medway and Beckville soils, 0 to 2 percent slopes, frequently flooded, brief duration	Sloan	Backswamps, Flood plains
ObxA	Miami silt loam, 2 to 6 percent slopes, eroded	Typic Argiaquolls	Depressions, Swales, Till plains
RtuAH	Ockley silt loam, 0 to 2 percent slopes	Westland	Depressions, Flats, Swales, Terraces
SldAH	Ockley silt loam, 2 to 6 percent slopes, eroded	Westland	Depressions, Stream terraces, Swales
SldAW	Rossburg and Landes soils, 0 to 2 percent slopes, frequently flooded, brief duration	Sloan	Backswamps, Flood plains, Meander scars
SngA	Shoals silt loam, 0	Sloan	Backswamps,

	to 2 percent slopes, frequently flooded, brief duration		Flood plains, Meander scars
SnlAP	Shoals silt loam, 0 to 2 percent slopes, occasionally flooded, very brief duration	Sloan	Backswamps, Flood plains, Meander scars
SnlAP	Sleeth silt loam, 0 to 2 percent slopes	Westland	Depressions, Swales, Terraces
SocAH	Southwest silt loam, 0 to 1 percent slopes, ponded, brief duration	Southwest	Depressions, Till plains
SocAW	Southwest silt loam, 0 to 1 percent slopes, ponded, brief duration	Treaty	Depressions, Till plains
SteA	Sloan silty clay loam, 0 to 1 percent slopes, frequently flooded, brief duration	Sloan	Backswamps, Flood plains, Meander scars
StjA	Sloan silty clay loam, 0 to 1 percent slopes, occasionally flooded, very brief duration	Sloan	Backswamps, Flood plains, Meander scars
StjA	Starks silt loam, 0 to 2 percent slopes	Mahalasville	Depressions, Outwash plains
ThrA	Starks-Crosby silt loams, 0 to 2 percent slopes	Mahalasville	Depressions, Outwash plains
ThrA	Starks-Crosby silt loams, 0 to 2 percent slopes	Cyclone	Depressions, Swales, Till plains
ThrA	Treaty silty clay loam, 0 to 1 percent slopes	Treaty	Depressions, Flats, Swales, Till plains

UfnA	Treaty silty clay loam, 0 to 1 percent slopes	Mahalaland	Depressions, Flats, Swales, Till plains
UfnA	Urban land-Crosby complex, 0 to 2 percent slopes	Typic Argiaquolls	Depressions, Swales, Till plains
UfoA	Treaty silty clay loam, 0 to 1 percent slopes	Mahalasville	Depressions, Flats, Swales, Till plains
UfxA	Urban land-Cyclone complex, 0 to 1 percent slopes	Cyclone	Depressions, Flats, Swales, Till plains
UhuA	Urban land-Cyclone complex, 0 to 1 percent slopes	Mahalasville	Depressions, Flats, Swales, Till plains
UhuA	Urban land-Fincastle complex, 0 to 2 percent slopes	Typic Argiaquolls	Depressions, Swales, Till plains
UhuA	Urban land-Mahalasville complex, 0 to 1 percent slopes	Mahalasville	Depressions, Outwash plains
UhuA	Urban land-Mahalasville complex, 0 to 1 percent slopes	Pella	Depressions, Outwash plains
UkbB	Urban land-Mahalasville complex, 0 to 1 percent slopes	Treaty	Flats, Outwash plains, Swales
UkbC	Urban land-Mahalasville complex, 0 to 1 percent slopes	Mahalaland	Flats, Outwash plains, Swales
UkpA	Urban land-Miami complex, 2 to 6 percent slopes	Typic Argiaquolls	Depressions, Swales, Till plains
UkpB	Urban land-Miami complex, 6 to 12 percent slopes	Typic Argiaquolls	Depressions, Swales, Till plains
UmyA	Urban land-Ockley complex,	Westland	Depressions, Swales,

	0 to 2 percent slopes		Terraces
UmyA	Urban land-Ockley complex, 2 to 6 percent slopes	Westland	Depressions, Stream terraces, Swales
UmyA	Urban land-Treaty complex, 0 to 1 percent slopes	Treaty	Depressions, Till plains
UnuA	Urban land-Treaty complex, 0 to 1 percent slopes	Mahalaland	Depressions, Till plains
UnvB	Urban land-Treaty complex, 0 to 1 percent slopes	Mahalasville	Depressions, Till plains
WmnA	Urban land-Whitaker complex, 0 to 2 percent slopes	Mahalasville	Depressions, Outwash plains
WofB	Urban land-Williamstown-Crosby complex, 2 to 4 percent slopes	Typic Argiaquolls	Depressions, Swales, Till plains
WqvA	Waynetown silt loam, 0 to 2 percent slopes	Mahalaland	Depressions, Outwash plains, Terraces
WqvA	Williamstown-Crosby silt loams, 2 to 4 percent slopes	Treaty	Depressions, Swales, Till plains
WqvA	Westland silty clay loam, 0 to 1 percent slopes	Treaty	Depressions, Flats, Swales, Terraces
WtaA	Whitaker silt loam, 0 to 2 percent slopes	Mahalasville	Depressions, Stream terraces, Swales
XfuB2	Miami-Rainsville complex, 2 to 6 percent slopes, eroded	Typic Argiaquolls	Depressions, Swales, Till plains
XfuC2	Miami-Rainsville complex, 6 to 12 percent slopes, eroded	Typic Argiaquolls	Depressions, Till plains

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