

REMOTE SENSING AND GEOSPATIAL APPLICATION FOR WETLAND MAPPING, ASSESSMENT, AND MITIGATION

Charles G. O'Hara, Consortium Manager

National Consortium on Remote Sensing in Transportation - Environmental Assessment
Engineering Research Center
2 Research Boulevard
Mississippi State, MS 39762
cgohara@erc.msstate.edu

ABSTRACT

High spatial and spectral resolution hyperspectral image data along with high resolution digital elevation data can provide the capability to detect wetland vegetation, provide improved detection of hydrologic features and conditions, and when combined with digital soils data, provide an improved contextual assessment for screening areas that have a high likelihood of containing wetlands. High spatial and spectral resolution hyperspectral image data and high resolution LIDAR data were collected for an area located between Asheboro and High Point, in the Deep River watershed, Randolph County, North Carolina. To determine the utility of such data for the preliminary identification of areas that have a high likelihood of being wetlands, methods of data synthesis, fusion, analysis, and comparison using geospatial and remote sensing technologies were developed. A combination of neighborhood analysis, hydrologic analysis, contextual analysis, and fusion techniques were developed and used to produce a preliminary wetlands likelihood determination map. The techniques were developed to provide a surrogate process that closely approximated determinations made as part of conventional field wetland assessments. The map product was compared to the results of a National Wetlands Inventory (NWI) survey recently completed as part of a US DOT Research Special Projects Administration (RSPA) technology application project as well as to a NC DOT field wetland assessment completed to U.S. Army Corps of Engineers standards. When compared to the results of conventional assessments, areas mapped as wetlands by NWI methods and by NC DOT field wetland assessment methods were identified by the analysis technique as having a high likelihood of being wetlands.

The early collection of high spatial and spectral resolution hyperspectral image data and high-resolution digital elevation data for transportation project areas can facilitate early planning and assessment, enhance screening for areas that have a high likelihood of containing wetlands, and provide preliminary indication of sites in the project study area suitable for wetland mitigation.

INTRODUCTION

Background on Wetlands Delineation

The objective of the Clean Water Act is to maintain and restore the chemical, physical, and biological integrity of the waters of the United States. Section 404 of the Act authorizes the Secretary of the Army, acting through the Chief of Engineers, to issue permits for the discharge of dredged or fill material into the waters of the United States, including wetlands. The Corps of Engineers *Wetlands Delineation Manual* (USACE, 1987) defines wetlands as "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 do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas." In most current approaches to the mapping and assessment of wetlands, field crews determine at sample locations which [if any] of three variables typical of wetland are present. These variables are hydrophytic (wetland) vegetation, hydric soil, and wetland hydrology.

Relevance to Application of Remote Sensing

Guidance given in the Corps of Engineers *Wetlands Delineation Manual* concerning the use of remotely sensed data states that, “Remote sensing is one of the most useful information sources available for wetland identification and delineation” (USACE, 1987). Since the development of the *Wetlands Delineation Manual*, remote sensing technology has improved dramatically. Improved spectral resolution of multi-band data provide increased spectral information allowing better differentiation of land cover, and improved spatial resolution increases the likelihood that “pure” pixels are collected for specific land cover types. Additionally, the availability of satellite and aerial images with high revisit rates or scheduled acquisitions provide planners, engineers, and analysts with the ability to acquire data when desired and under conditions that are ideal for needed data analysis.

PURPOSE AND SCOPE

This paper presents the results of a research project conducted to determine whether the use of remote sensing and geospatial technologies can help to select transportation alignments that minimize wetland impacts, provide an overall reduction in time and cost for assessing environmental impacts, and streamline the NEPA process in transportation projects. This paper highlights the use of high spatial and spectral resolution hyperspectral image data and high-resolution elevation data for predicting the likelihood of wetlands occurrence.

For an area in Randolph County, North Carolina, EarthData Technologies collected high resolution hyperspectral image data and high resolution LIDAR data. The data were collected as part of a US DOT Research Special Projects Administration (RSPA) Technology Application Project (TAP). The study area location was between Asheboro and High Point, North Carolina in the Deep River watershed.

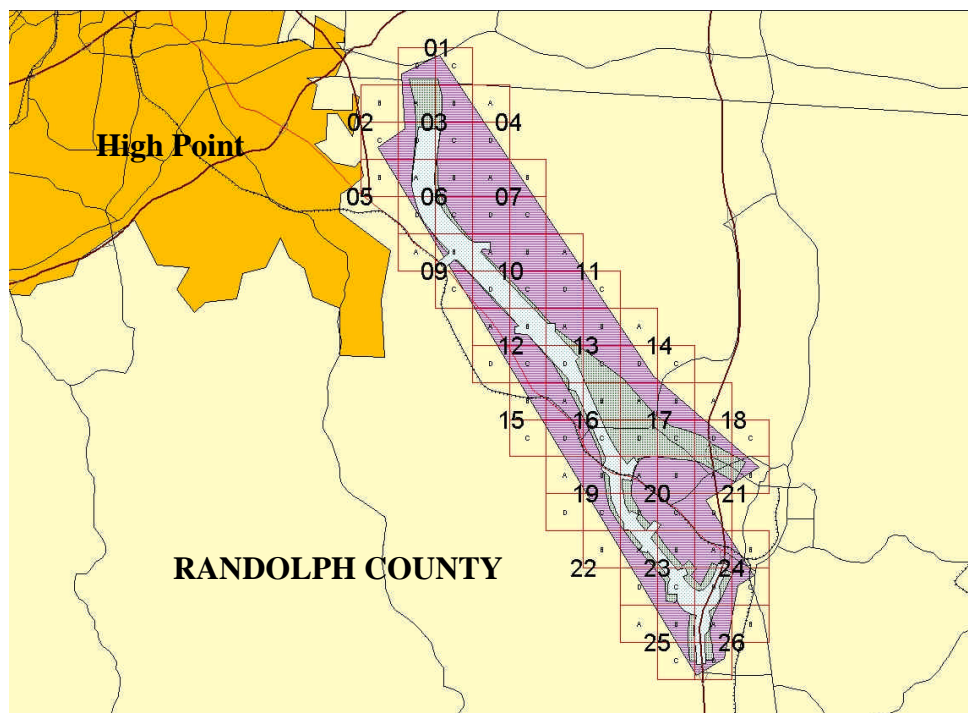


Figure 1. High Point, North Carolina, at the top left is in close proximity to the study area shown in light purple. The light green pattern-filled areas within the study area are potential transportation corridors. The grid and numbers overlaying the study area were used to organize the remote sensing data collection activities.

OBJECTIVES AND METHODS

Landscapes are almost always a complex mixture of developed and undeveloped areas which include forested areas or other land cover types that act as canopy over what lies below. The spectral signatures (seen by an aerial or satellite passive sensor) of understory, wetland vegetation, or water may be obscured by such forest canopy or other land cover types. Thus, the spectral signature of high spatial and spectral resolution remotely sensed image data alone cannot accomplish evaluation of water, wetland, and associated vegetation. Spectral analysis must be followed by data fusion techniques that analyze and combine products derived from the focal analysis of spectral products with elevation data derived topographic and hydrologic information products and soils data.

The object of this report is to demonstrate the use and analysis of high-resolution image and elevation data products in combination with digital soils data for predicting areas with a high likelihood of being wetlands. The resulting products may be used in 1) early screening of potential wetland areas for selection of roadway alignments, 2) assisting field wetland biologists by providing them with better maps than presently available to plan field work (if needed) for wetland determinations, and 3) helping to expedite the overall wetland mapping process. The complexity of the hyperspectral image data and the resultant land cover classification product required that the classified image be further processed to stratify the classes into groups to indicate the status of the cover type and then clarified into patterns of vegetation types in the vicinity of each pixel.

This paper presents methods and results to demonstrate how image pixels classified for a particular land cover may be analyzed within a neighboring area to determine if and how wetland vegetation criteria are met. Methods were developed to demonstrate how high-resolution elevation data can be used to determine the location of riparian buffer zones and local hydrologic features that may meet wetland hydrology requirements. Finally, the results of image and elevation analyses were combined with soils information to predict areas with high wetlands likelihood.

High-Resolution Hyperspectral Image Data and Classification

Remotely sensed image data varies from low-spatial and low-spectral resolution to high-spatial and high-spectral resolution. Data with pixel sizes that are 1m or better ground resolution are typically considered high-spatial resolution images. Digital data provide the ability to automate image-processing tasks. High spectral resolution data provide an increased ability to differentiate land cover classes. In creating a detailed classification of land cover for transportation projects, new sources of hyperspectral image data provide high spectral and spatial resolution for automated processing and detailed land cover classification.

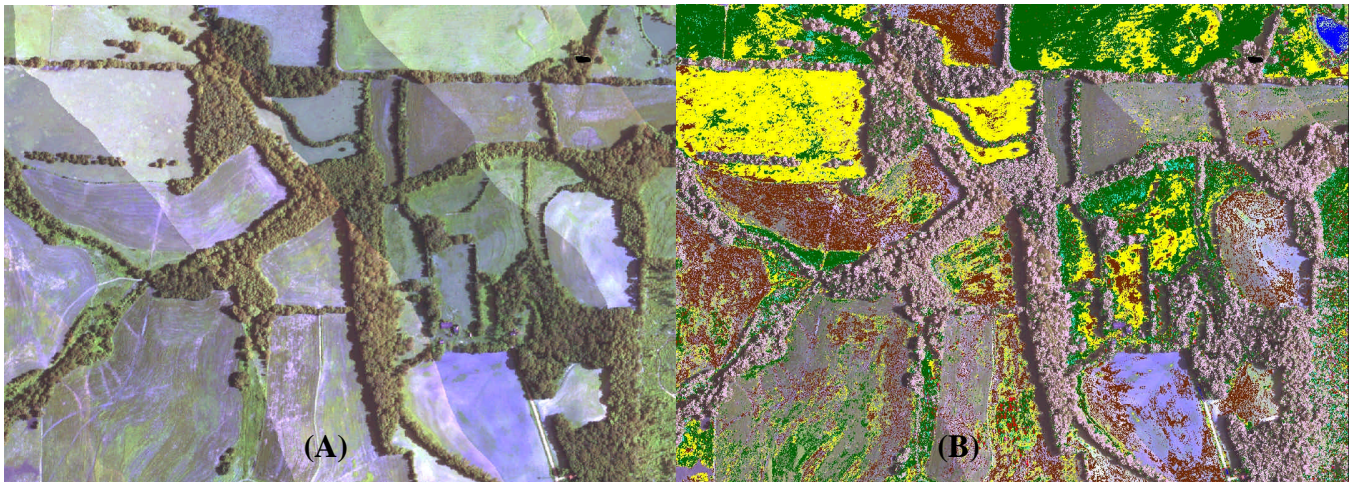


Figure 2. A natural color mosaic of CASI II data (A) is shown for an area within the central part of the study. The area is predominated by agricultural fields, forested border areas, highly vegetated and forested drainage, and grassland pastures. The classified results for the hyperspectral image data overlaying the original image (B) provides landscape “context.” However, the context provided by the image data does not sufficiently show assemblages of vegetation that would support a wetland determination.

To approximate traditional approaches to wetland mapping, the hyperspectral image data were classified according to a scheme that would correlate with the National Wetlands Inventory (NWI) classification scheme (Cowardin, 1979). Hyperspectral data acquisition, processing, and classification were conducted by ITRES Corporation. The classified results of processing the high-resolution image data do not provide a conclusive information product. The amount of detail provided by the high-resolution hyperspectral classified image products can be confusing with respect to making a determination about on-the-ground land cover conditions.

ANALYSIS OF WETLAND LIKELIHOOD

To extract useful information from the classified results, it is necessary to stratify the classification of vegetation into intelligible groups and then clarify the individual pixels by assessing their context among neighboring pixels. The clarified results can then be ranked and combined to provide a combined vegetation information product. The determination of wetlands must consider vegetation in the context of hydrology and soils. Thus, the analysis of vegetation information should be accompanied by an analysis of non-vegetation information, specifically dealing with hydrologic and soil indicators of potential wetland conditions. To provide support to the US DOT Technology Application Project, an algorithm was developed by the NCRST-E at Mississippi State University to assess, rank, and fuse both vegetation and non-vegetation information and then combine the results of both to generate a wetland likelihood result.

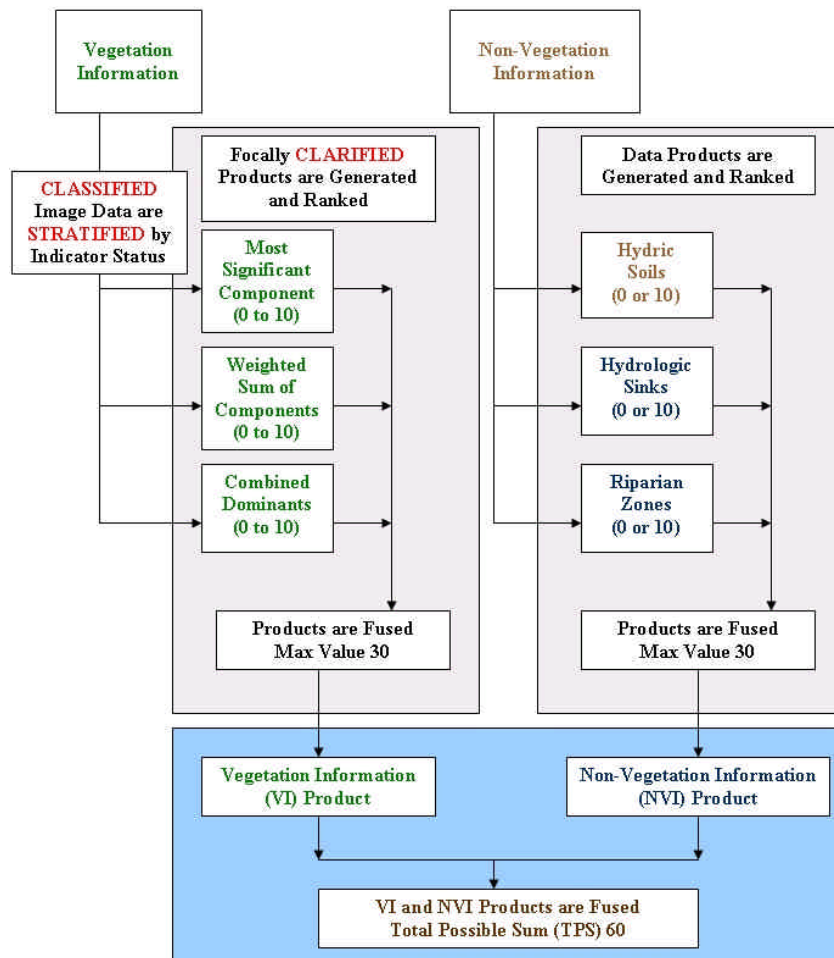


Figure 3. Process flow diagram for the wetlands assessment algorithm.

Because of the computational expense of data processing and testing the results of analyses, an “Analysis Development Area” was selected to develop and test algorithm processes. The area was selected for availability of additional high-resolution data such as 60 cm CASI-II data and additional LIDAR data for leaf-on conditions as well as leaf-off conditions.

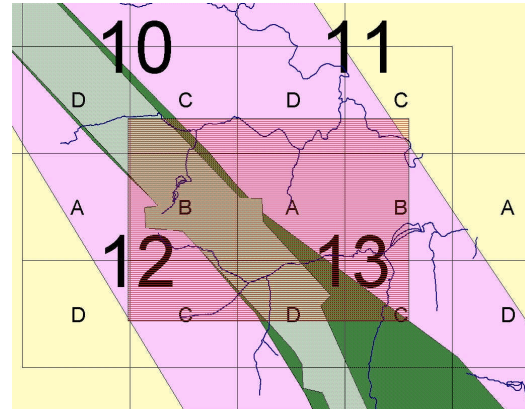


Figure 4. The “Analysis Development Area” shown in light red includes about 1.9 square miles or 1220 acres.

Assessing Vegetation Information (VI): Stratifying and Clarifying Classified Image Data

The high spatial and spectral resolution of hyperspectral image data makes possible the determination of specific plant species or vegetation types for the area imaged. For the purpose of conducting geospatial analysis of patterns of wetland vegetation distribution, it is necessary that the image data, classified by specific vegetation species or type, be stratified [into groups] by wetland and non-wetland likelihood. For the purpose of this study, the wetland indicator status was used to stratify the classed vegetative species. Each image class was associated with a wetland indicator status. For wetland vegetation, an indicator status is a category that provides “the range of estimated probabilities of a species occurring naturally in a wetland condition versus a non-wetland condition across the entire normal distribution of the species” (FIA Field Guide, 1989). The indicator status category reflects the likelihood that a species will be found in a wetland. Stratification was accomplished by “recoding” the vegetation classes with code values specific to each wetland indicator status category. The numerical code value was assigned based on the weighted likelihood that a group would occur in a wetland, with 10 being the highest likelihood and 0 being the lowest. For any given area, the neighboring codes provide a good indication of the nature of the vegetative assemblage. Therefore, a series of neighborhood analysis techniques using focal analysis were used to clarify the stratified product.

Table 1. Wetland indicator status, code values, and description of vegetation species and types included in the wetland indicator status group.

Wetland Indicator Status and Code Value	Description
Obligate (OBL) Code Value 10	OBL species, under natural conditions, almost always (probability > 99%) occur in wetlands. Examples of obligate species are bald cypress and water tupelo.
Facultative Wet (FACW) Code Value 6	FACW species usually occur in wetlands (probability of 67% - 99%), but can be found occasionally in non-wetlands. Examples of FACW species are pond pine, slash pine, laurel oak, and gallberry.
Facultative (FAC) Code Value 3	FAC species have about an equal likelihood of occurring in wetlands as in non-wetlands (probability of occurring in wetlands is 34% to 66%). Examples of FAC species are loblolly pine, red maple, sweetgum, blue beech, sumac, and yaupon.
Facultative Upland (FACU) Code Value 1	FACU species usually occur in non-wetlands but occasionally can be found in wetlands. Estimated probability of occurrence in wetlands is 1% to 33%. Probability of occurrence in uplands is >34%. Examples of FACU species are white pine, basswood, redbud, and mountain laurel.
Obligate Upland (UPL) Code Value 0	UPL species almost always occur in non-wetlands (probability 99% + of occurrence in uplands - probability of only 1% of occurrence in wetland) under natural conditions. Examples of UPL species are Virginia pine, shortleaf pine, scarlet oak, and flame azalea.

Clarifying Stratified Data: Vegetation Pattern Analysis

The determination of wetlands is made for an area, typically defined by a minimum mapping unit. In traditional field wetlands mapping, samples are collected within the study area, vegetation is classified, soils are assessed for hydric determination, and the hydrology of the area is assessed to see if wetland indicators are present. In an image, a single isolated pixel represented as an obligate wetland vegetative type does not by itself constitute a wetland. The single pixel in the classified scene must be assessed as a single sample on the landscape and considered in the context of the other vegetation in the area (along with the hydrology and soils indicators) to determine if the requirements for a wetland are present. A series of techniques have been developed to assess the vegetation in areas adjacent to potential wetland pixels within a classified high-resolution remotely sensed image. These techniques were developed to provide a close surrogate for on-the-ground techniques wherein species are counted and assessed.

Neighborhood analysis using focal geospatial processing provides a method for assessing the pixels surrounding each individual pixel in an image. Since many wetland assessments are conducted based upon a ¼ acre minimum mapping unit, the methods developed for this analysis were likewise designed to consider neighboring pixels within a ¼ acre area. A circular focal neighborhood with a radius of 18 one-meter pixels was used. The resultant area is approximately 1017 square meters or about ¼ of an acre. The actual size of ¼ acre equates to roughly 1011.75 square meters. Since partial pixels cannot be used in such an analysis, an 18-pixel radius is the closest approximate to a ¼ acre focal neighborhood that can be used.

To approximate on-the-ground techniques for assessing vegetation, focal analyses were developed to look at the majority of the surrounding vegetation, the sum of vegetation components, and the count of components that meet criteria for wetlands classification. These analyses consist of most significant component (MSC), weighted sum of components (WSC), and combined dominants (CD).

Most Significant Component (MSC). The MSC determines, for each pixel, the majority value of the pixels that are in the focal neighborhood (a circular region with a radius of 18 one-meter pixels around each pixel). The MSC function returns the most frequently occurring value in the neighborhood. The MSC serves to filter out the noise of minor constituents and provides a clear picture of the vegetative types (grouped by indicator status value code) that occupy a majority of the landscape for a given area.

Weighted Sum of Components (WSC). The WSC determines, for each pixel, the sum of all vegetative species and contextual classified components weighted by the likelihood that the species or contextual component occurs in a wetland or near water. Since the wetland indicator status value code decreases for species with a decreasing likelihood of occurring in a wetland, a sum of all value codes for pixels in the focal neighborhood provides an important indicator of the weighted mixture of vegetation in each pixel's neighborhood. In this analysis, water is given the same value code as OBL, thus the "context" of water provides a proximity influence to the adjacent vegetation types.

Combined Dominants (CD). In most wetland assessment field guides, an area is determined as meeting the wetland vegetation criterion if more than 50 percent of the dominant species from each identified strata are obligate wetland (OBL), facultative wetland (FACW), or facultative (FAC) species. The CD function conducts a count of the number of pixels in the neighborhood of each cell that have wetland indicator status value code of 10, 6, or 3 and divides the count by the total number of cells in the focal neighborhood. The CD provides an overall indication of areas likely to meet the vegetative criterion for wetland determination.

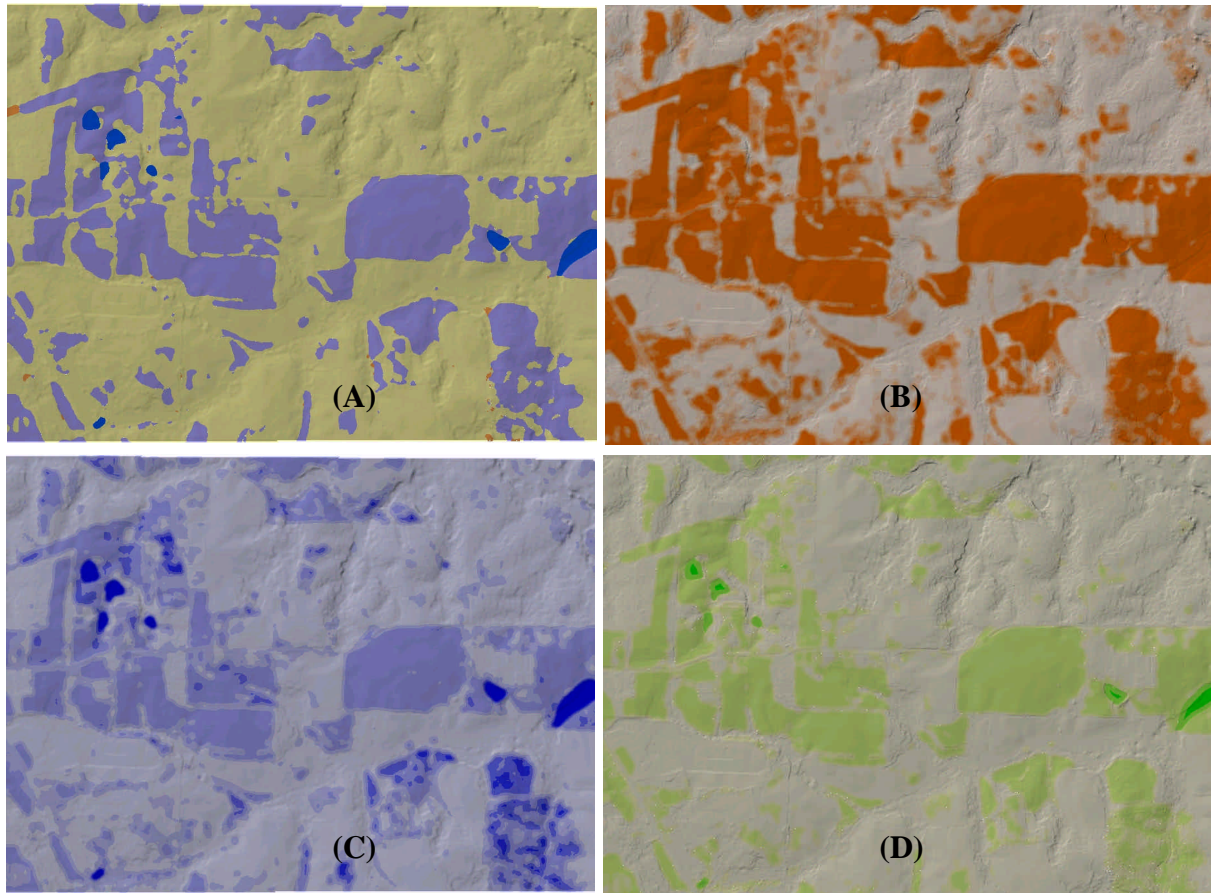


Figure 5. Clarified Vegetation Information (VI) products generated for the Most Significant Component (A) with increasing blue indicating the majority vegetation’s likelihood of occurring in a wetland; the Weighted Sum of Components (B) with increasing brown indicating that the sum of components favor wetlands; and Combined Dominants (C) with increasing blue indicating that the combination of species (meeting wetlands criteria) favor wetlands. The combination of MSC, WSC, and CD are shown in the Vegetation Information (D) product with increasing green indicating increasing likelihood that the overall vegetation assemblage meets wetlands criteria

Non-Vegetation Information (NVI) from Hydrologic and Soils Data Analyses

A high-resolution digital elevation model (DEM) was produced for the analysis development area using data collected by EarthData’s airborne LIDAR system. The LIDAR (Light Detection and Ranging) system creates detailed and highly accurate elevation information via precise timing of thousands of laser pulses striking the ground surface. After processing the LIDAR data, the resultant digital terrain model provides a “bare earth” surface that is the result of removing natural cover and man-made structures from the raw LIDAR data.

The Filled DEM and Hydrologic Depressions (Sinks). To conduct hydrologic analysis, a DEM must provide information so that water on the surface can be routed to flow properly from grid cell to grid cell. When there are localized hydrologic depressions, water can flow in, but at the lowest point in the depression the water becomes “trapped” because there are no lower elevation “cells” in the local area to which the water may flow. In reality, overland flow fills small terrain depressions and then additional water (after the depression is full) is able to continue across the land surface. Likewise, a DEM must be filled in order that water may properly flow. The LIDAR DEM is filled to perform hydrologic analysis. This makes possible the subtraction of the original DEM to create a creation of a “sinks” surface. The sinks surface provides the approximate location and size of localized hydrologic

depressions. These “sinks” are areas where surface water is likely to pond and stand on the land surface. Such areas are likely to be flood storage sites and potential sites for wetland soils and vegetation to develop.

Creating Riparian Buffer Zones from the Synthetic Stream Network. The filled DEM is used to develop flow direction and accumulation information products. Flow direction and accumulation are used to create a synthetic stream network on the landscape. Streams occur where there is a sufficient amount of upland area drained (as determined by flow accumulation) such that flow begins. Areas around streams typically are zones that are transitional from water to land environments and habitats. The DEM-derived synthetic stream network is buffered to include an 18-meter distance from the theoretical drainage centerline that represents the transitional or riparian zone. Within the study area, wetlands along streams are typically hidden by the canopy of trees that thrive in this transitional environment.

Digital Soils Data (SSURGO) from NRCS County Soils Data. The U.S. Department of Agriculture, Natural Resource Conservation Service (NRCS) maps county soils information and the digital product (SSURGO) may be used to determine the mapped distribution of hydric soils in an area. Hydric soils are defined as “soils that are saturated, flooded, or ponded for a long enough period to develop anaerobic conditions in the upper horizons. These soils possess characteristics that are associated with reducing conditions and in turn favor the regeneration, growth and development of hydrophytic (wetland) vegetation (USACE, 1987).”

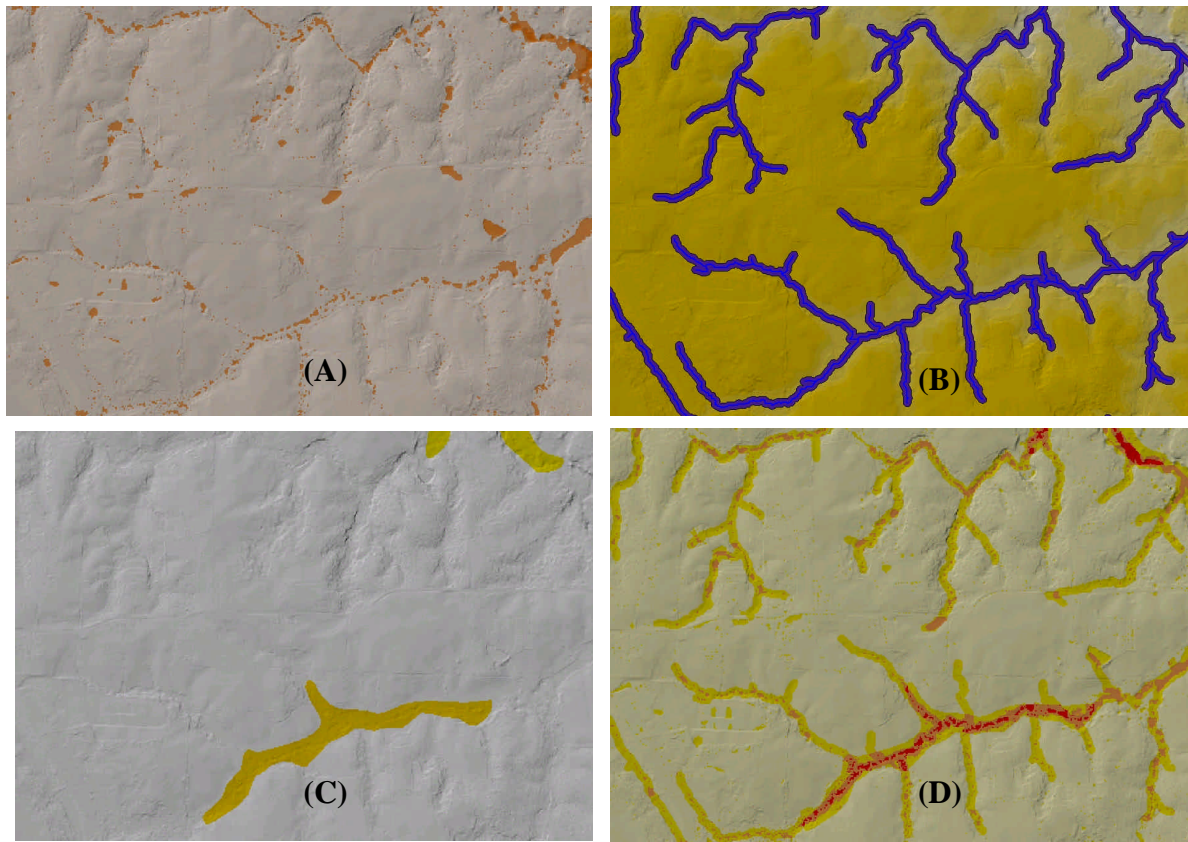


Figure 6. Non-Vegetation Information (NVI) products include topographic sinks (A) shown in brown, riparian buffer zones (B) shown in blue, and areas mapped for hydric soils occurrence (C) shown in yellow. The combination of data produces the Non-Vegetation Information (NVI) surface (D) where increasing brown shows increasing likelihood that non-vegetation information favors the likelihood that wetlands criteria are met for a given location.

Combining Vegetation and Non-Vegetation Information

The vegetation information (VI) items generated from the analysis of classified high spatial resolution hyperspectral image data provide continuous surfaces of data values that are gradationally ranked and combined. The non-vegetation information (NVI) products provide non-continuous surfaces in which wetland conditions are assessed as being either present or not present. The VI and NVI products are combined in a total possible sum (TPS) to provide a contextual analysis of vegetation, hydrology, and soils to determine the likelihood of wetlands occurrence for a given area.

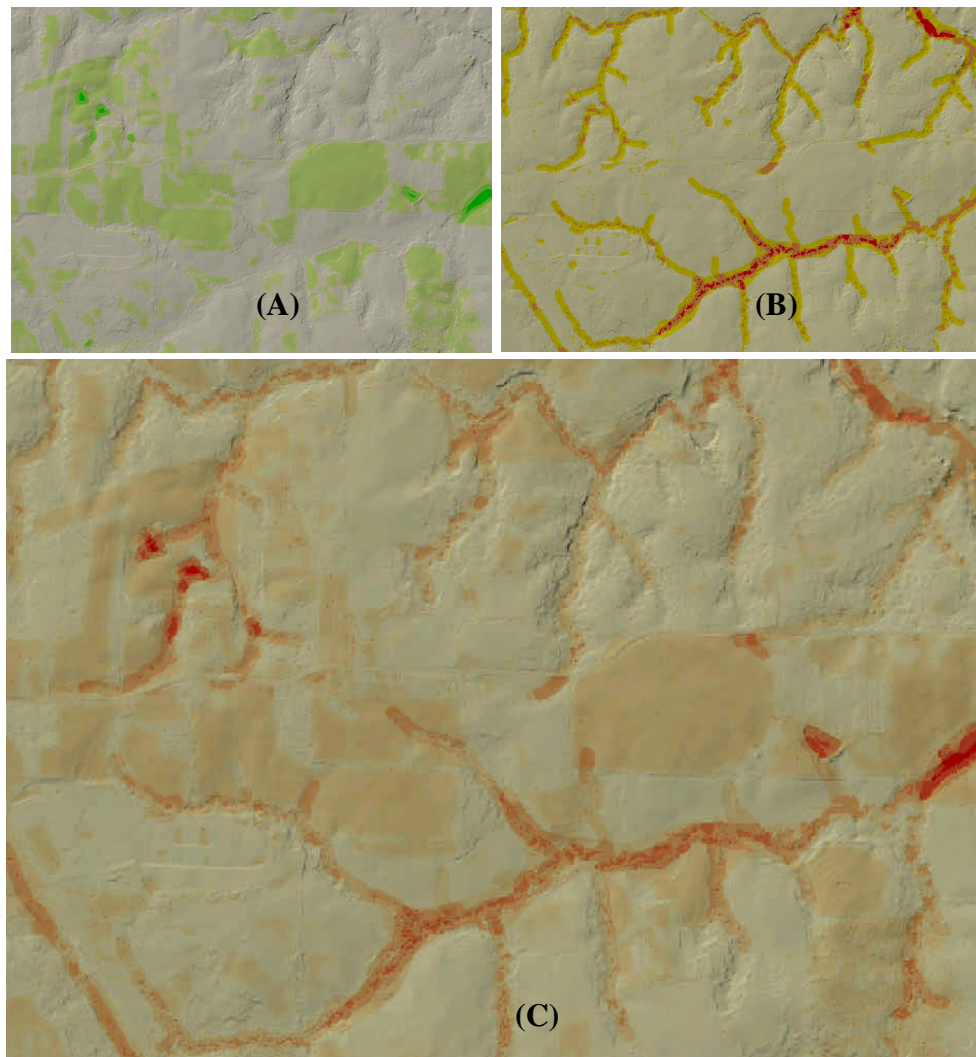


Figure 7. The VI (A), NVI (B), and the Total Possible Sum (C) products are shown, with increasing shades of brown in the TPS indicating increasing likelihood of wetlands occurrence. The TPS may prove to be useful for comparison with existing data, for early screening of potential wetland areas, for planning field work, and for planning transportation alignments that travel a path of least likelihood of wetland impacts.

VALIDATION OF WETLAND LIKELIHOOD ANALYSIS RESULTS

The results of a National Wetlands Inventory survey (i.e. photo interpretations and field classifications) were compared to the results of the wetlands likelihood analysis, as were field wetland determination made by the North Carolina DOT. When compared to the total possible sum (TPS) product it is apparent through visual inspection that the patterns of areas on the landscape predicted as being highly likely of supporting wetlands correspond well to the NWI and North Carolina DOT survey results.

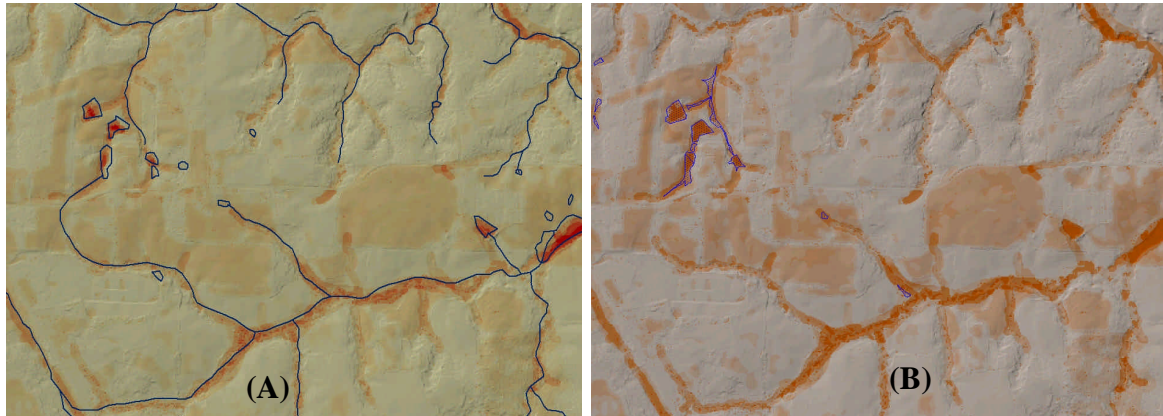


Figure 8. The NWI line and polygon features (A) are shown in blue, overlaying the predicted likelihood of wetlands shown in increasing brown (A) and orange (B). NC DOT mapped features (B) are shown in blue and include on non-water areas mapped as wetlands. The NWI features include surface-water streams and evidence a greater overall pattern or agreement with the analysis results.

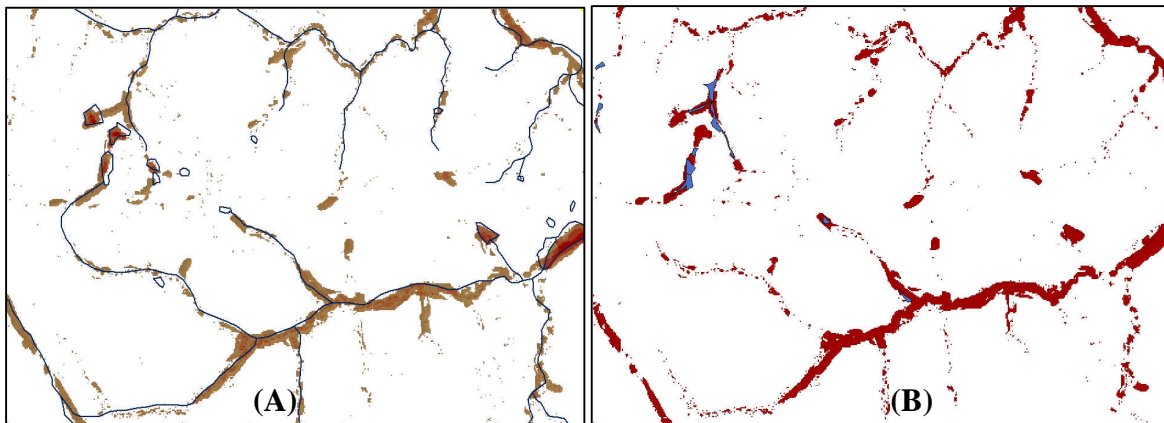


Figure 9. To better illustrate the agreement between field surveys and the analysis results, the TPS areas with scores greater than 20 (TPS20) were selected and are shown in brown (A) and red-brown (B). The value “20” represents one-third of the total possible sum and it is reasonable to assert that areas which exceed 33 percent have a high likelihood of meeting at least one out of three wetland criteria. The NWI line and polygon features (A) are shown in blue and the NC DOT mapped features (B) are similarly shown in blue overlaying the TPS20 surface. The degree to which the analysis predicts likelihood of wetlands occurrence is evidenced by the direct overlay of the field mapped features.

Estimating and measuring agreement between the mapped wetlands and the TPS20 was facilitated by generating a Euclidean distance grid from the TPS20 areas. The NWI and NC DOT mapped wetlands areas were then compared directly to their distance away from the TPS20 areas. The greater the area of the NWI or NC DOT mapped wetland features that directly correspond to the TPS20 the better the agreement. The tabulation of percent NWI area versus distance away from the TPS20 provides a good indication of the overall agreement between the traditional NWI photo interpretation wetlands assessment and the areas predicted as having a high likelihood of being wetlands.

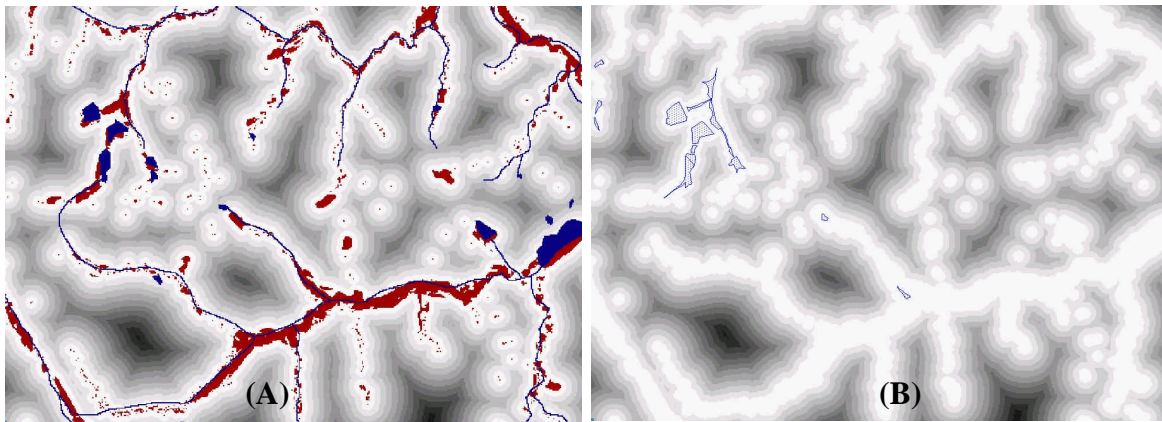


Figure 10. The TPS20 areas is shown in brown (A) and white (B) with distance away from TPS20 shown in increasing shades of gray. The NWI mapped features (A) are shown in blue as are the NC DOT mapped features (B). NWI and NC DOT areas directly overlying the TPS20 have 0 distance from TPS20.

Table 2. NWI and NC DOT mapped feature areas were tabulated with respect to distance away from TPS20 to demonstrate the close agreement between the traditional wetlands mapping and the geospatial and remote sensing analysis approach to assessing likely wetlands areas. Tabulations for the NWI features are shown in the gray highlighted cells and tabulations for NC DOT mapped features are shown in blue highlighted cells.

NWI Area (sq-m)	Percent NWI Area	TPS20 Distance in 5m cells	NC DOT Area (sq-m)	Percent FWA Area	TPS20 Distance in 5m cells
140,175	70.09%	LT 1 cell	11,175	81.87%	LT 1 cell
162,250	81.13%	LT 2 cells	12,225	89.56%	LT 2 cells
174,175	87.09%	LT 3 cells	12,750	93.40%	LT 3 cells
191,300	96.65%	LT 4 cells	13,050	95.60%	LT 4 cells

SUMMARY AND CONCLUSIONS

High spatial and spectral resolution hyperspectral digital image data and high-resolution elevation data can be used to perform analysis of the likelihood of wetlands. Hyperspectral digital data can be used to generate detailed land cover and vegetation information. Vegetation information products resulting from stratifying vegetative types by wetland indicator status and performing neighborhood analysis to clarify results significantly reduces the confusing complexity of and the “noise” in high-spatial resolution hyperspectral classified imagery. When combined with non-vegetation information generated from hydrology and soils data, a more complete analysis of the likelihood of wetland occurrence is possible.

LIDAR-based digital elevation data can be used to create data layers related to hydrologic conditions including a filled hydrologic surface layer, a hydrologic sinks surface layer, and other hydrologic data derivatives such as flow direction and flow accumulation layers. These data products can then be used to generate synthetic stream networks which can be buffered to develop estimated areas of riparian or transitional zones. Estimation of these transitional zones is an area where the analysis procedures developed for this paper may be further refined – for instance, to provide variable width buffers or transitional areas that may take into consideration the presence of various types of vegetation as indicated by the classified spectral information products.

Hydric soils information as provided in digital versions of the NRCS county soils data (SSURGO), in combination with the hydrologic settings data, allows the determination of non-vegetation information. The combination of hydrologic sinks, transitional buffer zones, and hydric soils data can be used to estimate the non-vegetation components of a wetlands determination. However, NRCS county soils data have been compiled over time and from base materials that in most cases lack the spatial and spectral resolution of current high-resolution imagery. Significant improvements in digital processes for wetlands determination would be facilitated by improved methods for using leaf-off high-spatial resolution, hyperspectral data in conjunction with high-resolution elevation data for mapping the occurrence of hydric soils.

Through neighborhood analysis, hydrologic analysis, and data fusion techniques, analysis products can be generated that closely estimate the likelihood that wetlands criteria are met. For the analysis development unit in the Randolph County, North Carolina study area, these estimates closely approximate the results of a traditional NWI survey and an NC DOT field wetland assessment. When compared to the results of the conventional NWI and NC DOT wetland mapping methods, over 95% of the areas mapped as NWI wetlands or NC DOT’s Field Wetland Assessment areas were within 4 analysis cells of the areas predicted as having a high likelihood of wetlands (TPS20).

The digital analyses developed and described herein can be completed in a timely, efficient, and standardized manner yielding results that meet the needs of transportation planners and environmental analysts. The results may be used to conduct preliminary roadway alignment planning, to screen for areas that have a high likelihood of wetland occurrence, and to plan fieldwork in the project areas. The data required to conduct these analyses can be scheduled for acquisition from commercial data vendors. The methods for conducting the analyses can be accomplished using most desktop image processing and GIS software, with little effort required to implement the analysis algorithms within the specific software environment.

The results presented in this paper concern a relatively small area which will be augmented with results from the larger High Point, North Carolina study area. Ongoing efforts regarding other study areas will help to refine the analysis methods presented. These efforts will result in an improved understanding of the cost, utility, and limitations of the techniques and of the data products used and described. Likewise, improvements in remote sensing data products and availability and in methods for the use of current information products to assist traditional wetlands mapping techniques will likely result in cost reductions, improved efficiencies, better accuracy of results, and increased acceptance and use of “digital workflows” as an integral part of wetland-mapping efforts.

REFERENCES

- Cowardin, L.M., V. Carter, F. Golet, and E. LaRoe. 1979. *Classification of Wetlands and Deepwater Habitats of the United States*. U.S. Fish and Wildlife Service. 103 pp.
http://www.nwi.fws.gov/Pubs_Reports/Class_Manual/class_titlepg.htm
- FICWD (Federal Interagency Committee for Wetlands Delineation), 1989, *Federal Manual for Identifying and Delineating Jurisdictional Wetlands*, U.S. Government Printing Office, Washington, D.C., 76 pp.
- O'Hara, C.G., Davis, A.A., and Kleiss, B.A., 2000, A decision support system for prioritizing forested wetland restoration in the Yazoo Backwater Area, Mississippi: USGS Water Resources Investigation Report: WRIR 00—4199.
http://ms.water.usgs.gov/ms_proj/wetlands/restoration_dss/
- USDA, Forest Service, 1989, FIA field procedures for Wetland Identification, U.S. Department of Agriculture Forest Service, Southern Research Station, Asheville, NC. 11pp. Unpublished data on file with: USDA Forest Service Southern Research Station, Forest Inventory and Analysis Research Work Unit, P.O. Box 2680, Asheville, NC, 28802.
<http://www.srs.fs.fed.us/sustain/data/fia/wetlands.pdf>
- USACE (U.S. Army Corp of Engineers), 1987, *Wetlands Delineation Manual*, Tech. Rept. Y-87-1, Department of the Army, Washington, D.C.