JASON WILLIS LEE
Integration of Remote Sensing and Rule-Based Modeling Techniques for Mapping Piedmont Wetlands
(Under the Direction of DR. ELIZABETH KRAMER)

Wetlands continue to be lost in the state of Georgia. Consistent and timely inventories are needed to gauge and study these losses, but an affordable solution for statewide inventorying has yet to be found. Reliance on the National Wetlands Inventory (NWI) is not sufficient, since that project, though accurate, is considerably behind schedule due to inadequate funding. In order to complement the NWI, a protocol was developed for the Piedmont region of Georgia using rule-based modeling techniques and 1970’s Landsat MSS imagery to produce a historical inventory of wetlands. The final classification was then accuracy assessed to determine the protocol’s usefulness, and a preliminary loss analysis was performed, which showed that wetlands are still being lost on the Georgia Piedmont. Results indicate that this protocol is a reasonable alternative to the manual approach employed by the NWI, but that the level of detail will suffer.

INDEX WORDS: Wetlands, Rule Based Modeling Techniques, Landsat MSS, Landsat TM, Georgia Piedmont, DEM, Classification, Landuse, Wetland Loss

REMOTE SENSING OF PIEDMONT WETLANDS USING RULE BASED MODELING TECHNIQUES

by

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B.S., The University of Georgia, 1998

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2002

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May 2002

DEDICATION

This thesis is dedicated to my wife Rachel, whose support, patience and love made the long hours possible; to my parents, Willis and Sandra, for always being there for me; and also to the memory of my grandmother, Elsie.

ACKNOWLEDGEMENTS

I want to thank Dr. Elizabeth Kramer, whose mentoring and expansive vision made this project a reality. I would like to thank Dr. Rhett Jackson for sharing with me his limited time and his extensive knowledge of hydrology. I would like to thank Dr. Ron Carroll, whose dedication inspires everyone around him. The NARSAL lab at the Institute of Ecology has been a constant source of information as well as entertainment. I want to thank each of you for being much more than colleagues.

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INTRODUCTION

Importance of Wetlands

Wetlands can be considered the transition zones between terrestrial and aquatic ecosystems. They maintain qualities of both, often being under water part of the year and dry at other times, and so have always been difficult to identify and properly define. There are many definitions ascribed to wetlands, and these definitions can often be confusing and even contradictory (Mitch and Gosselink, 1993). However, almost all consist of three main components: a permanent or temporary inundation of water, hydric soil conditions, and flora that is specifically adapted to those conditions.

Ecologists have come to recognize wetlands as critical ecosystems. This realization, which has been accepted by scientists, policymakers and ordinary citizens alike, has caused a drastic paradigm shift; areas that were once considered wastelands (and treated accordingly) are now protected with federal policy and are prime targets of conservation and restoration efforts. A new academic field, wetland ecology, has arisen to better study wetland values and biology. The findings of wetland ecology stress the significance of wetlands; that they are vast pools of biodiversity, and they perform a multitude of ecosystem functions. Wetlands serve as habitat for wetland dependant fowl, fish, timber, as well as other ecologically and economically important species. Wetlands provide protection against floods and improve water quality. Wetlands are major sources of tourism due to their aesthetic and cultural values. Wetlands can also act as carbon sinks. These properties stress that wetlands are valuable for ethnocentric and non-ethnocentric reasons (Mitch and Gosselink, 1993, Childers and Gosselink, 1990).

The recognized importance of wetlands is expressed in the ‘no net loss of wetlands in size and function’ recommended in 1988 by the National Wetlands Policy Forum, and in the ‘no net loss of wetlands’ policy goal declared in 1989 by President George H. W. Bush. This policy has been maintained to varying degrees by the two succeeding presidential administrations.

History of Wetlands and Humans

Unfortunately, the former paradigm on wetlands, in which they were a much maligned, even feared, feature of the landscape to be eradicated (with the same zealousness usually reserved for single species such as wolves) by whatever means necessary, has led to a dire state of affairs. Much of the world’s wetlands have been converted into other, non-wetland land uses, or degraded such that they do not function as formerly. Here in the conterminous United States, some place that figure of conversion as high as 53% since European settlement (Dahl, 1990; Shaw and Fredine, 1956). This means that on average, in the lower 48 states between the 1780s and 1980s wetlands were lost at a rate of over 60 acres/hour. Because of this rate of loss and the potentially disastrous effects of continued loss, the halting of this trend is crucial to sustainable development in the United States.

Current Legal Status of Wetlands in Georgia

Even since federal policy began to regulate wetland loss, the trend of wetland destruction has continued in the state of Georgia and much of the United States (Dahl, 1990). In Georgia, much of these losses are confined to smaller, less conspicuous wetlands, especially riverine and isolated wetlands (Kundell and Woolf, 1986), which are the most prevalent types in the Piedmont region of Georgia. These types of wetlands are also regulated solely by federal policy in Georgia, as no state laws are applicable to them.

The Federal Clean Water Act of 1972 provides the basis for protection of isolated and riverine wetlands in Georgia. Section 404 of the CWA requires that a permit be obtained from the U.S. Army Corps of Engineers (COE) before “dredged or fill material” can be deposited into “waters of the U.S.” “Dredged or fill material” is defined loosely as any substance that would displace water, but the phrase “waters of the U.S.” is more ambiguous. Over the past 20 years, the COE, under considerable pressure from environmental groups and by court rulings, has broadened this definition from being only (actual) navigable waters to include all waters of the U.S. and all wetlands larger than 0.5 acres. However, the Supreme Court has recently redefined the USACE’s authority with respect to its jurisdiction over isolated wetlands, declaring that isolated wetlands are not included in the “navigable waters” definition. This still presents an ambiguity though, since “adjacent” wetlands are protected. Adjacent wetlands are defined as “bordering, contiguous, or neighboring a ‘navigable water’”. In effect, the question of what is an “isolated” wetland and what is an “adjacent” wetland remains unanswered.

The practical interpretation of Section 404 is that activities such as excavation, drainage, clear-cutting, water supply constriction (or any modification of hydrology-including pumping and siphoning) or other upland activities affecting protected wetlands are not regulated, as long as there is no associated fill or discharge material deposited in the wetland. In effect a loophole is left open: where economically feasible, wetlands can be drained and then lose their legal wetland status (so that 404 regulations will no longer apply).

Section 404 also exempts “normal ranching, farming and silviculture practices”, unless these practices convert wetlands into non-wetlands. The COE has very liberal definitions of what is allowable in these situations. Construction of farm ponds can be done without permit, and conversion of wetlands to pine plantations does not require mitigation. Forested wetlands may also be cut and converted to pasture. These three practices are perhaps the major sources of wetland losses in the state of Georgia (Bob Lord, EPA, personal communication).

Categorized permits are also issued by the COE. These permits allow many modifications of wetlands to proceed without regulation. These exemptions include activities such as road building, utility line construction, construction of farm ponds, maintenance of drainage ditches, and construction of temporary sedimentation basins on construction sites (unless there is discharge that is not incidental). Nationwide permits are also in effect for all wetlands smaller than 0.5 acres.

For all instances where a wetland is destroyed by filling, mitigation is required. Mitigation is the ‘replacement’ of wetlands that are affected or lost. This usually consists of preservation of wetlands that already exist (through purchase) or restoration of wetlands that are degraded or converted. To a lesser extent wetlands are created, but the limited success of these creations has led to diminishing use of this option (COE website). The COE reports that in Georgia permit holders average about 2 acres of mitigation for every acre of wetland loss (COE website). However, as noted above, the USACE’s regulations define wetland loss conservatively. There are also problems due to lack of enforcement. The COE does not allocate many resources to monitoring wetlands, but rather relies on citizen involvement to report infractions Georgia (David Crosby, COE, personal communication).

The Environmental Protection Agency derives its regulatory power from section 402 of the CWA. Veto power over all wetland permits issued by the COE is within its jurisdiction, but this is rarely used. The Fish and Wildlife Service (FWS), the EPA and the National Marine Fisheries Service (NMFS) review permit applications and provide recommendations on issuance. Also, the EPA has set national water quality for wetland standards (Water Quality for Wetlands, EPA, 1990), but individual states are not required to follow them unless they do not develop their own standards, in which case the EPA is obligated to step in. Georgia has not yet developed water quality standards for wetlands (nor have most other states). Because there are many types of wetlands and thus many levels of resistance to perturbations, determining water quality standards adequate for all wetlands is a difficult matter. Wetlands that do not contain standing water all year present yet another challenge.

Wetland Mapping Background

In order to monitor and document wetland change, the U.S. Fish and Wildlife Service established the National Wetland Inventory in 1975. The primary function of the NWI is to map wetlands in the United States in ten-year 'snapshots'. To obtain the level of detail desired on these maps, the NWI approach uses a combination of photo-interpretation of high-altitude color infrared aerial photography and ground reconnaissance (Tiner, 1990). This approach, though accurate, is time consuming and expensive. For instance, the snapshot of 1984 has only recently been completed for

Georgia. For these reasons, other modes of wetland detection are needed. The most obvious other source of imagery to accomplish mapping wetlands is Landsat satellite imagery. There is a continuous coverage of the U.S. since the early 1970's, when the first Landsat MSS was launched, until the present. These archives could be used to create a historical database that would begin with the first wetland regulations, and supply policymakers with information relevant to wetland protection. However, the following distinction between the NWI and this approach should be understood.

The NWI producers attempt to adhere to the regulatory (U.S. Army Corps of Engineers) definition as closely as possible. That definition of a wetland is as follows:

"The term wetland means those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances to support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas. (33 CFR328.3(b); 1984)".

The definition according to this project is limited to the following: does the area contain standing water or saturated soils that can be remotely sensed by satellite? In practice, this means that wet areas must be visible from above, i.e., if there is forest cover, then it must be a cloud free, leaf off condition to be remotely sensed. The window for sensing wetlands is further limited to the times that saturation occurs. Fortunately on the Georgia Piedmont, the heavy rainfalls during a typical winter season combined with leaf off conditions provide this window. However, since clouds and rainfall occur in concert, acquiring a leaf off, cloud free scene with adequate rainfall can be problematic. For this reason, it should also be understood that the limited definition of wetlands presented here can be hampered by proper scene availability.

Objectives and Justifications of Study

The objective of this project was to develop a consistent methodology to evaluate changes in wetland distributions within the Piedmont region of Georgia. To do so, an efficient yet effective protocol had to be defined. 1970's Landsat Multi Spectral Scanner (MSS) imagery and a rule-based model were the basis of this protocol. In order to test the accuracy of the protocol, a wetland map was produced accordingly and checked for errors. The resultant map is the earliest wetland map of the entire Piedmont region of Georgia, and so has specific uses in the wetland ecology arena. These include wetland loss studies, identification of sites for mitigation and restoration, and future inventorying. To illustrate these uses, a wetland loss analysis was performed for a five county area by interpreting 1998 imagery for wetlands, a comparison is drawn between the wetlands in the 1998 and 1974 Landcover Maps of Georgia, and wetland conversions to and from types of landcovers are detailed.

Literature Review

The primary impediment to using Landsat imagery is accuracy. With the best resolution at only 30m (TM) and 80m for MSS, wetlands have been hard to identify using this source. Due to the often ephemeral nature and the multitude of types of wetlands, the spectral signatures of wetlands are variable and can also be non-distinguishable at times. For instance, a dry forested wetland and a forested upland may have virtually the same spectral signature, making spectral interpretation of wetlands in satellite imagery problematic. To complicate classification further, only the refined Landsat TM satellites, launched in 1982 and 1984, utilize a sensor exactly tuned for water body penetration, which greatly enables wetland detection. This is an improvement upon the older MSS satellites, which were launched in 1972, 1974 and 1978. That additional spectral band (blue), the 0.45-0.52μm wavelength, has only the 0.5-0.6μm MSS sensor as a counterpart (NASA, 1982). Also, TM band 5(1.55-1.75μm) shows differences in soil moisture content (Lillesand and Kiefer, 1994) and has no MSS equivalent.

Despite these limitations, there have been successes, especially with the spectrally improved TM data. The Ohio Wetlands Inventory, which is based on a combination of hydric soil maps and supervised classifications of Landsat TM imagery, was successful and also relatively easily updateable (Yi et al., 1994). However, not all states, including Georgia, have complete hydric soil maps.

Lunetta and Balogh (1999) used a multi-temporal approach to evaluate Landsat TM's usefulness in identifying wetlands. This method is meant to circumvent the seasonal conditions that prohibit ready identification of wetlands. Using spring images that coincided with the annual inundation period in Maryland and Delaware, but before leaves begin to appear, they identified saturated areas. Then, using leaf on images and limited rule-based classification, they successfully discerned between wetland types.

Ernst-Dottavio et al. (1981) demonstrated that there are significant enough differences between permanent wetlands, open water and upland classes to be detected by MSS data, but had considerable problems differentiating among wetland classes and also ephemeral wetlands versus upland classes in Northeastern Indiana. Jensen et al. (1986) found that Spring MSS imagery was more effective in mapping wetlands in the Savannah

River watershed than TM Summer imagery was, proving that acquisition date can be as important as spectral sensitivity.

Iverson et al (1997) developed an integrated moisture index (IMI) to predict forest composition and productivity in Ohio forests by using 1:24,000 Digital Elevation Models (DEMs). The following ARC-INFO programs were used to create the IMI: FLOW ACCUMULATION, which determines the potential accumulated water flow due to gravity and CURVATURE, which calculates the shape of the landscape (flat, concave, or convex) and the HILLSHADE command, which accounts for the varying effects of solar radiation. Species were then assigned to areas based on their site moisture index ranges. The success of this project indicates that these geomorphological landscape features are strongly influential on hydrologic regimes.

Sader et al. (1995) used a rule based GIS model to improve accuracy when mapping wetlands using TM imagery in Maine. They incorporated existing NWI maps, soils data, slope percentage from DEMs and a hydrography layer into their decision rules, resulting in a classification accuracy nearly comparable with the NWI. They reported that hydric soils, the NWI, and slope percentage were the most important variables in GIS modeling of wetlands.

In conclusion, previous attempts to identify wetlands with satellite imagery have been promising and thus warrant continued endeavors. The best accuracies obtained are associated with rule based models and standard classifications derived from spectral signatures. It is my contention that a parsimonious rule based model can sufficiently aid interpretation so that even MSS data can be used to accurately identify wetlands.

LOCATION AND SITE DESCRIPTION

Physical Description

The entire Piedmont region runs from Montgomery Alabama to New York City, encompasses six state capitals and Washington D.C., and contains some of the fastest growing areas in the United States. The term Piedmont means "foot of mountain", meaning the foothills of the Appalachians in this case. The topography consists mainly of gently rolling hills and valleys, while the geology is described as largely metamorphosed Paleozoic and Precambrian rock (Godfrey, 1997). The Piedmont was formed 300 million years ago when the Appalachian Mountains were rising from uplift and simultaneously eroding, resulting in this rolling topography (Miller et al. 2000). The original metamorphic and igneous rocks have been weathered to a porous soil-like material termed saprolite to depths of 50-100 feet, and Ultisols are the primary soils that have subsequently formed (Miller et al. 2000).

The Piedmont region of Georgia (Figure 2.1), as defined by Keys et al (1995), is the region north of the Fall Line, which separates the Piedmont from the Coastal Plain, and south of the Appalachians (the Blue Ridge Province) and the Cumberland Plateau. It is approximately 44,000 km^2 or 4,400,000 hectares in extent, and contains the city of Atlanta and most of its metropolitan sprawl, which has been referred to as "the fastest spreading human settlement in history" (Lockard, 2000).

Historical and Current Landuses

The pre European Piedmont landscape was managed primarily by fire. Native Americans used fire to control the undergrowth, providing grazing for deer and other game and facilitating travel. Bartram aptly described the landscape in this period in his book Travels (Harper, 1996), saying that the Piedmont streams were perfectly clear and non turbid, and that the soils were dark and rich. These descriptions stand in stark contrast to the heavily turbid streams and lack of topsoil of today. The Piedmont was completely covered in old growth deciduous forest, so much so that the canopy stretched virtually unbroken across the entire area (Godfrey, 1997). This canopy was interrupted only by occasional agricultural fields cultivated by Native Americans (Harper, 1996, Trimble 1973). European settlement brought quick changes to the Piedmont. Beavers, which numbered 60 – 400 million in pre European North America, were trapped to the point of extirpation in some areas of the Piedmont by 1900 (Seton, 1929). Large tracts of land were clearcut and converted to farmland, peaking during the cotton booms of the 1860's and 1920's. The land management practices associated with this intense agriculture resulted in eroding an average of 7.5 inches of topsoil throughout the Georgia Piedmont (Trimble, 1973). Much of this eroded topsoil remained in the floodplains and river channels, creating wetlands through accretion of sediment in stream channels and on the floodplains (Trimble, 1969), and perhaps filling others up. This last cotton boom was followed by a gradual abandonment of agriculture lands to forest (including marginal wetlands such as highly fertile river bottoms) that persists today. The eroded topsoil (that has not washed downstream) is still present in the Piedmont streambeds today, combined with more currently eroded soil. There is now evidence of reversal; that less sediment is entering Piedmont streams than is exiting in at least some areas (Martin, 2001). The beaver population is making a recovery on the Piedmont, returning to the remaining available habitat, although it is estimated they are at best only 10 -15 percent (6 -12 million) of their pre European population (Naiman et al, 1988). However, the fastest growing landcover type on the Georgia Piedmont is now suburban uses, with a gain of almost 150,000 hectares over the past 20 years (Georgia Landcover Trends 1974-1998). This high impact landcover often clashes with beaver wetlands, which may cause unwanted localized flooding.

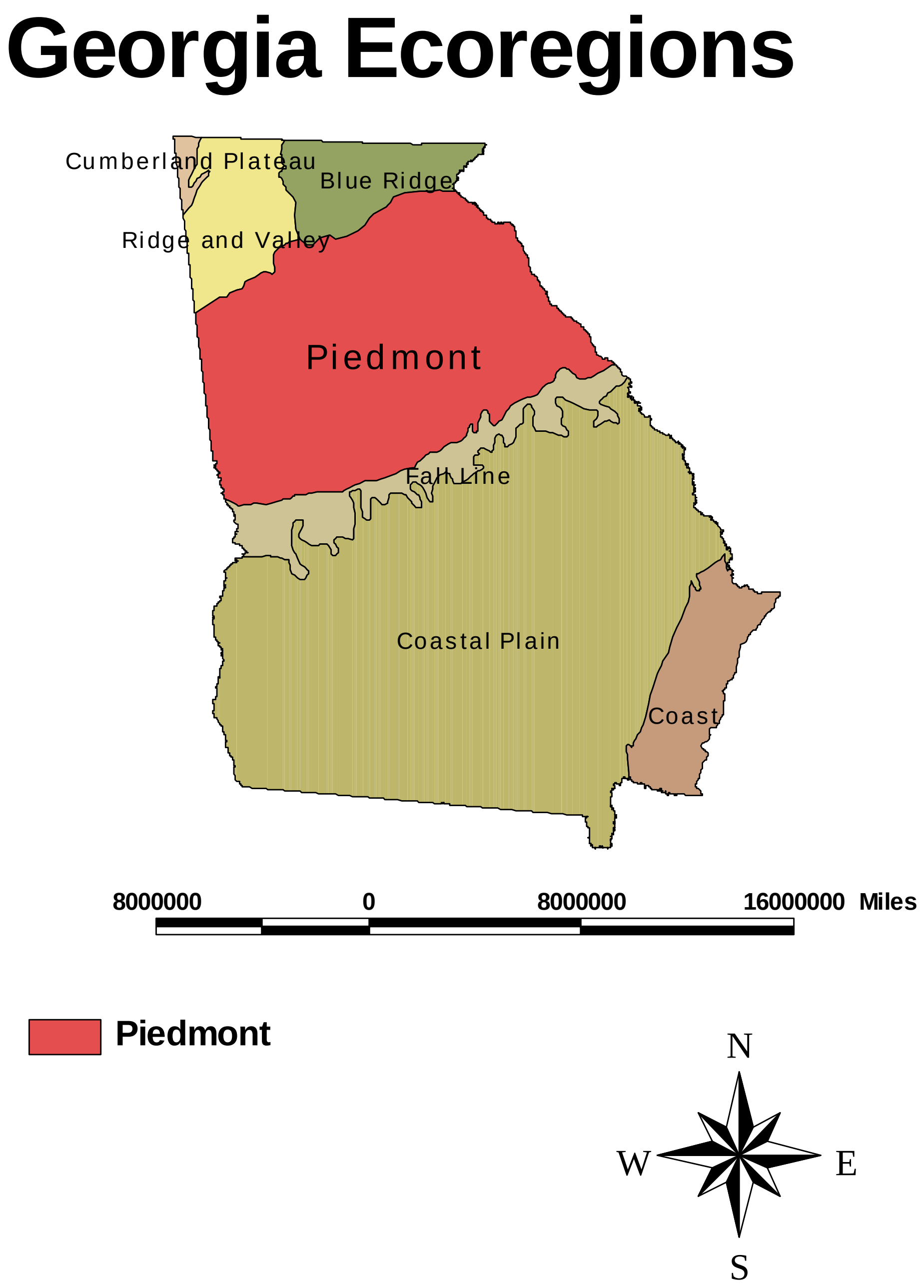

Figure 2.1 Location of the Georgia Piedmont, from Keys et al (1995), with the Piedmont highlighted in red.

METHODS

General Overview

This study defines a protocol for mapping wetlands in the Piedmont area of Georgia using multi-temporal Landsat MSS data from the 1970's. The MSS data was combined with modeling techniques that facilitated the speed of the classification process and improved accuracy. The rule-based model uses (1999) 1:24000 DEMs and the NWI. These two sources can be employed to simply rank the pixels of the satellite imagery according to likelihood of wetland occurrence, decreasing extraneous information and allowing increased interpretation time in areas where wetlands are most likely to occur. The DEMs are the most logical starting point for a wetland identification model at the Landsat resolution because they contain the information most indicative of wetland presence or formation in climates with adequate rainfall: topography sufficiently conducive to water retention. The NWI is also a reliable source of wetland presence as it is the most detailed wetland map for this area to date.

Imagery

Dates of high rainfall (State Climate Office Website), cloud-free (less than 10%) scenes were selected for leaf off imagery. Scenes were spread out over a 3-year period (1974- 1976), according to MSS availability. All scenes (Paths 18 and 19, Rows 36 to 37, and also Path 17, Row 37) were then georeferenced using the (leaf on) orthorectified North American Landscape Characterization (NALC) dataset as reference images. UTM

Zone 17, NAD 83 was the final projection chosen. Some spatial misregistration occurred during this process due to the pixel size (90 meters resampled to 60 meters) of the data (which hindered locating exact ground control points). It was not possible to correct this problem, which limited some comparisons (especially pixel by pixel) with other wetland maps. A 1998 leaf off TM scene (Path 18 Row 37) was also chosen and clipped for a five county area in the Georgia Piedmont (Clarke, Oconee, Greene, Morgan and Oglethorpe counties). See Table 3.1 for a comparison of Landsat MSS and TM imagery.

Variable Creation

A pre-release version of the National Elevation Dataset (NED) data was obtained from the Georgia GIS Data Clearinghouse. The NED is a seamless mosaic of existing DEMs (resolution of 1 arc-second or approximately 30 meters). The NED was clipped for the Georgia Piedmont region with a 1-kilometer buffer. The Piedmont boundaries used are those delineated by Keys et al (Ecological Units of the Eastern United States). The northern boundary was modified so that all metro Atlanta counties were included. Slope gradient (degrees) was then computed from the DEM using the ARC/INFO program SLOPE.

The NWI coverages were then mosaiced together to create a seamless coverage of the Piedmont. All NWI codes were then recoded to two categories: wetland and non-wetland, with all open water categories being included as wetland. This vector coverage was then converted to a raster format in ARC/INFO's POLYGRID program.

By overlaying the SLOPE and the NWI (Figure3.2), it was found that 65 % of NWI wetlands occurred at a slope gradient of 0 to 1.999 degrees, and 10 % were found at

2 to 2.999 degrees. Only 25 % of NWI wetlands were found at slopes of 3 degrees or greater. This knowledge was used to establish cutoff values for the slope index. These two slope ranges account for 15% and 28%, respectively, of the total area of the Piedmont. This knowledge was used in creating cutoff values for the index.

The final wetland index was created with weighted values as follows (see Table 3.2): slopes of 0 to 1.999 degrees were assigned 4 points, a slope range of 2 to 2.999, 2 points, and a positive (there is a wetland) for the NWI, 8 points. The resultant index from the slope and NWI overlay contains values of 0, 2, 4, 8, 10 and 12, with a value of 0 indicating the least likely occurrence of wetlands, and a value of 12 having the highest likelihood of wetland occurrence. A version of the index was then resampled to 60-meter pixels for consistency with the MSS data (Figure 3.3).

Imagery Processing

The next step involved dividing each Landsat scene into three images: very likely to contain wetlands (index values 8, 10, and 12), likely to contain wetlands (values 2 and 4), and not likely to contain wetlands (0 values). This was done by masking the MSS imagery with the appropriate index values. This reduces the amount of spectral variability in each image, decreasing interpretation time and improving accuracy. This will be explained further after the next step is discussed.

These 3 sets for each of the 6 scenes (all 4 bands) were the inputs into the ERDAS Iterative Self-Organizing Data Analysis Technique (ISODATA) (Tou and Gonzalez, 1974) function. ISODATA clustering uses spectral distance to divide an image into categories according to the differences among pixel values. This ordering is based on the premise that values within a given cover type should be close together in spectral space and that different classes should be separated. The ISODATA iteratively classifies all pixels in an image, redefining the criteria of each class and reclassifying at each iteration. The resulting classes are thus natural groupings of the image values, and it is left up to the interpreter to determine what their identities are. This provides the advantage of visual inspection of all candidate pixels, and helps to account for the wide variability of both wetland and water signatures.

The number of these classes per image is dependant upon the interpreter's preliminary assessment of the spectral range of the input image. An image containing a highly diverse range of spectral signatures will require that the interpreter request a large number of classes, while a more homogenous image will demand fewer. A key feature of the ISODATA is that as the amount of classes is increased, more finely divided clusters are created. For instance, a class that contained both turbid water and clear water in a large image could be separated if more classes are requested. However, requesting more classes in an image does not guarantee that all landcover types will be recognized as an individual category. Spectral variation among landcover types and spectral similarities between landcover types cause errors of both omission and commission. Elimination of areas that may be confused with wetlands from an individual ISODATA reduces these problems. As the spectral variation of an input image is reduced, pixels with moderately different signatures are more likely to be separated out as an individual class.

Since each input image had a relative likelihood of wetland occurrence (per the wetland index), each resultant ISODATA cluster could be interpreted accordingly. In

ISODATA clusters that were most likely to contain wetlands, interpretation consisted mainly of eliminating those pixels that did not appear to be wetlands. On the other end, for the input images that were unlikely to contain wetlands, interpretation consisted of identifying the few wetlands that were present.

Decision Rules

To provide a baseline for the MSS scenes, radiance values of wetlands were also determined by an overlay of the NWI and the MSS data. Radiance values were reported in digital numbers (DN's), in the 0-255 range (Figures 3.4 – 3.10). DN's are simply measures of brightness recorded by the satellite sensor. The spectral response patterns were divided into water and all other wetlands using a sample area of known wetlands from the NWI. These response curves, along with preliminary ISODATA clustering, were used to designate decision rules for interpretation. Band 3, though included in the ISODATA cluster, was not used in decision rules due to similarities between wetlands and water in that band. The high variability in the water signatures is probably due to the wide spectral contrasts between clear water, turbid water, shallow water, deep water, bare sand (from lake drawdowns), and edge vegetation.

Each generated ISODATA cluster was subjected to decision rules, with positive decisions meaning that that cluster was called either wetland or open water. If individual clusters contained both pixels within and outside the desired range, then that cluster was subjected to further ISODATA clustering to separate the landcover types. The positive decision rules were approximately as follows, with slight modifications to account for the spectral differences between scenes (see Tables 3.3 and 3.4). The general trend of narrowing the range of positive decisions as the likelihood of wetland occurrence declined (according to the rule based model) was supposed to provide a more conservative estimate.

In imagery areas that satisfied wetland index values of 8, 10 or 12: if any class had (predominantly) radiance values of 10 (DN) or less in band 4 (0.8-1.1μm), a DN between 14 to 30 in band 2 (0.6-0.7μm), and a DN of 18 to 29 in band 1 (0.5-0.6μm) then it was called water. If any class had radiance values of 11 to 20 in band 4, 12 to 19 in band 2, and 19 to 23, band 1, then that class was called wetland. All other pixels were called non-wetland.

In imagery areas that coincided with wetland index values of 2 and 4 the range of reflectance values was narrowed as follows. If any class had values of 10 and under (same) in band 4, 20 to 28 in band 2, and 21 to 27 in band 1, then that class was called water. If any class had values of 13 to 18 in band 4, 14 to 17 in band 2, and 19 to 21 in band 1, then that class was called wetland. All other pixels were called non-wetland.

In imagery areas that coincided with wetland index values of 0, the range was narrowed even further. If a class had values of 10 and under in band 4, 21 to 25 in band 2, and 23 to 26 in band 1, then that class was called water. If any class had values of 16 to 18 in band 4, 15 to 16 in band 2 and 20 to 21 in band 1, then that class was called wetland.

During this stage some classes that fell within the desired spectral ranges were eliminated. This was usually in highly developed areas such as urban centers, and only when these landcover types were clearly discernible from the raw MSS imagery, displayed in bands 4 (red), 2 (green) and 1(blue). There were also pixels that did not fall within the desired ranges that were called wetland or water since they were clearly discernible on the raw imagery.

The final step consisted of merging all three classifications together to create one scene-wide raster image. This image was then manually edited for obvious, visible mistakes such as wetland pixels inside large reservoirs (open water). The final Piedmont map was created by merging all final scene maps together.

The 5 county TM scene was also processed using the same methodology. The scene was subset according to the wetland mask, and interpreted accordingly. Similar decision rules, slightly adjusted for the different bandwidths of TM scenes, were used.

Comparison of MSS and TM

Wetlands and open water were compared for the 5 county areas by totaling the area (in hectares) for each category per classification. The totals were then listed in a table to facilitate comparison.

Comparison with 1998 Landcover and 1974 Landcover

Wetlands and open water were compared for the Piedmont by totaling the area for each category per classification. A pixel by pixel analysis was also done by determining what landcover each pixel of changed wetland had been converted to in 1998. Also, a pixel by pixel analysis was then done to determine what landcover 1998 wetlands had been converted from using the 1974 Landcover map.

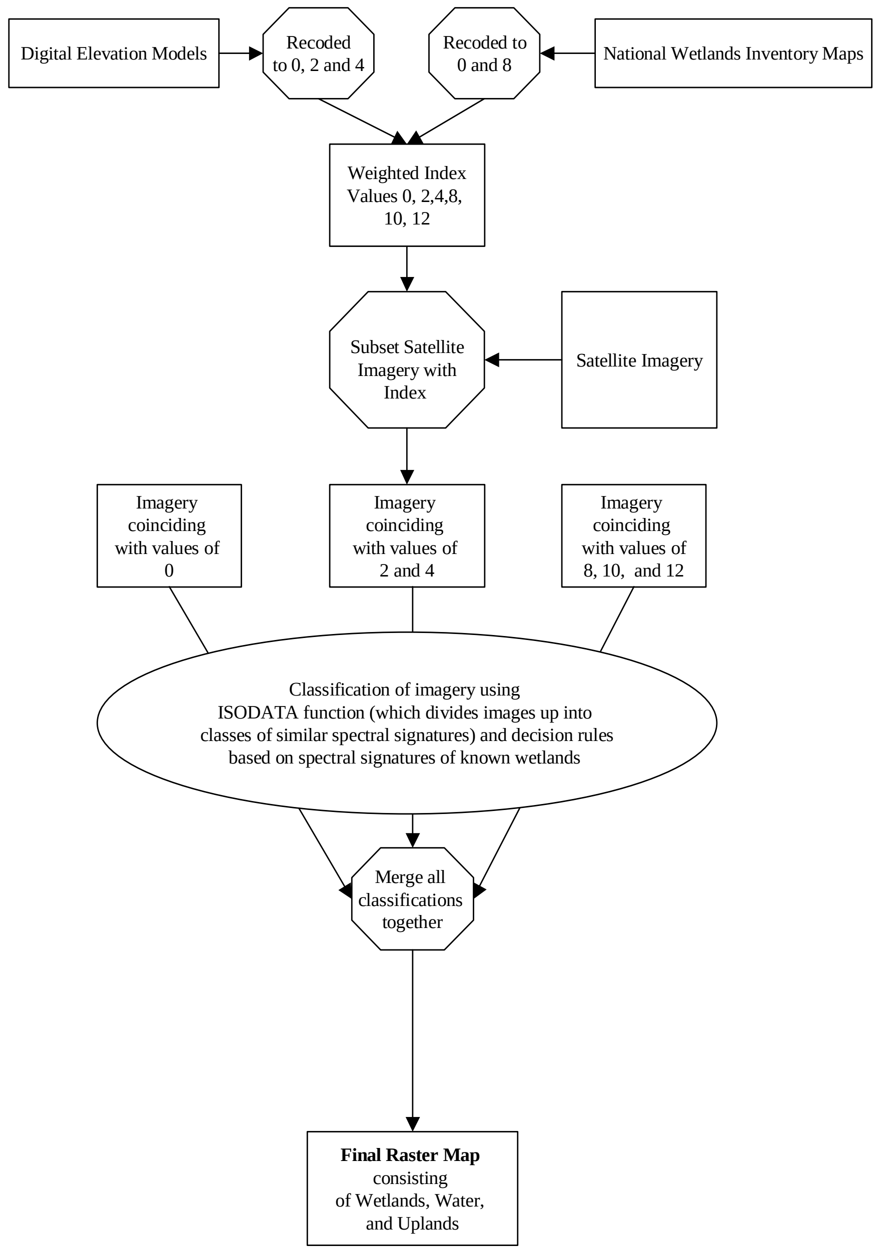

Figure 3.1 Methodology Flow Chart

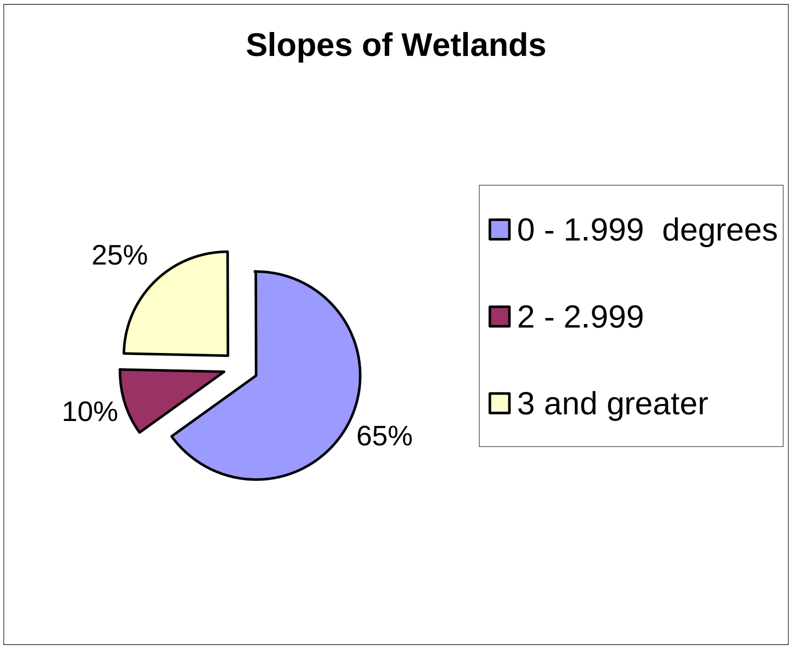

Figure 3.2 Slope ranges that Georgia Piedmont wetlands are located on, according to the NWI and DEM. The 25% of wetlands that are at slopes of 3 degrees or greater may be attributable to spatial misregistration between the two data sets. These values were used to weight the index according to slope.

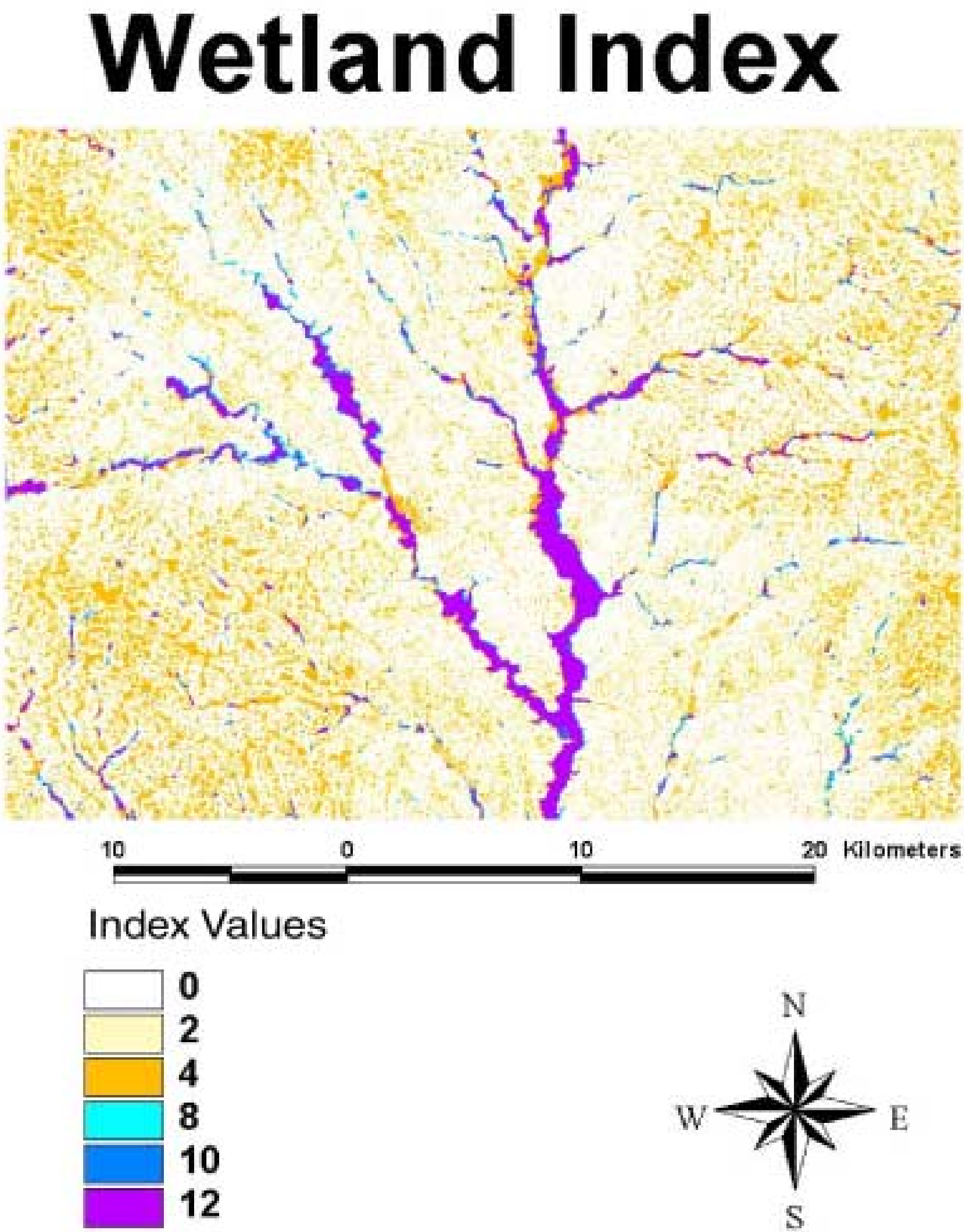

Figure 3.3 Wetland Index, with values of 0 (clear) indicating lowest probability of wetland occurrence, and values of 12 (purple) the highest. This area is centered on Greene County, GA.

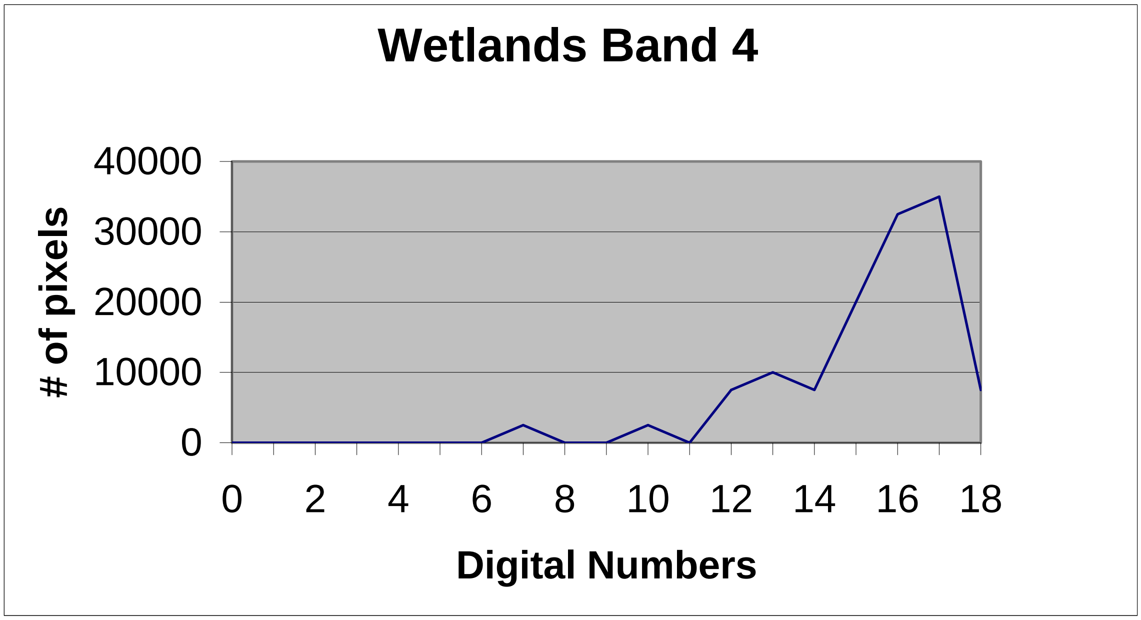

Figure 3.4 Reflectance of some known NWI wetlands in band 4 of raw MSS imagery. These reflectance curves were used to approximate what wetlands reflected like in individual scenes.

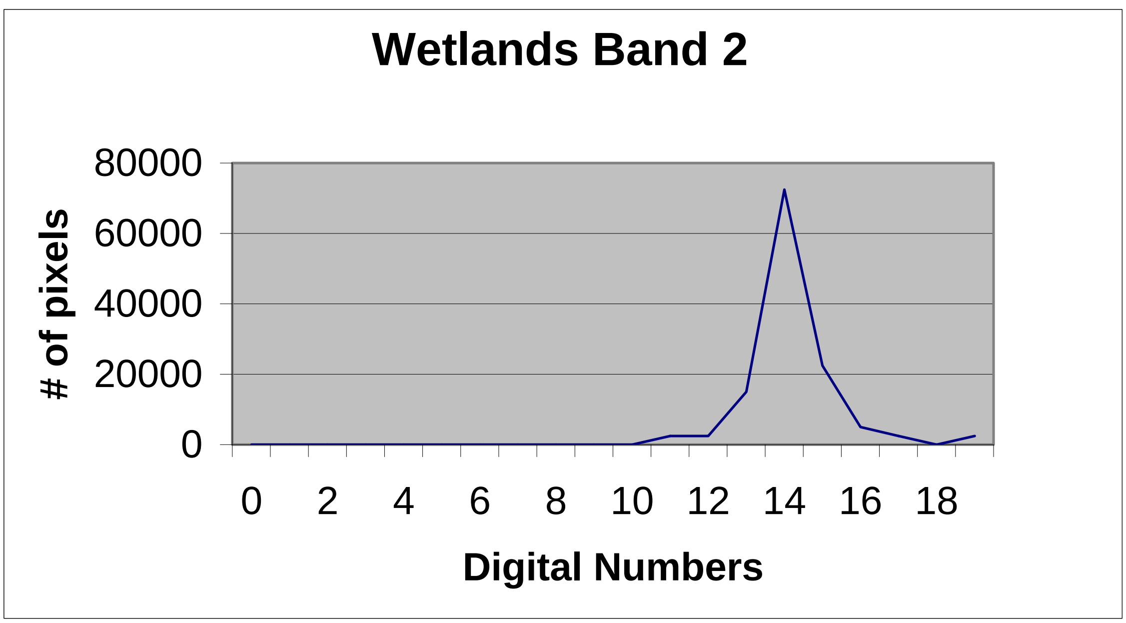

Figure 3.5 Reflectance of NWI wetlands in band 2 of raw MSS imagery.

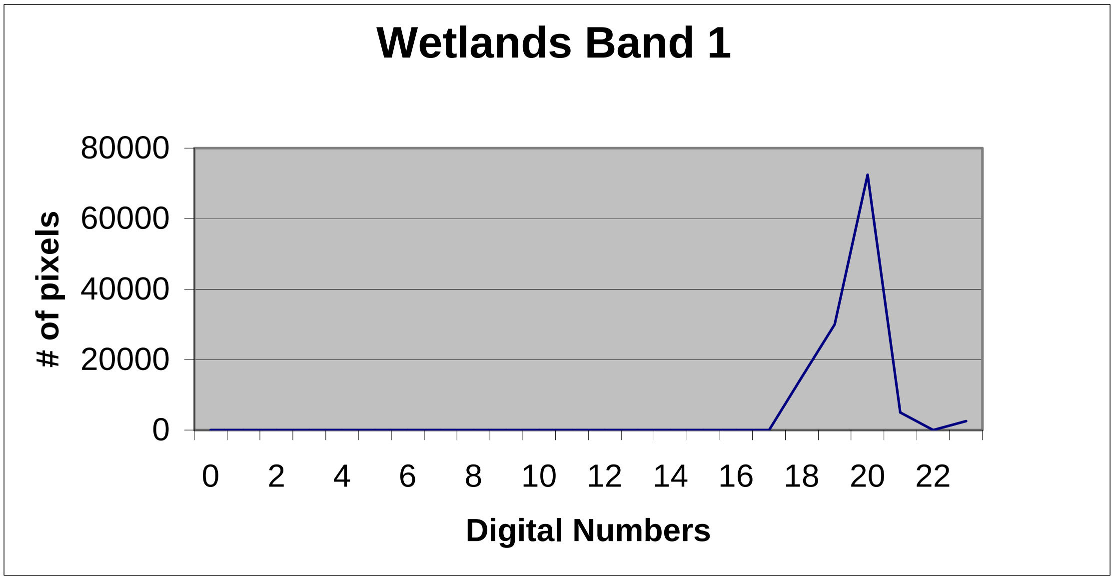

Figure 3.6 Reflectance of NWI wetlands in band 1 of raw MSS imagery.

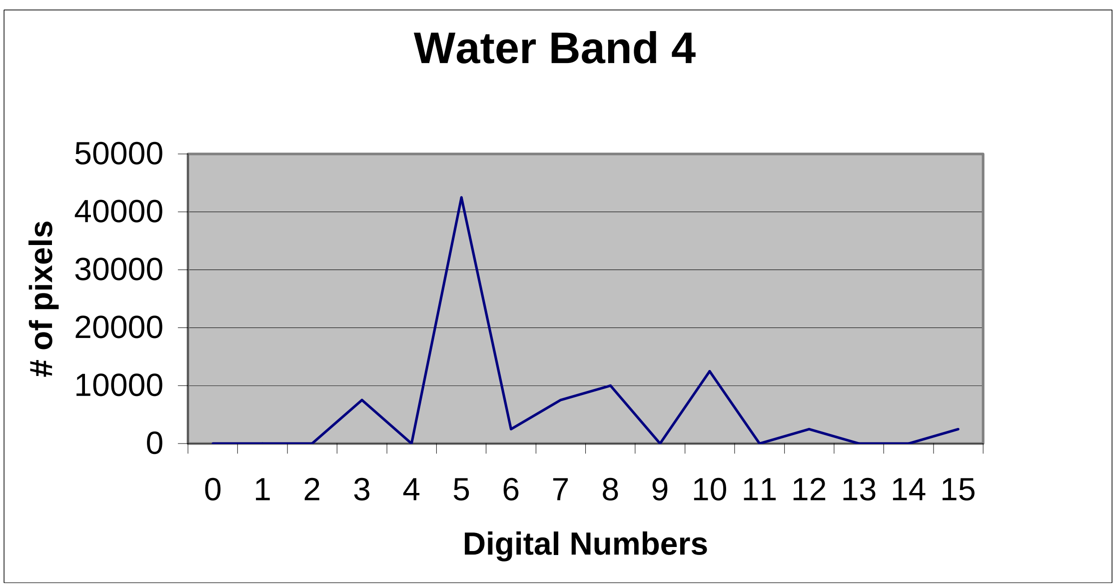

Figure 3.7 Reflectance of NWI water in band 4 of raw MSS imagery.

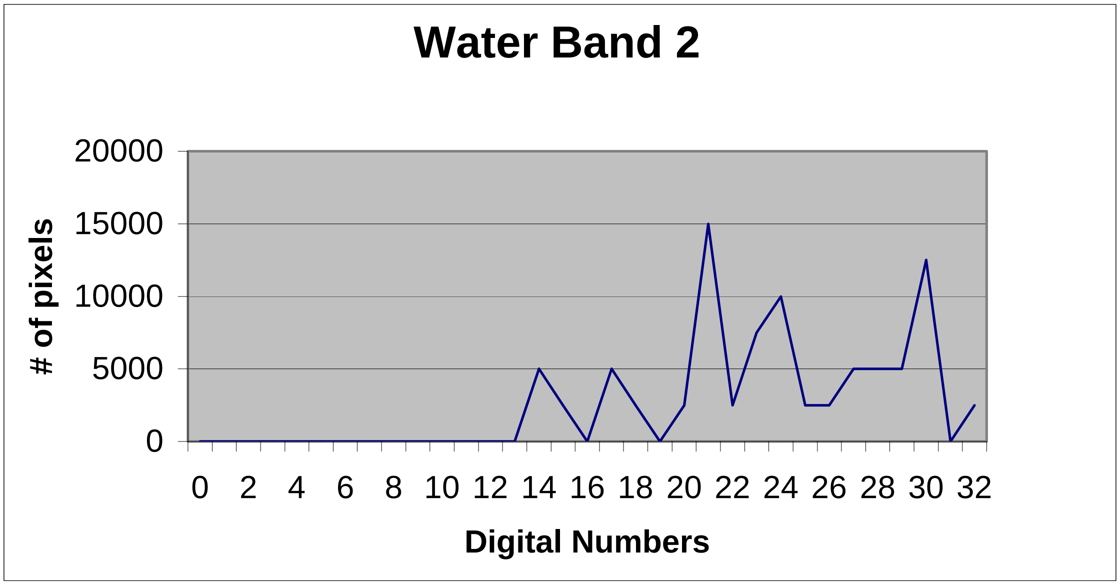

Figure 3.8 Reflectance of NWI water in band 2 of raw MSS imagery.

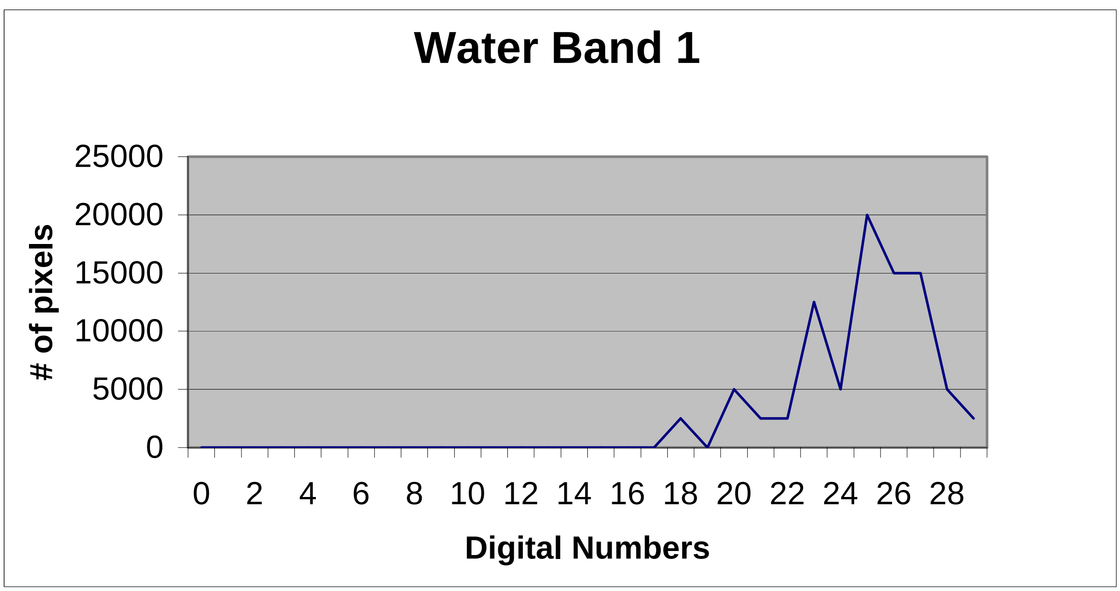

Figure 3.9 Reflectance of NWI water in band 1 of raw MSS imagery.

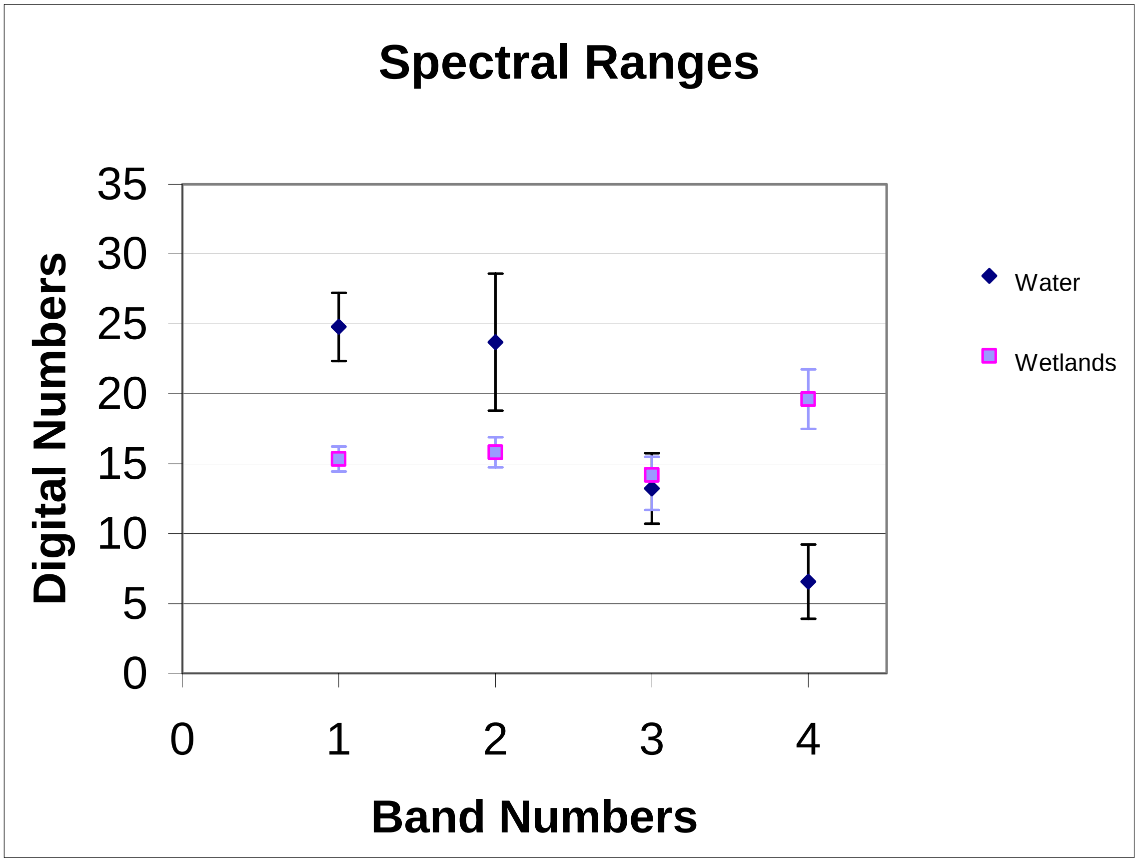

Figure 3.10 Reflectance of wetlands and water from NWI and MSS overlay, shown with standard deviations. All reflectance values for each band of each known wetland were included.

Table 3.1 Table comparing differences in number of bands, wavelengths of sensors, and ground resolution (pixel size) between Landsat MSS and TM satellites.

Landsat MSS				**Landsat TM**		
Bands	Wavelength	Pixel Size		Bands	Wavelength	Pixel Size
1	.5-.6 µm	80 meters		1	.45-.52 µm	30 meters
2	.6-.7	"		2	.52-.56	"
3	.7-.8	"		3	.63-.69	"
4	.8-1.1	"		4	.76-.9	"
				5	1.55-1.75	"
				6	10.4-12.5	120 meters
				7	2.08-2.35	30 meters

Table 3.2 Table showing resultant contributions of slopes and NWI to wetland index.

Index Values	2	4	8	10	12
Variable Contribution	Slope of 2-2.999	Slope of 0-1.999	Positive for NWI	Positive for NWI & slope of 2-2.999	Positive for NWI & slope of 0-1.999

Table 3.3 Positive decision rules used for determining that a given class is water.

	(Index Values): 8, 10 and 12	**4 and 2**	**0**
Band 4	10 or less (DN)	10 or less	10 or less
Band 2	14 to 30	20 to 28	21 to 25
Band 1	18 to 29	21 to 27	23 to 26

Table 3.4 Positive decision rules used for determining that a given class is wetland.

	(Index Values): **8, 10 and 12**	**4 and 2**	**0**
Band 4	11 to 20	13 to 18	16 to 18
Band 2	12 to 19	14 to 17	15 to 16
Band 1	19 to 23	19 to 21	20 to 21

ACCURACY ASSESSMENT

Need For An Accuracy Assessment

An accuracy assessment is an integral part of introducing a new protocol for classifying landcovers. In order to see if the method is worth repeating and to compare the potential of this protocol with other methods, the reliability of the results must be tested. Using a (separate) data set that is randomly produced and is not employed in the generation of the classification provides a valid form of assessment. The most common way to represent the classification accuracy of remotely sensed data is in the form of an error matrix (Congalton, 1991). This method was used here, and supplemented with techniques that account for its shortcomings.

Methods

An adequate accuracy assessment for the wetland map presented problems on two fronts: the size of the area to be sampled from (number of samples), and the time gap between the 1970's MSS data and today. Since accessibility to many areas is limited, both of these problems were compounded by the necessity to ground truth every sample. Air photos were deemed inappropriate for these reasons: there are not color infra red (CIR) photos for the 1970's, and there are inaccuracies associated with interpretation of black and white air photos for wetlands. By visiting a site however, usually a reasonable decision (as to whether or not the point was a wetland in 1974) can be made. The following protocol was designed to circumvent these problems.

First, the wetland map was used as in input in the CLUMP program in ERDAS. This program identifies all contiguous pixel groups and gives them a unique identifier, so that the pixel groups can be treated individually. In effect, CLUMP creates patches of groups of contiguous pixels. For instance, a linear feature such as a river, which in raster format consists of many pixels containing their own unique identification, will be 'clumped' together and given a single identifier. All size classes, including single pixel CLUMPS, were kept. The CLUMP was then masked by a 60 meter-buffered roads coverage of the Piedmont, resulting in a CLUMP that contained only mapped wetlands and open water within 60 meters of current roads. This CLUMP was then the input in an ArcView Avenue Script designed to randomly generate points according to typical stratified random sampling design. One hundred-twenty five points were requested for water clumps, and 125 for wetlands. A moving window of only one pixel was used so that even the smallest size class could be sampled. For the upland points, the same procedure was employed, with one change: the points were generated in the ERDAS statistics package. A total of 200 upland points were generated.

A total of 201 reference points were visited out of the possible 250, 109 for water pixels and 92 for wetlands. Eighty six upland points were sampled. This number of samples is above the minimum suggested by Lillesand and Keifer (1994), who recommend at least 75 samples per category if the interpreted area is more than 4000 km^2. As many accessible points as possible were visited (many points were inaccessible for various reasons, including private property and roads coverage inaccuracies) and a GPS unit was employed to ensure ground accuracy.

Once a wetland or water point was located on the ground, all possibilities were considered: was it a wetland or water, and if so, could it have been a wetland or water in the 1970s? If it was not a wetland or water, could it have been a wetland or water in 1970s? Validation consisted of considering any visible signs of recent human influence on the landscape or hydrology, a cursory estimation of tree ages, and of any other indicators. If no certain conclusions could be drawn, then that point was dropped from the accuracy assessment.

When an upland point was located on the ground, all possibilities were again considered: was it an upland site, and if so, what type? Would it have been an upland site in 1974? It should be noted that due to the vast area involved for this category, it is probable that more points are needed to adequately sample this area's accuracy in relation to wetland omission.

A standard error matrix was used to report the results. This assessment consists of creating a table of errors of exclusion (omission) and inclusion (commission) with the landcover classes being mapped. Also, the overall percentage correct and a Kappa coefficient were calculated. The Kappa coefficient serves as and indicator of the extent to which the percentage correct values of an error matrix are due to 'true' agreement versus 'chance' agreement (Lillesand and Kiefer, 1994).

Wetland Boundaries

Since individual points do not describe accuracies associated with extents of wetlands, another type of assessment was devised. To see how mapped wetlands compared with actual boundaries of wetlands on the ground, a few accessible wetlands were picked to spatially delineate (digitize) with a GPS unit, and then comparisons were drawn from a direct overlay of the matching wetland coverage. Also, in order to show the type of wetland most omitted from the map, a wetland dominated by evergreen understory (privet) was digitized by GPS, and compared to the final wetland map.

RESULTS

Introduction

Pre-classification images and results for the MSS classification are presented graphically, followed by error matrices and Kappa statistics from the accuracy assessment. Also presented graphically are the TM classification and the digitized routes used to compare boundaries. Next, results of the MSS and the TM classifications are listed for comparison. Finally, results from the comparison with the 1998 Landcover are listed.

Final Wetland Classification

The raw MSS imagery and a portion of the results for the MSS classification are presented in Figures 5.1 and 5.2. This area is from path 18, row 37, centered on Athens-Clarke County, at the confluence of the North and Middle Forks of the Oconee River. For Figure 5.2, the county outlines (in black) provide a scale perspective. Figure 5.2 also shows that (with the 1:24,000 hydrology, in red) the Piedmont wetlands are mostly riparian.

Visually, the map appears to accurately represent Piedmont wetlands. The larger wetlands follow river corridors, and smaller, more isolated wetlands are interspersed in the surrounding uplands. This is typical in this region, and so reflects wetland distributions on the Georgia Piedmont. The larger, known reservoirs such as Lake Oconee also show up well, indicating that the open water class was mapped accurately.

Error Matrices and Kappa Statistics

The accuracy assessment for the MSS classification is summarized in Table 5.1. The wetland class was identified with a producer's accuracy (omission) of 96 percent, and a user's accuracy (commission) of 93 percent. Water was classed with a producer's accuracy of 100 percent and a user's accuracy of 95 percent. Upland was classed with a producer's accuracy of 92 percent and a user's accuracy of 100 percent. The overall accuracy of the classification was 96 percent, and the Kappa statistic (KHAT) was 94 percent.

Table 5.1 shows little confusion between any classes was evident. The conservative approach used when performing the classifications may cause few errors of commission, but such an approach increases errors of omission. Despite sampling considerably from the upland area, no errors of omission were recorded. This is most likely because of the inability to adequately sample so large an area, especially an area that is unlikely to contain wetlands. Some omission errors due to MSS spatial and spectral resolution may have also gone unnoticed, and an attempt to account for this follows (ROUTES section). Since each pixel is 60 by 60 meters, the total area covered (by each pixel) is 3,600 m^2. A ground object which is half the size of this (1,800 m^2) may be the dominant spectral signature in a given pixel. However, a ground object that is 3,600 m^2 or larger may be divided equally between two or more pixels, and so be undistinguishable by spectral analysis. So, this coarse resolution obviously misses many wetlands smaller than a pixel, primarily isolated and small, linear wetlands, small farm ponds, and wetland edges.

Accuracy For Routes

The results of the overlay of the digitized routes (wetland boundaries) with the wetland map are presented graphically in Figures 5.3 through 5.7 (GPS Routes 1 through 5). Points are connected to aid visual assessment. As evident, the exact extents of most wetlands were incorrect. This error seems to be consistently due to the marginal land between uplands and wetlands, areas that in wet years may be wetlands, and in dry years not. As noted above, this could be attributable to a low water level for this imagery's acquisition date, or the location of the wetland edge in relation to the pixel. Another possibility is spectral insensitivity to shallow water environs, which may contain vegetation that skews the typical water signature. Another problem is that shallow water areas can also allow reflection of the benthic substrate. This is evident in reservoirs edges, where annual drawdowns for flood control produce a side effect of no littoral habitat. Emergent vegetation is thus kept at a minimum in these lakes, but these were often still called wetland instead of open water (Figure 5.8). Spatial misregistration of the map itself may also play a part.

The results of the digitized privet wetland are displayed in figure 5.9 (GPS Route 6). The Oconee River forms the eastern boundary of the wetland. The raw MSS imagery for that same area is shown in Figure 5.10, with the digitized wetland displayed in and brown, and the hydrology (the Oconee River) in blue. Though standing water was probably present at this location when the imagery was acquired, the privet's evergreen canopy prevents light penetration. Contrast this area with the wetland located to the east (the Oconee River, with its deciduous canopy), where the darker, bluish color indicates standing water. On-site inspections yielded anoxic soils and hydrophytic vegetation at both sites. The total amount and area of these types of wetlands on the Piedmont has not been assessed as of yet. Privet, however, is an invasive species capable of changing the hydrology of floodplains by increasing sediment accretion rates and isolating riverine wetlands from inundation (Ward, 2002). Privet is present in disturbed floodplains across the Piedmont (Ward, 2002), so omitting them from any wetland map could be a significant source of error.

Comparison of TM and MSS Results

The results of the 5 county area are shown for both the TM and MSS classifications in Table 5.2.

For the five-county area, approximately 7,670 hectares of open water were created in the 25-year period. Much of this figure can be attributed to the damming and subsequent filling of the reservoir Lake Oconee (5,360 hectares), but there was also a considerable gain in farm ponds, both in-stream and excavated (3,560 hectares). Also created along with these reservoirs are emergent wetlands. The edges and deltas (inlets of instream reservoirs) of most reservoirs eventually become emergent wetlands after colonization by wetland plants. Even Lake Oconee, being one of the few reservoirs in Georgia not managed for flood control, contributes a significant amount of littoral habitat. These contributions, however, offset the overall loss of wetlands in this area.

For the same time period, approximately 140 hectares of wetland were lost. As noted, this is an overall estimate, and does not consider relocation of wetlands or even conversion from one type to another. For instance, if a forested wetland was flooded under a reservoir, and an equally sized emergent wetland was created at the inlet of the reservoir, the loss will be zero.

Comparison with 1998 and 1974 Landcover Maps

The 1998 Landcover Map is the most obvious overall source of comparison for the 1974 map. Table 5.3 shows that an overall loss of 12,000 hectares (12%) of wetlands occurred over the 20-year period, while 43,000 hectares of open water were created. This comparison indicates that wetland loss is still occurring on the Georgia Piedmont, and that open water is increasing.

However, an overall comparison does not account for the amount of relocation- where a wetland was converted in one area, but another was created elsewhere. Nor can an overall comparison determine what landcover category wetlands were converted into. A pixel-by-pixel comparison (Figures 5.11) with the 1998 Landcover was used to determine what landcover type wetlands were converted to. It must be noted that this type of comparison is affected by spatial misregistration, in which slight differences between the spatial registration of the maps can be a source of error. When this type of error occurs, the results can be particularly misleading. For instance, if a single pixel wetland is located at grid coordinates (x, y) on the 1974 map and (x + 1, y) on the 1998 map, then a pixel by pixel comparison will mistakenly conclude that that wetland has been converted. If a shift occurs over large areas of either map, then the results of a pixel by pixel comparison can be a significant source of error.

Since the pixel by pixel comparison with the 1998 Landcover produced more conversions than total losses, wetlands in the 1998 Landcover were then compared with the 1974 Landcover to see what landuse categories were converted into wetlands (Figure 5.12).

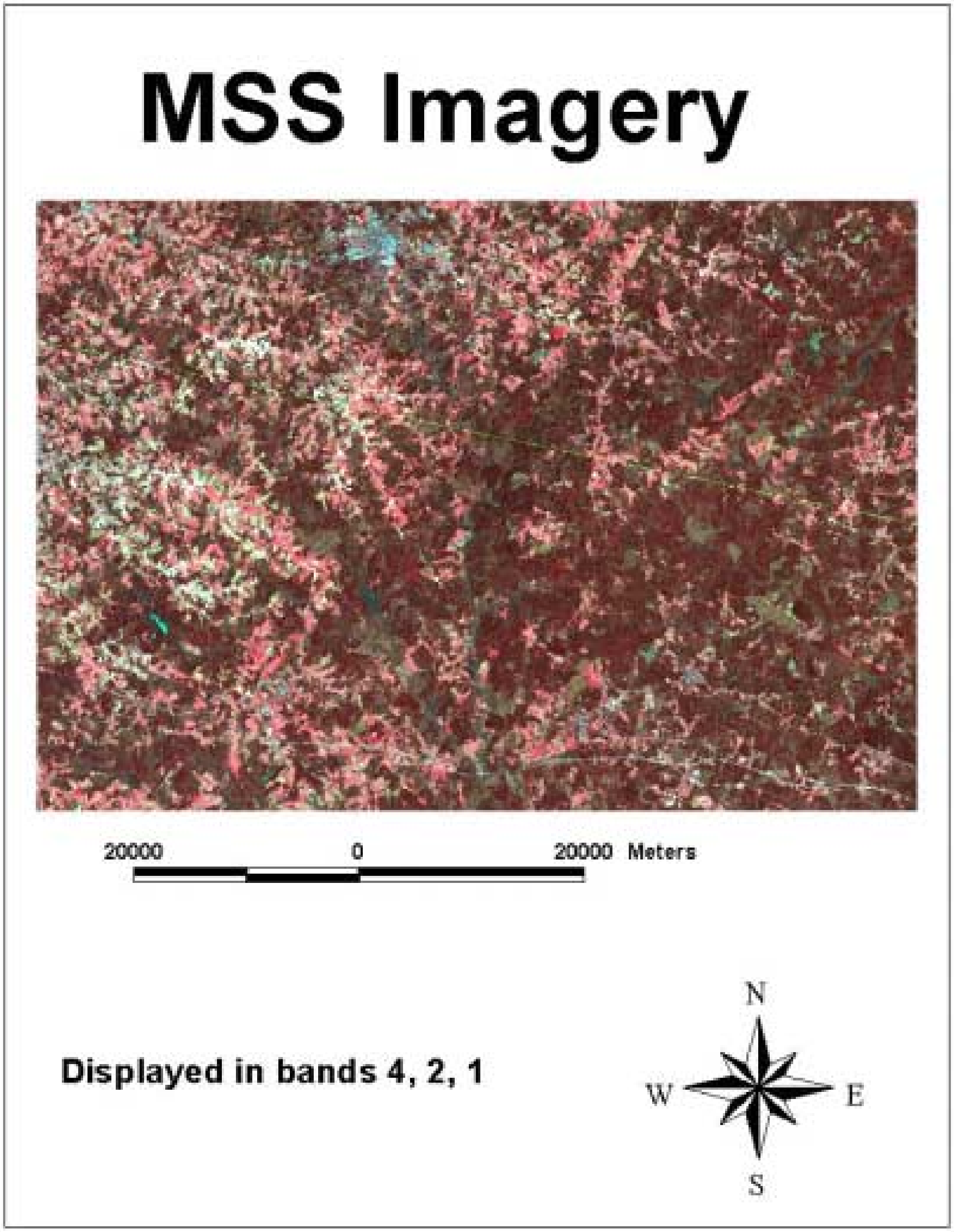

Figure 5.1 Unclassified MSS imagery, with Athens, GA at top of image (bluish-white).

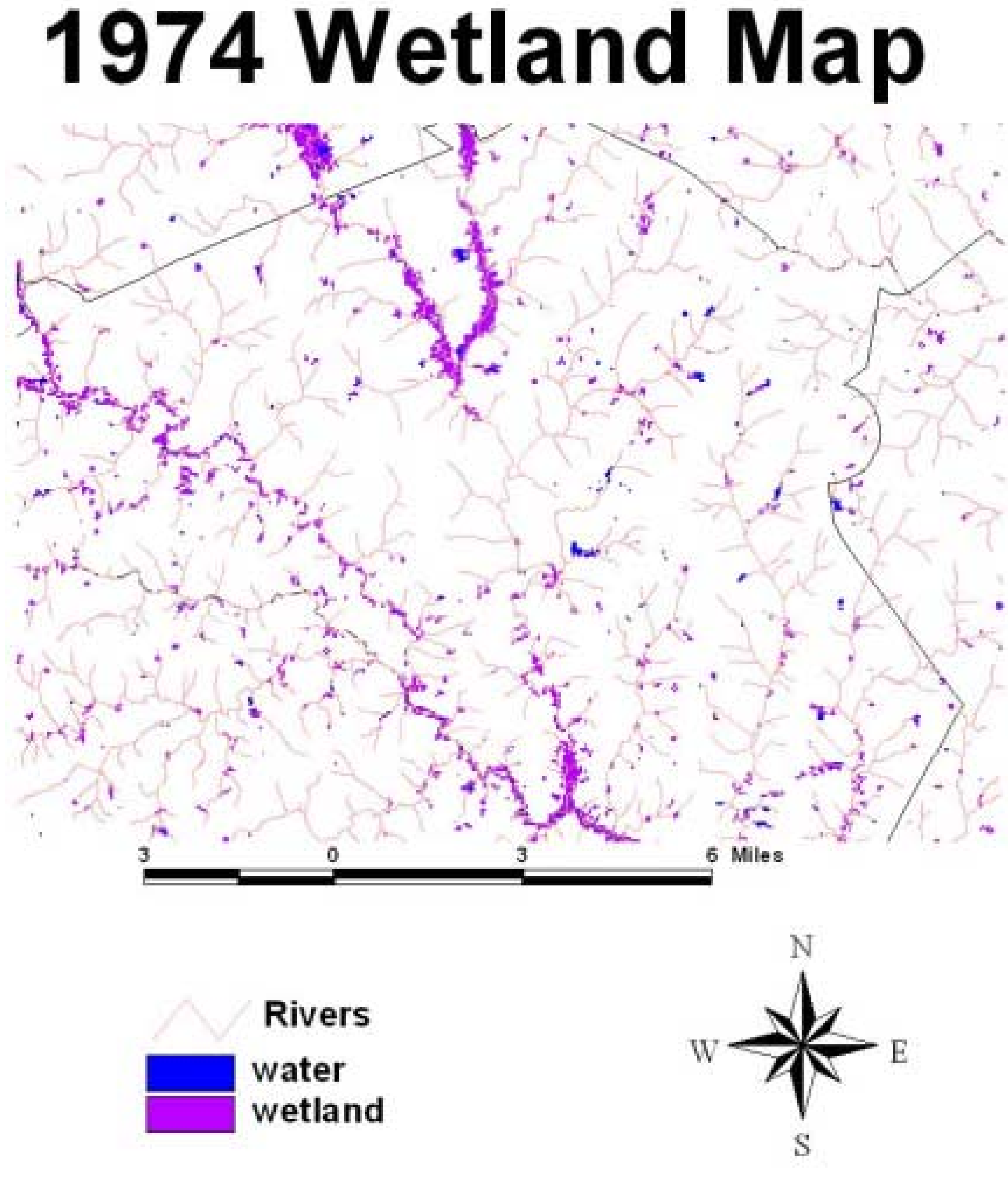

Figure 5.2 Portion of final wetland classification centered on Athens, GA, with hydrology (rivers and streams) in red and county lines in black.

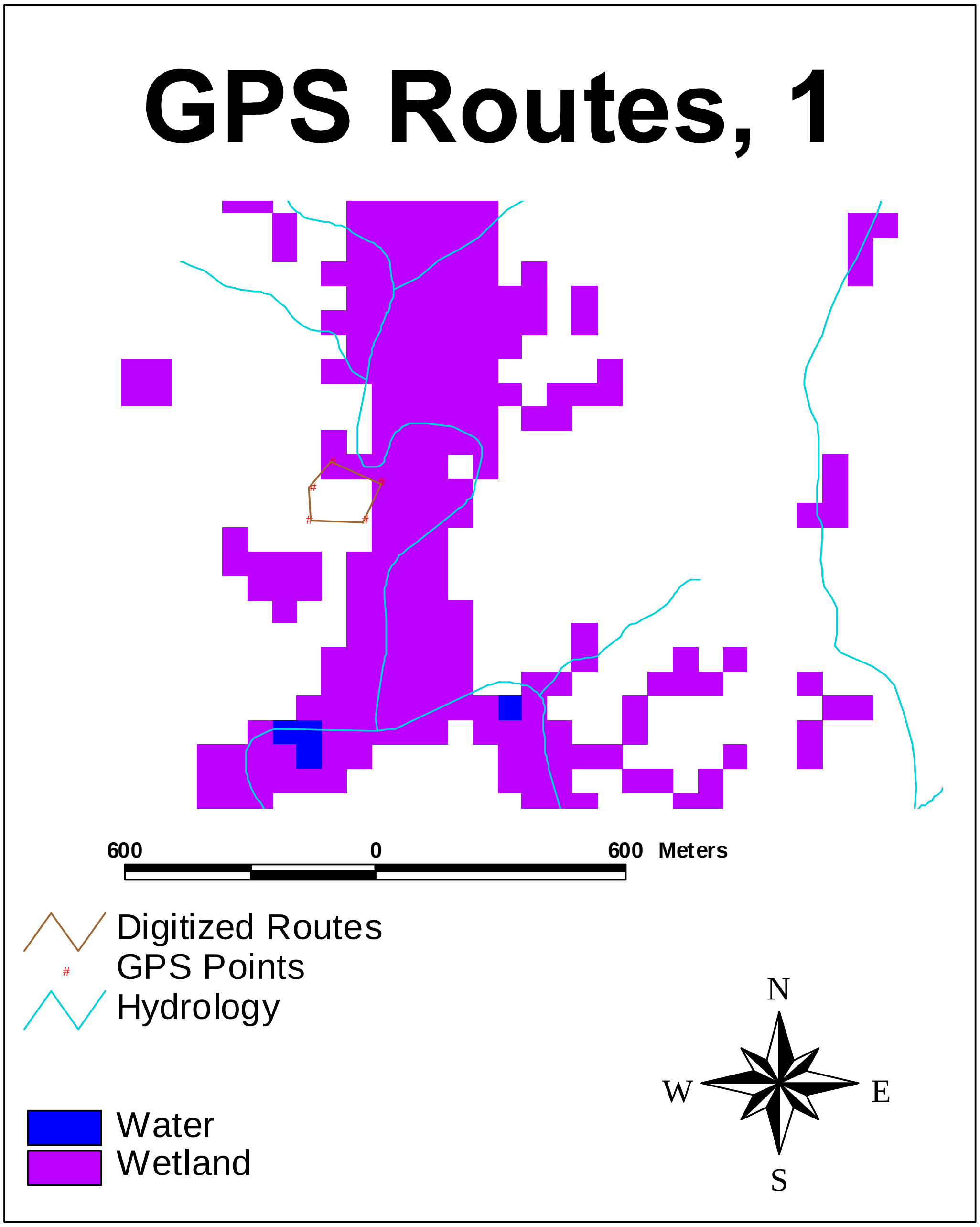

Figure 5.3 Digitized route near the confluence of the Middle and North Forks of the Oconee River, showing errors of extents and spatial misregistration. The hydrology network is shown as the midpoint of the streams, not to actual size. The purple (wetland) and blue (wetland) areas are the final classification of the 1974 wetland map.

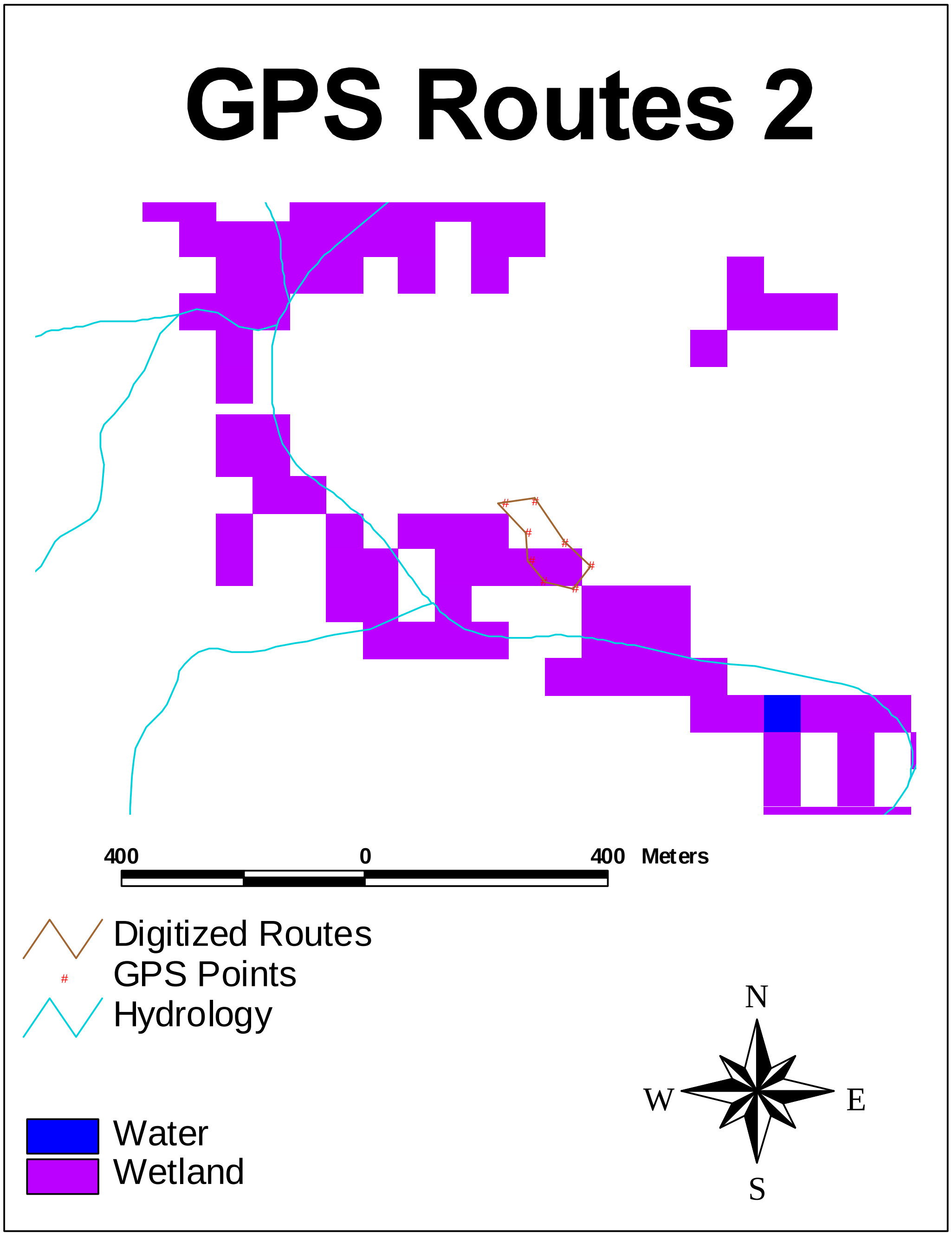

Figure 5.4 Digitized route near the State Botanical Gardens of Georgia, on the Middle Fork of the Oconee River, showing errors of extents and spatial misregistration error.

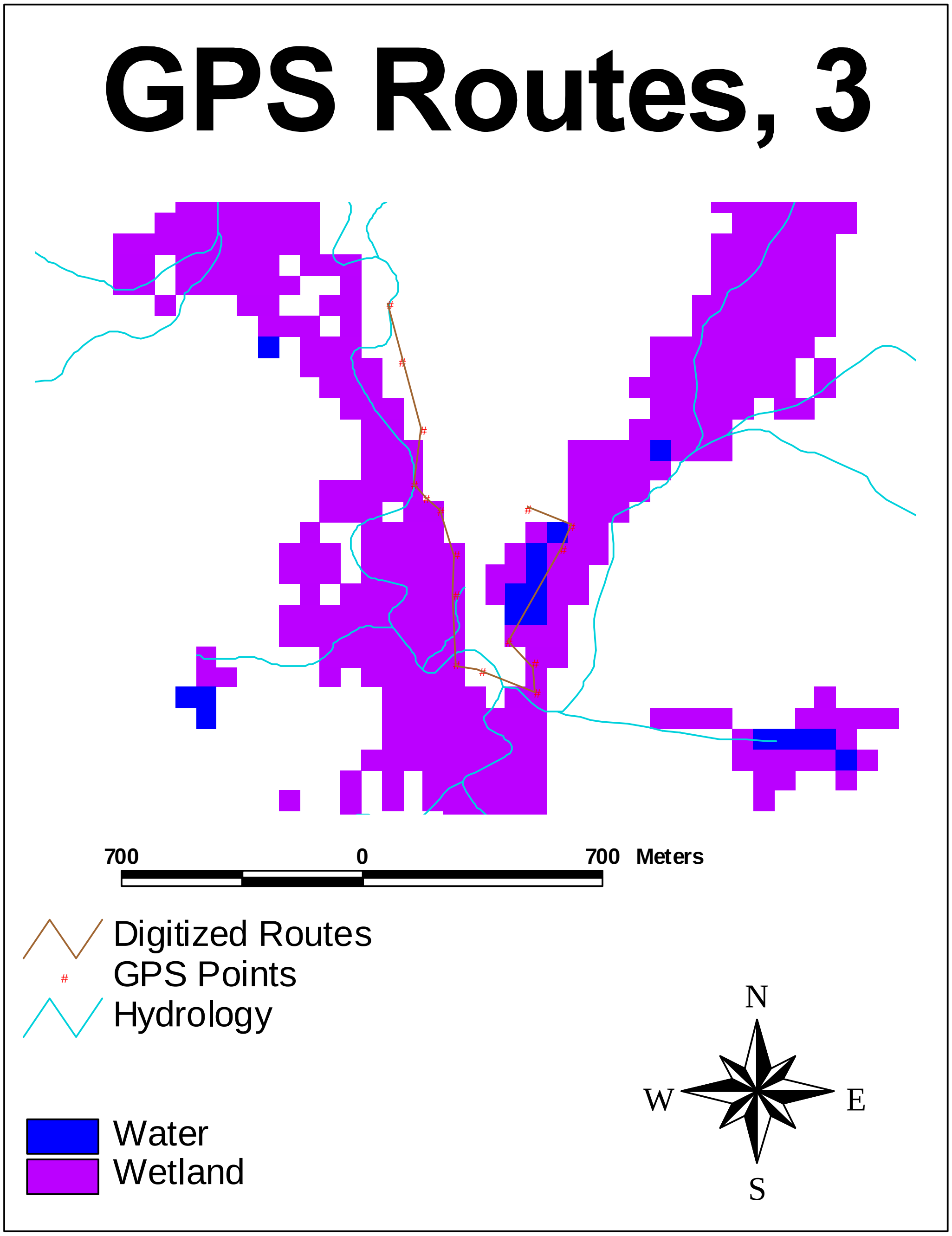

Figure 5.5 Digitized route near Sandy Creek Nature Center, Athens, GA. This route best reflects the mapped wetland extents.

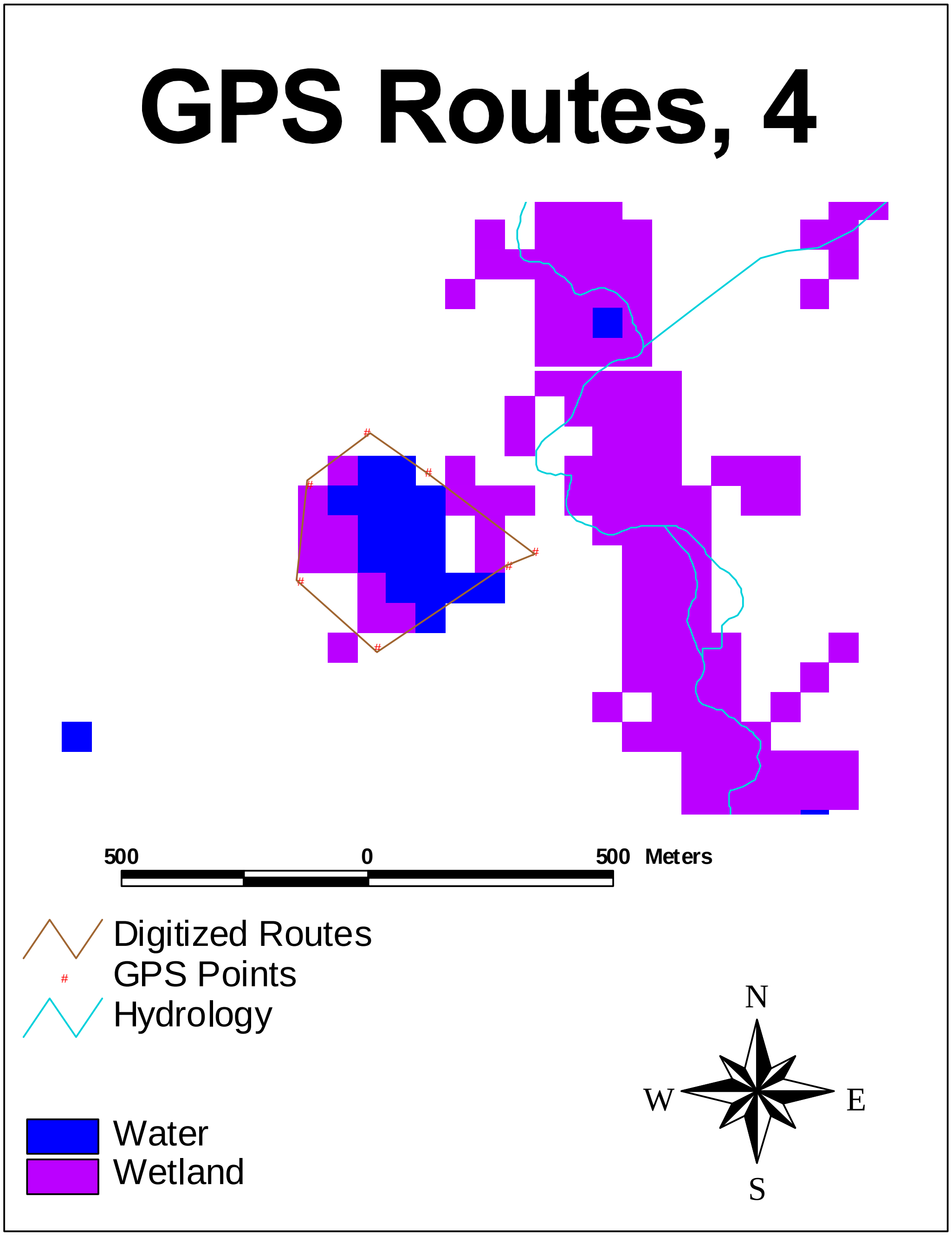

Figure 5.6 Digitized route of and oxbow lake near Sandy Creek near Athens, GA. This route also appears to correlate with the mapped wetlands.

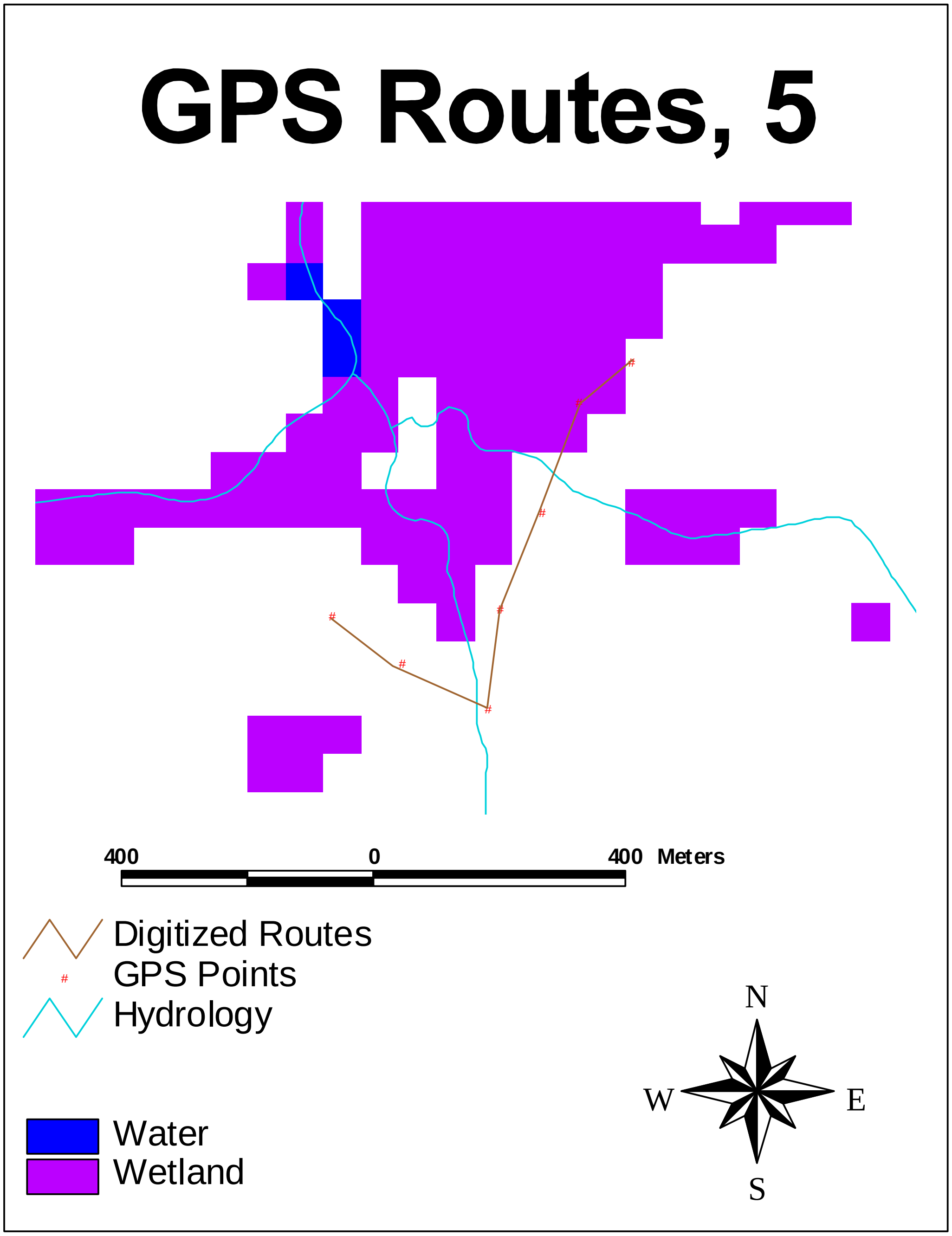

Figure 5.7 Digitized route near Scull Shoals, Greene County, GA. This again shows either errors of extents or spatial misregistration.

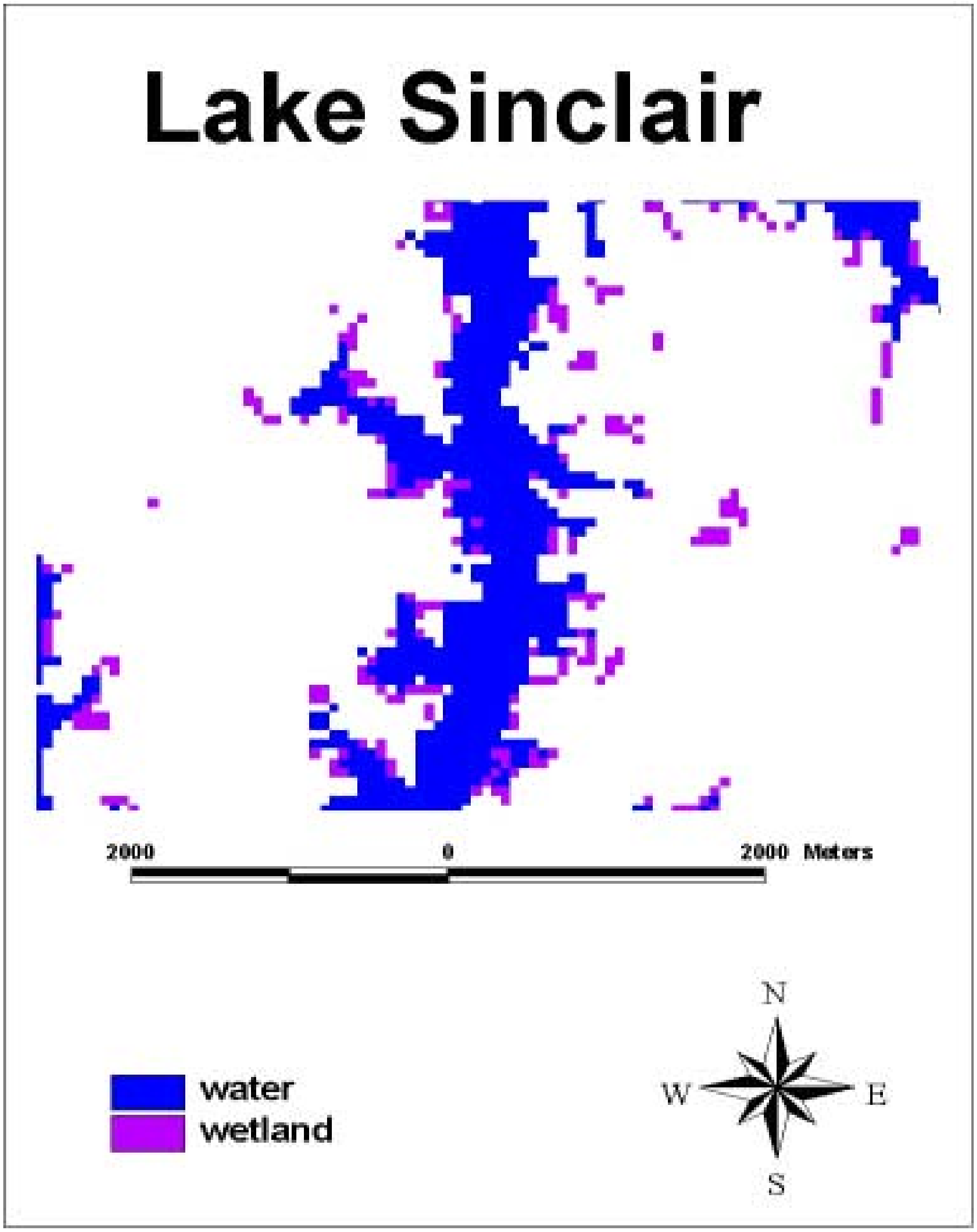

Figure 5.8 1974 wetland map, centered on Lake Sinclair, Hancock County, GA. The edges of the lake are classed as wetland, although they probably contain little emergent vegetation.

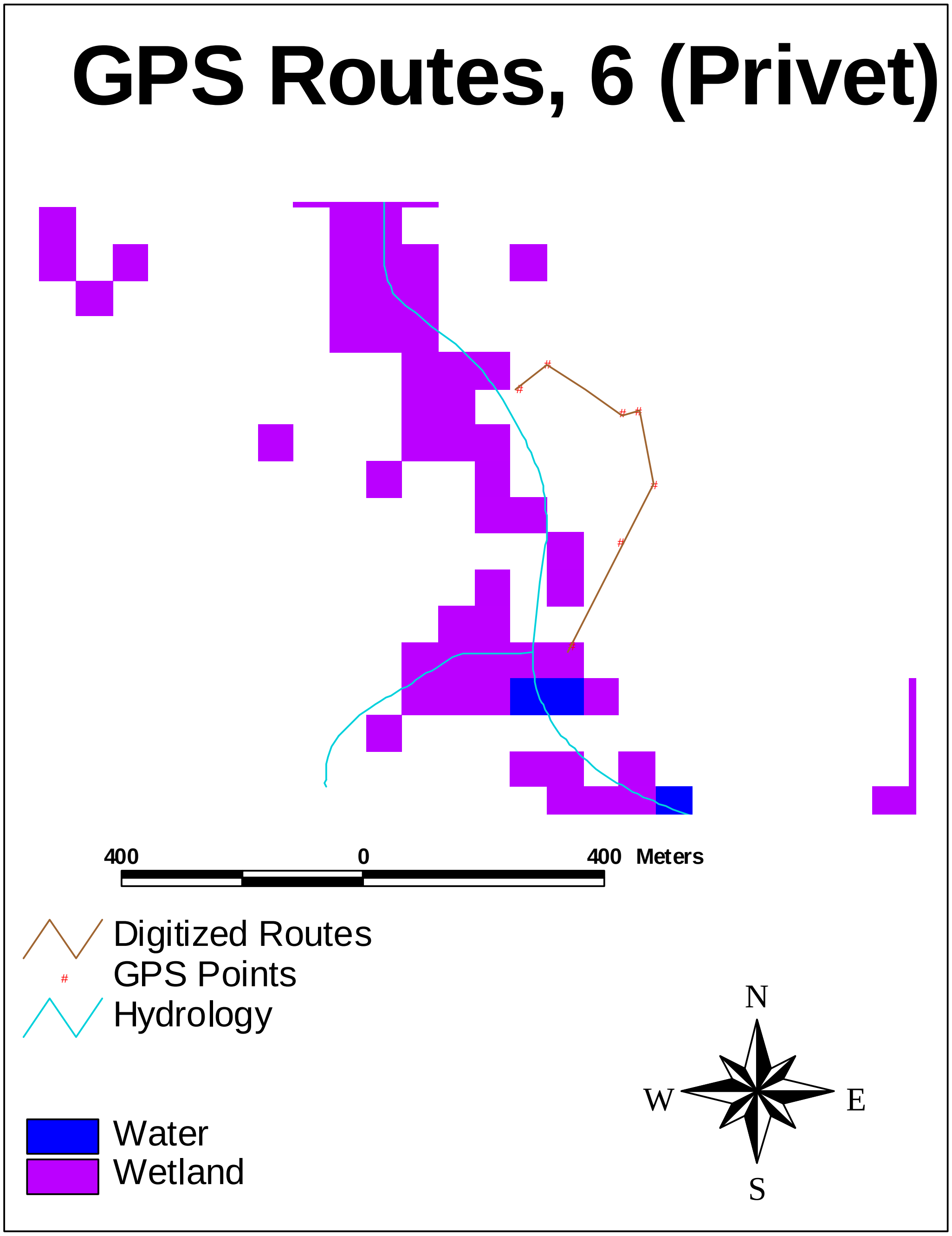

Figure 5.9 Digitized route of a privet wetland in Whitehall Forest, near Athens, GA. The privet wetland was entirely missed due to the closed canopy, which does not allow light penetration. The hydrology is the Middle Fork of the Oconee River.

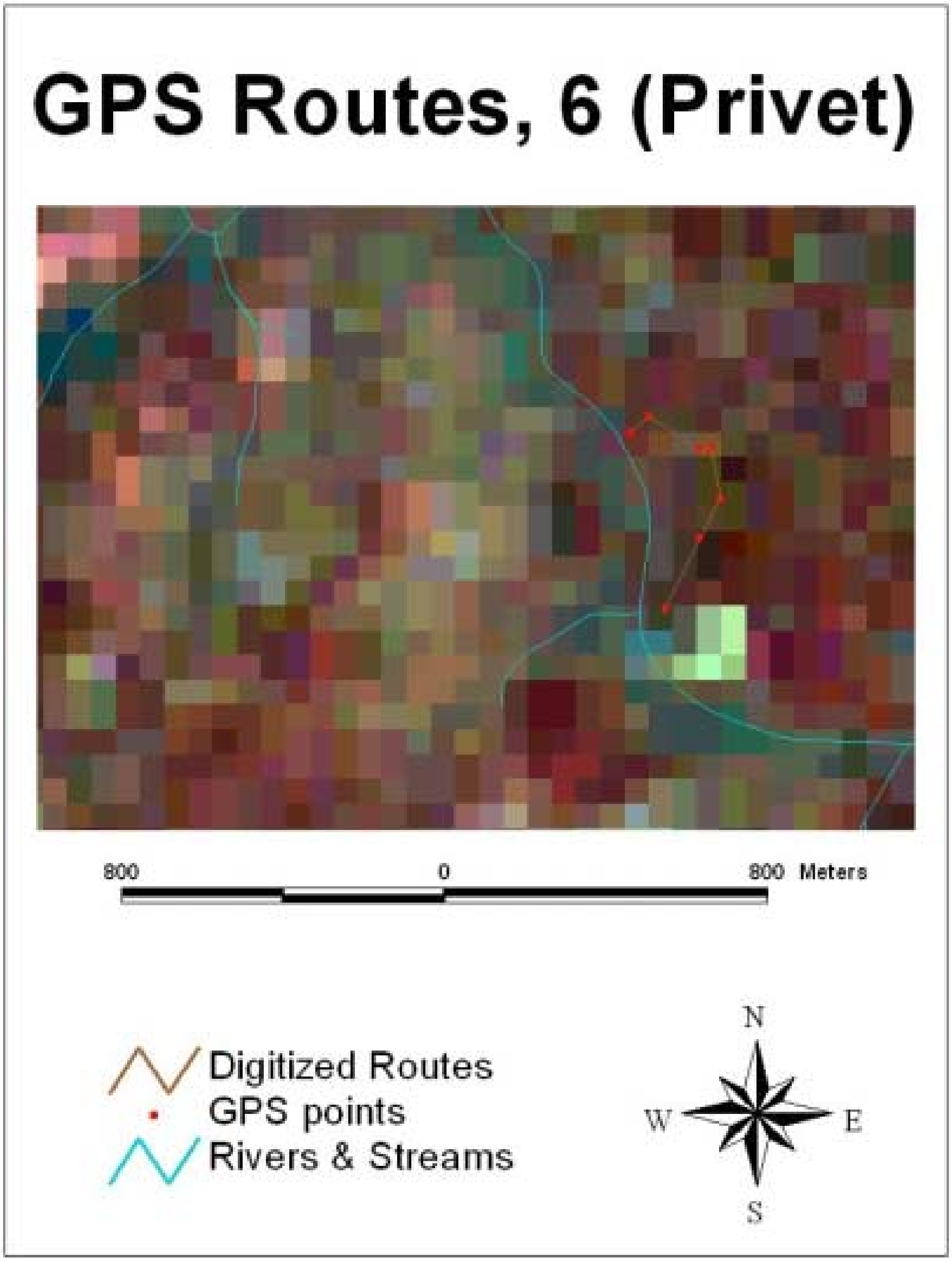

Figure 5.10 Figure 5.9 digitized route shown on the raw MSS imagery. The area reflects similar to the surrounding pine forest (red) as opposed to the blue color of the forested wetland along the Oconee River.

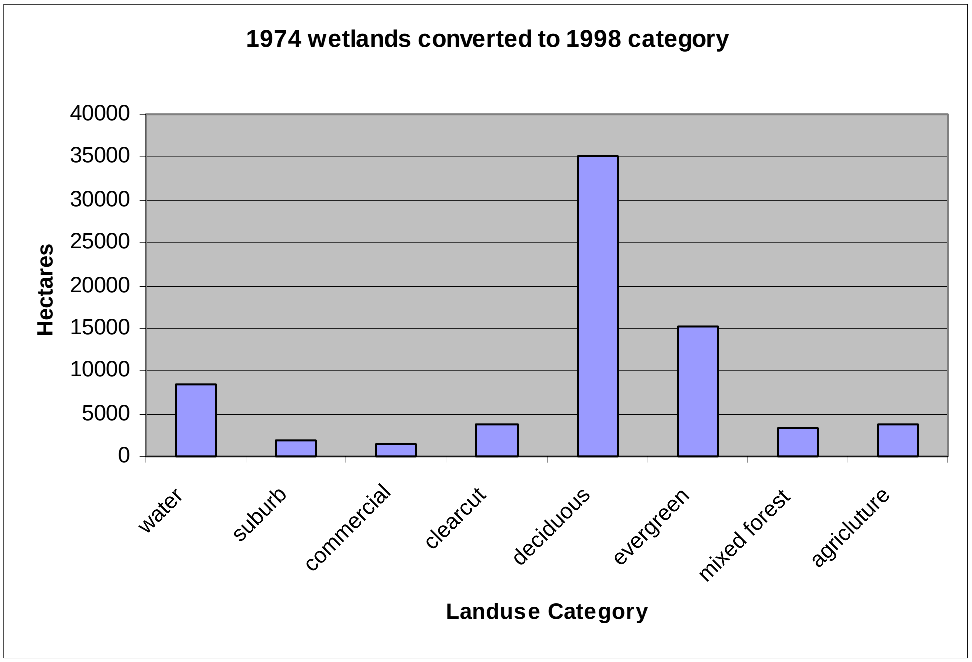

Figure 5.11 1974 wetlands converted to 1998 landcover type.

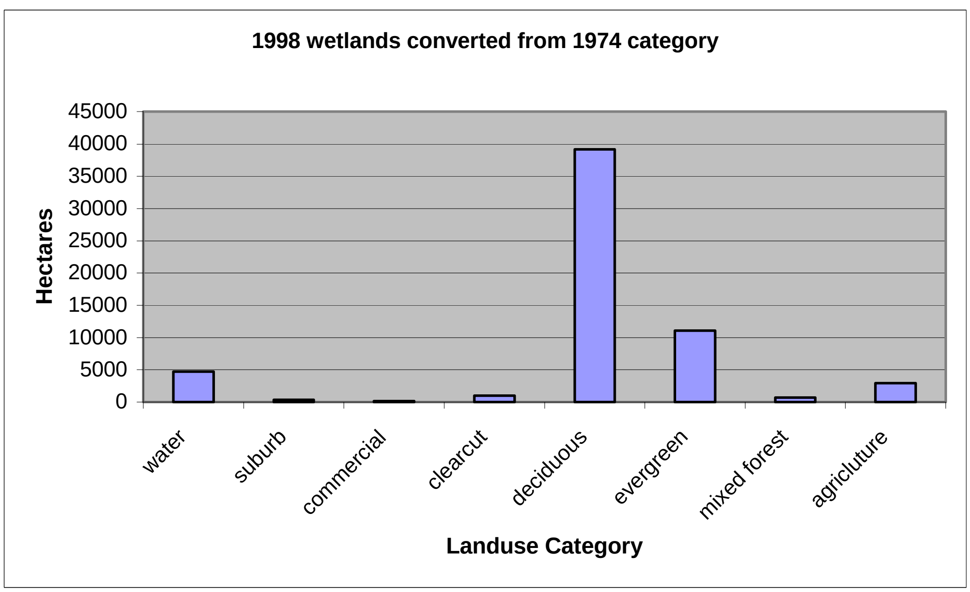

Figure 5.12 1998 wetlands converted from 1974 landcover type.

Table 5.1 Confusion Matrix for Accuracy Assessment

	water	wetland	urban	deciduous	pine	ag	Row Total
water	**104**	4	1	0	0	0	109
wetland	0	**86**	4	1	1	0	92
upland	0	0	**32**	**9**	**25**	**20**	86
Column Total	104	90	37	10	26	20	287

Producer's Accuracy		**User's Accuracy**		**Overall Accuracy**
Water =	100%	Water =	95%	
Wetland =	96%	Wetland =	93%	**96%**
Upland =	92%	Upland =	100%	
Xii	276			
Xi*Xi	27614			
N(Xii)-(Xi*Xi)	51598	**KHAT =**	**94%**	
N2-(Xi*Xi)	54755			

Table 5.2 The total areas of wetlands and open water for the 5 county area

		Hectares	
MSS-1974	Water	1246	
	Wetland	12501	
			Lake Oconee
TM- 1998	Water	8919	5357
	Wetland	12361	
Difference	Water	7673	
	Wetland	-140	

Table 5.3 Overall Comparison for MSS and 1998 Landcover, in hectares.

	1974		1998		Difference
Wetlands	102643		89882		-12761
Water	86128		129076		42948

DISCUSSION

Protocol and Final Classification

The final wetland map, produced by an integration of rule based modeling and ISODATA techniques, represents a relatively accurate inventory of wetlands on the Piedmont. This approach is hindered by hydrological, resolution and image acquisition factors, but nevertheless can be used to obtain at least an overall estimate of wetlands in the Piedmont region. The resulting map must be understood as a map of hydrology (or, standing water that can be remotely sensed), and not as a map that satisfies the three criteria used to assess wetland presence according to the Fish and Wildlife Service. But, as hydrology is the most crucial factor in the creation of wetlands, mapping flooded areas produces a surrogate that is still valuable.

Mapping flooded areas using satellite imagery, ISODATA techniques and rule based modeling allows a large area to be processed and interpreted in a minimal amount of time. Unfortunately, it is difficult to assess the accuracy of a project of this magnitude. Mapping the entire Georgia Piedmont for wetlands and open water constitutes covering a tremendous expanse of land, and so has inherent problems relating to accuracy sampling. The attempts made here suggest that this map should be used only with consideration of its overall correctness, but also of its errors at the local level, which contain errors of extents of wetlands.

The map should be most useful for overall estimates of wetland amounts and distributions. These estimates could be incorporated into wetland loss studies, landuse change studies, and habitat assessment studies. The map could also be useful for locating wetlands on the ground, though not in distinguishing among many of the types of wetlands.

Comparison of MSS and TM

Table 5.2 affirms that wetland loss is occurring in the five county area, and that open water is growing as a landuse type. The results also show that comparisons between the MSS data and TM are feasible, and that an accurate historical database can be built by using the two types of imagery. Both classifications resulted in maps that reflect wetland distributions in the five county area, and so are comparable in terms of overall wetland loss and distribution. This confirms that this rule based protocol for classifying wetlands can indeed be employed as a consistent, effective tool for efficiently mapping wetland trends and distributions on the Georgia Piedmont.

Comparison with 1998 and 1974 Landcover Maps

The pixel by pixel comparison with the 1998 Landcover map (Figure 5.11) shows significantly more conversions than the overall estimates (Table 5.3). The overall loss on the Piedmont was 12,000 hectares (12%), while the combined conversions of wetlands to other landuses in 1998 total 72,900 hectares**.** This difference is made up by conversions to wetlands from other landuses (Figure 5.12), which total 60,200 hectares. This means that only 29,700 hectares remained unchanged from 1974 to 1998. Is this high rate of conversion due to spatial misregistration, or is it due to relocation of wetlands, or both? Unfortunately, it is not possible to easily discern between the two types to obtain an actual measure, and even though a direct overlay of the two maps appears to show significant spatial shift, other explanations are plausible. For instance, the primary landcover type that wetlands were converted to was deciduous forest, but even more deciduous forest was converted to wetland. What would cause this trend? Since wetlands on the Piedmont are usually surrounded by deciduous forest (on slightly drier soils), a slight spatial shift between the two maps would cause conversions to and from deciduous to be abnormally high, but this still could not account for all of the change shown here. The other possibility is that these conversions are the result of a combination of natural and man-made hydrogeomorphic activity, wherein wetlands are succeeding to deciduous forest and vice versa. These processes include beaver pond construction and subsequent abandonment, and stream channel movement (vertically or meandering across the landscape, thus isolating some former wetlands and creating others). Stream channel movement could be widespread responses to the excessive amount of eroded sediment present in stream channels from past landuses and increased runoff (and so increased stream power) from urbanized areas. Other hydrological modifications include draining (for mosquito control, or to enhance property values) and water supply constriction (from diversion ditches that isolate wetlands from their watershed, isolation by privet invasions, and decreased flooding due to upstream impoundments). Decreases in groundwater flow due to reduced infiltration (from increased impervious surfaces) may be a factor in heavily urbanized areas. Creation of wetlands for mitigation banking (a total of 2,100 hectares on the Piedmont, USACE website) also relocates wetlands.

Similar problems arise when analyzing the changes to and from evergreen forest, mixed forest, clearcuts and agriculture, which are also transitional categories that change naturally and according to management. 15,200 hectares of wetland were converted to evergreen forest, while 11,100 hectares were converted from evergreen forest to wetland. This statistic could be attributed to changes in privet distributions along riparian zones, which can have reflectance signatures similar to pine forests and mixed forests in leaf off imagery (and in some leaf on areas), and also prevent standing water to be remotely sensed. There may also be some conversion to pine silviculture.

3,400 hectares of wetland were converted to mixed forest, while 714 hectares were converted to wetland from mixed forest. Privet dynamics may also play a large role in these conversions, since they often invade disturbed riparian zones and can thrive under deciduous canopies, giving them the appearance (from satellite imagery) of a deciduous and evergreen forest. 3,700 hectares of wetland were converted to clearcuts, while 1,000 hectares of wetland were created from 1974 clearcuts. This may represent an increase of hardwood removal in the Piedmont wetlands. 3,800 hectares of wetland were converted to agriculture, while 2,900 hectares of agriculture were converted to wetland. This conversions to agriculture may represent local landuse choices such as ditching and drainage for a more terrestrial landuse (creation of pasture), and the conversions from agriculture may indicate continual abandonment of marginal agriculture lands.

8,400 hectares of wetlands were converted to water, and 4,700 were converted from water to wetland. The majority of these conversions to water were probably due to construction of farm ponds and larger reservoirs, while the conversions from water to wetland were probably due to the creation of edge wetlands along impoundments and the infilling of impoundments.

Landuse categories like suburban and commercial that are unlikely to have been converted to wetlands, but likely to have been created from wetlands, are easier to analyze. In these circumstances, it is probable that the difference between converted to numbers in 1998 and converted from numbers in 1974 can be considered overall losses to those categories, with spatial misregistration as the major reason for conversions to wetlands. That overall loss is 1,500 hectares of wetland converted to suburban uses, and 1,300 hectares of wetland converted to commercial uses. These numbers are higher than what the USACE (USACE website) reports as permitted for the Piedmont (1300 hectares for all permitted wetland alterations, which includes other conversions besides suburban and commercial). As noted, the mitigated wetlands (on the Piedmont) reported by the USACE total 2,100 hectares, which they say is primarily forested wetland. This is an overall gain of 800 hectares. They do not however, keep a mapped database of these mitigated wetlands, which could be used to analyze losses and gains with the 1974 wetland map.

CONCLUSIONS

Protocol and Final Classification

This approach provides an efficient means to obtain at least a conservative estimate of wetlands and open water on the Piedmont region of Georgia. The two restraining factors usually associated with producing a wetland map were successfully avoided. The time required to produce the map is minimal compared to the NWI manual approach, and this labor reduction makes the protocol economical. Though limited by hydrological, resolution and image acquisition factors, the final classification proved to be an accurate inventory, and so is a resource for studies of landuse changes affecting wetlands in the Piedmont region of Georgia since the mid 1970's.

Depending on the availability of other ancillary data such as hydric soils maps and higher resolution DEM's, the accuracy of this approach could be considerably increased. Each piece of information that can be employed to help identify wetlands will boost the efficiency and accuracy of the process. As more wetland data becomes available, they should be considered for inputs into any attempts to model for wetlands. However, this parsimonious model, based solely on slope and NWI, seems effective enough for basic wetland hydrology identification as long as the proper imagery can be acquired.

Originally, the rule-based model was to incorporate two other parameters, both based on DEM's. These two parameters are the results of two ARC/INFO programs, FLOW ACCUMULATION and CURVATURE. The program FLOW

ACCUMULATION calculates accumulated flow to each cell, based on each cell's elevation values in relation to each other. The result is a raster product that contains input values of for each pixel, in other words a value that relates how many pixels are upslope contributors to a given pixel. Wetlands are likely to occur at cells that have a high number of contributing cells. In order to produce the FLOW ACCUMULATION, a FLOW DIRECTION grid must be created first, in which elevation values are used to determine which direction water will flow due to gravity. The second program, CURVATURE, calculates the shape of the landscape (flat, convex or concave) in degrees. The result is a raster map that contains a positive, negative, or zero value, depending on the curvature at each cell. Wetlands would be likely to occur at concave and zero values, since these cells would accumulate water and not drain over land. Once these grids were created, it was decided that the products were inadequate due to inconsistencies in the DEM. The deciding factor was that correct stream hydrology could not be achieved using the FLOW DIRECTION program. Since these programs are based on the same data source as the SLOPE function, and so there is some repetition involved, this decision should not have had a major impact on the accuracy of the model. However, if higher quality DEM's can be obtained, these products can be used to further increase the power of the index.

An important limitation for uses of the final map is that is does not distinguish among wetland types. A possibly remedy for this lies in the use of leaf on imagery (especially early spring) to determine types. The usual procedure is that once wetland locations and extents have been mapped using the leaf off imagery, then leaf on imagery could be used to aid in discernment between wetland types, which should contain different signatures (an emergent wetland should have a different signature than forested wetland).

Overall, the success of this project indicates that Landsat satellite imagery is well suited for future wetland inventories, and so spatial changes in wetlands can be affordably mapped at intervals of 10 years or less. This 1970s wetland map provides an inventory from which wetland change analysis can begin, while the rule-based protocol provides an efficient means to continue monitoring our wetland resources. The map should also be relevant to various studies and projects, including landuse change studies, hydrologic regulation plans, water quality projects, carbon sink studies, and for possible mitigation sites. Other uses, such as studies of individual wetlands where concern for exact boundaries is an issue may find this map and this method inadequate.

Ecological Implications

Landuse changes, when considered at the local scale, often seem insignificant for a variety of reasons, the most important of which is lack of noticeable effect. Little perceptible direct repercussions affecting human daily activity occurs because of a loss of deciduous forest in a neighborhood. In fact, many landuse changes will increase property values for local residents, providing a short-term gain for those stakeholders. The creation of a reservoir where a forested wetland stood, a new mall or neighborhood where a deciduous forest was, or the draining of a mosquito infested, isolated wetland can create obvious rewards for local residents. These incentives in favor of landuse changes cannot be overlooked, but the detrimental effects associated with certain conversions should be considered as well. Wetland loss, in particular, has local ramifications that can be perceived, even measured, over both the short and long term. These impacts can directly affect man, such as water quality degradation and decreased aesthetic appeal, or indirectly through loss of habitat for game species and decreased flood control capacity.

These impacts are not limited to local perturbations. When wetland loss occurs on a regional scale, the overall effects can be devastating to the environment. The high quality of life associated with abundant natural resources, as is the case on the Georgia Piedmont, will suffer as those same resources are consumed disproportionately with their renewable capacities. Already, water consumption has become a contentious issue with neighboring states Alabama and Florida, centered on the amount of in-stream flow for two river basins, the Apalachicola-Chattahoochee-Flint basin and the Alabama-Coosa-Tallapoosa basin. The three states must find a way to satisfy their withdrawal needs, and still maintain the ecological integrity of these systems. This issue, called the tri-state water wars, has reached crisis levels due to the continuing drought of 1998 to 2001. Wetlands, which naturally store water and then release it during dry periods, provide habitat for spawning fish species, and supply nutrients to downstream areas, are an integral part of the equation.

The overall conversions of wetlands are cause for alarm. Wetlands are still being converted on the Piedmont, and the rate of wetland loss is a staggering 12% over the course of only 24 years (1974 to 1998). Losses to suburban and commercial landuses are still significant. However, these conversions are to a variety of landuses, with the largest conversions being to deciduous forest, which is also the largest category converted to wetland. This trend may reflect a number of processes occurring simultaneously on the Georgia Piedmont, which suggest that the wetlands on the Piedmont are part of a complex, dynamic hydrological regime, and that Piedmont wetlands are affected by any modifications to this regime, natural or man-made. This is particularly pertinent to conservation of Piedmont wetlands because current regulations only address the issue of filling of wetlands, and not activities that may indirectly affect them. The recognition of a connected landscape wherein each component contributes to the health of the system is needed, and must be reflected in public policy in order to further the goal of a sustainable Piedmont.

For example, issues such as increases in the open water category must be considered in the context of their full ecological implications. These increases come primarily from impoundments, or ponds and lakes that are built instream through damming (Merrill, 2001). These reservoirs can block passageways for migratory fish species, especially in rivers and large streams. The impoundments may fragment the previously continuous forested wetlands that serve as wildlife corridors. They may also disrupt the hydrology that maintains wetlands downstream, minimizing the annual floods that wetlands depend on. Ponds on small, perennial streams provide some ecological benefits, however, by decreasing nutrient and sediment loading, creation of edge wetlands, and serving as refugia (especially in times of drought) for wildlife. These functions are dependant on the individual management of the ponds. Small ponds are not an ecological substitute for beaver ponds, though. Beaver ponds (which are in a constant state of succession in step with the colonization and eventual desertion by the beavers) are an amalgamation of habitats, with very little deepwater area and so provide more varied benefits. The effects of other landuse practices, such as road building (especially ditching for roads) act in concert with other hydrological modifications to impact wetlands and streams.

In order to better understand exactly what the landuse dynamics taking place on the Piedmont mean, more specific questions need to be addressed through research. The first step in this analysis is continual mapping of the Piedmont to determine when these changes are taking place. Did most of the changes occur in the few years following 1974, or has the modifications intensified in the past few years? The next steps should be concerned with detailed spatial analysis through GIS to address the issue of local landuse practices and their effects on wetlands. Questions include: Are wetlands downstream from impoundments being converted to deciduous, and being created upstream? Are wetlands near privet invasions being converted at a high rate? Are wetlands being converted primarily near areas of intensive urban and suburban modifications? Are the conversions to forest landuses occurring gradually all across the Piedmont, indicating stream downcutting through historical sediment and biogeomorphic activity (beaver wetlands)? Answers to spatially oriented questions such as these may provide us with the proper means for conservation of wetlands.

As the human population continues to increase on the Piedmont along with increased intensive landuses, pollutants such as nutrients and impervious surface runoff will increase, as will resource consumption, especially water and land. It follows that our dependence on remaining wetlands will only continue to increase as well, which makes curtailing wetland loss pivotal in developing a sustainable Piedmont. The incremental losses that are occurring on the Georgia Piedmont must be monitored so that they can be considered in landuse decisions and planning. This will help ensure a future environment that not only functions as we need it to, but also maintains our natural heritage.

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