Remote Sensing and Geospatial Applications for Wetland Mapping and Assessment

December 2001

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http://www.ncrste.msstate.edu/publications/ncrste_tg003.pdf
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ABSTRACT

Identifying and mapping wetland features that occur in agricultural areas from aerial photography is a challenging task, but the use of advanced airborne remotely sensed data and data processing techniques can improve the process of providing preliminary data for screening likely wetland areas from the impact of transportation projects. Landscapes where the land use is predominately agricultural typically have land cover in a complex mixture of pasture grassland, agricultural crops, trees, shrubs, and grasses; rural development and residences; and well-developed or improved drainage. In these areas, small streams may be completely obscured by the canopy of trees that feature prominently in riparian zones and buffer overland flow of water into drainage features. Trees alongside streams often hide understory and wetland vegetation as well as the water itself. In the collection, synthesis, and assessment of data, the use of aerial photography alone does not provide sufficient information to the environmental analyst to map the occurrence, nature, and distribution of wetland features. However, high-resolution, hyperspectral data and digital elevation data can provide the capability to detect wetland vegetation, provide improved detection of hydrologic features and conditions, and (especially when combined with digital soils data) provide an improved contextual assessment for screening areas that have a high likelihood of containing wetlands.

High-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 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 U.S DOT Research 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, over 95% of the areas mapped as wetlands by NWI methods or by NC DOT field wetland assessment methods were within 4 analysis cells of areas identified as having a high likelihood of being wetlands.
1.0 Introduction

The objective of the Clean Water Act, formerly known as the Federal Water Pollution Control Act (33 U.S.C. 1344) 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 Federal Highway Administration (FHWA) continues to support the United States Army Corps of Engineers in the development and implementation of a regionalized functional wetlands assessment methodology for the evaluation of wetlands as required under the public interest review procedures of the Section 404 permit program. State highway agencies continue to have a need for an effective, consistent, scientifically sound approach to wetlands assessment to evaluate wetlands impacts under the requirements of National Environmental Policy Act (NEPA) as well as Section 404 permit applications.”

In the Corps of Engineers *Wetlands Delineation Manual* (Wetlands Research Program Technical Report Y-87-1, 1987) wetlands are defined 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.

“Hydrophytic (wetland) species have physiological mechanisms, morphological structures, and reproductive adaptations that allow them to exist, grow, and reproduce in areas that are periodically inundated or that have saturated soil conditions.” (FIA Wetlands Delineation Guidebook, 1989)
“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 vegetation.” (FLA Wetlands Delineation Guidebook, 1989)

"Wetland hydrology encompasses all hydrologic characteristics of areas that are periodically inundated or have soils saturated to the surface at some time during the growing season. Areas with evident characteristics of wetland hydrology are those where the presence of water has an overriding influence on characteristics of vegetation and soils due to anaerobic and reducing conditions, respectively. Such characteristics are usually present in areas that are inundated or have soils that are saturated to the surface for sufficient duration to develop hydric soils and support vegetation typically adapted for life in periodically anaerobic soil conditions. Hydrology is often the least exact of the parameters, and indicators of wetland hydrology are sometimes difficult to find in the field. However, it is essential to establish that a wetland area is periodically inundated or has saturated soils during the growing season.” (CE Wetlands Delineation Manual, 1987)

In Part IV of the Wetlands Delineation Manual methods and guidance are provided for gathering and analyzing data for making a preliminary finding, for the selection of assessment methods, for making routine or comprehensive determinations, for making determinations in atypical situations, and for making wetland determinations in natural situations where the three-parameter approach may not always apply. In Section B, Part IV, potential sources of information are discussed that may be helpful in making a wetland determination.

“When the routine approach is used, it may often be possible to make a wetland determination based on available vegetation, soils, and hydrology data for the area. However, this section deals only with identifying potential information sources, extracting pertinent data, and synthesizing the data for use in making a determination. Based on the quantity and quality of available information and the approach selected for use (Section C), the user is referred to either Section D or Section E for the actual determination. Completion of Section B is not required, but is recommended because the available information may reduce or eliminate the need for field effort and decrease the time and cost of making a determination.”

Available data that may be helpful in making a preliminary wetland determination:

- USGS quadrangle maps
- National Wetlands Inventory products
- Plant database
- Soil Surveys
- Stream and tidal gage data
- Environmental impact assessments (EIAs), environmental impact statements (EISs), general design memoranda (GDM), and other similar publications
- Documents and maps from State, county, or local governments
- Remote sensing
- Local individuals and experts
- USGS land use and land cover maps
- Applicant's survey plans and engineering designs
Of particular note is the description in the Corps of Engineers *Wetlands Delineation Manual* about the use of remotely sensed data:

“Remote sensing is one of the most useful information sources available for wetland identification and delineation. Recent aerial photography, particularly color infrared, provides a detailed view of an area; thus, recent land use and other features (e.g., general type and areal extent of plant communities and degree of inundation of the area when the photography was taken) can be determined. The multi-agency cooperative National High Altitude Aerial Photography Program (HAP) has 1:59,000-scale color infrared photography for approximately 85 percent (December 1985) of the conterminous United States from 1980 to 1985. This photography has excellent resolution and can be ordered enlarged to 1:24,000 scale from USGS. Satellite images provide similar information as aerial photography, although the much smaller scale makes observation of detail more difficult without sophisticated equipment and extensive training. Satellite images provide more recent coverage than aerial photography (usually at 18-day intervals). Individual satellite images are more expensive than aerial photography, but are not as expensive as having an area flown and photographed at low altitudes. However, better resolution imagery is now available with remote sensing equipment mounted on fixed-wing aircraft.”

*(CE Wetlands Delineation Manual, 1987)*

Also of interest is the statement that, “in a routine wetland determination, when the quantity and quality of information obtained is sufficient for making a wetland determination an onsite inspection of the area may not be necessary (Routine determination – Level 1) *(CE Wetlands Delineation Manual, 1987).*

Today’s multi-spectral and hyperspectral data provide the ability to conduct automated classification of land cover and land use. Digital data provide the ability to automate image processing and analysis. Multi-band data provide increased spectral information allowing better differentiation of land cover classes. The ability to conduct automated classification of multi-band image data provides a significant advantage over single band images that only provide the ability to conduct photointerpretation of the emulsion-based image product. Additionally, the availability of satellite and aerial images with high revisit rates or scheduled acquisitions provide the transportation planner with the ability to acquire data when desired under conditions that are ideal for the analysis of needed data. The cost of these data are significant, and additional cost-benefit analyses are required to fully assess the utility, costs, and benefits of these data to multiple transportation activities and other application areas, all of which might participate in cost-shared acquisition of needed data.
2.0 Purpose and Scope

This paper explores the use of high-resolution hyperspectral imagery and high-resolution elevation data for preliminary wetland determination, mapping, and assessment, and will help to determine whether the use of such data are cost effective, meet environmental analyst’s requirements, and improve wetland identification, mapping, and assessment. The overall objective of this and related research is to determine if the use of advanced data for wetlands screening can help to select transportation alignments that minimize wetland impacts, to provide an overall reduction in time and cost for environmental assessment of wetland impacts, and to streamline the NEPA process.

Recent advances in remote sensing technologies provide high-resolution hyperspectral imagery which can be used to identify individual plant species as well as high-resolution elevation data products that can be used to provide improved understanding of the topography and hydrology of the area. Additionally, the availability of digital soils data from U.S. Department of Agriculture, Natural Resource Conservation Service (NRCS) county soil surveys (SSURGO datasets) to supplement the enhanced image and elevation data sets provide an opportunity to conduct advanced data fusion, classification, synthesis, and assessment of wetlands at early stages of project planning.

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 U.S DOT Research Special Projects Administration (RSPA) Technology Application Project (TAP) with funding and support also provided by North Carolina Department of Transportation (NC DOT). The study area location was between Asheboro and High Point, North Carolina in the Deep River watershed. The data were evaluated by highway engineers for use in preliminary roadway design, and the data were assessed by environmental analysts to determine their utility for the preliminary identification of areas that have a high likelihood of being wetlands.
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.
3.0 Objectives and Methods

Agricultural landscapes may include mature forested cover. Where mature forest is present, the spectral signatures (seen by an aerial or satellite passive sensor) of understory, wetland vegetation, or water may be obscured by the forest canopy. Thus, in these areas, 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 accompanied by data fusion techniques that analyze the combined information products of spectral analysis with elevation data derived topographic and hydrologic information products such as flow accumulation, topographic depressions, and topographic slope.

The object of this report is to demonstrate the use and analysis of high-resolution image and elevation data products (in combination with other available information) for making early determination of 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) to help expedite the overall wetland mapping process.

Best available data such as location of hydric soils as provided by digital soils data are useful to complement information about vegetation and hydrology so that a preliminary determination concerning wetlands can be made. For the study area, digital soils data, digital orthophotography, stream vectors, USGS quadrangle maps, and land cover and use maps were available. These data are useful in the general assessment and characterization of the study area, but, by themselves, do not provide sufficient quantity or quality of information to provide a preliminary wetland determination.

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 may 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 generate a preliminary wetlands determination map.
3.1 High-Resolution Classified Image Data Analyses

Remotely sensed image data varies from low-spatial and low-spectral resolution to high-spatial and high-spectral resolution. Data with pixels 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 differences in land cover classes. To create a detailed classification of land cover for transportation projects, new sources of hyperspectral image data provide high-spectral and high-spatial resolution for automated processing and detailed land cover classification.

Hyperspectral image data were collected for the project at .6m and at 1m ground resolution by ITRES Research Limited using the Compact Airborne Spectrographic Imager II (CASI-II). The image data were corrected for atmospheric conditions using the Empirical Line Correction procedure and geocorrected to NAD83, North Carolina State Plane grid in units of meters (zone 3200) (Appendix 1 and 2).

Figure 3. A natural color mosaic of CASI II data 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 objective of the classification was to create a scheme that would correlate with the National Wetlands Inventory (NWI) classification scheme (Cowardin, 1979).

<table>
<thead>
<tr>
<th>Description</th>
<th>Wetland Class and Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unclassified</td>
<td>n/a</td>
</tr>
<tr>
<td>Sedges, higher elevations</td>
<td>OBL</td>
</tr>
<tr>
<td>Grasses, less dense</td>
<td>FAC, FACU</td>
</tr>
<tr>
<td>Tree and scrub/shrub</td>
<td>FAC, FACU, U</td>
</tr>
<tr>
<td>Dense grasses</td>
<td>FAC, FACU</td>
</tr>
<tr>
<td>Sedges and rushes, lower elevations</td>
<td>OBL</td>
</tr>
<tr>
<td>Willow</td>
<td>OBL, FACW</td>
</tr>
<tr>
<td>Unvegetated soil</td>
<td>n/a</td>
</tr>
<tr>
<td>Clear water</td>
<td>n/a</td>
</tr>
<tr>
<td>Water with vegetation</td>
<td>n/a</td>
</tr>
<tr>
<td>Water with vegetation and sediment</td>
<td>n/a</td>
</tr>
<tr>
<td>Water with sediment</td>
<td>n/a</td>
</tr>
</tbody>
</table>

*Figure 4.* The classified results for the area shown in figure 3. Due to the complex nature of the data, the high-resolution classification product does not provide a clear depiction of the distribution of features on the landscape.
The initial 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 product can be confusing with respect to making a determination about on-the-ground land cover conditions. To extract useful information from the classified high-resolution product it is necessary to stratify the data into intelligible groups.

**Figure 5.** When combined with the original image, the classified results for the hyperspectral image data can be viewed in the “context” of the landscape. However, the context provided by the image data does not sufficiently show assemblages of vegetation that would make a wetland determination an easily accomplished task. The analyses of neighboring vegetation, hydrologic setting, and soils type are needed to make a preliminary estimation of the likelihood of an area being a wetland.
For the purpose of conducting geospatial analysis of wetland distribution, it is necessary that the image data, classified by vegetation type, be stratified into groups by wetland and non-wetland likelihood. For the purpose of this study, the wetland indicator status was used to group vegetative species. Therefore, 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 across the entire normal distribution of the species” (FIA Field Guide, 1989). In essence, the indicator status category reflects the likelihood that a species will be found in a wetland.

The image classes, stratified into groups by wetland indicator status, may be used to perform geospatial analysis. However, it is necessary to provide the grouped data with code values specific to each indicator status category. In addition, the numerical code value was assigned based on the weighted likelihood that a group would occur in a wetland setting with a 10 being the highest likelihood and 0 being the lowest. The resultant groups and code values are tabulated below.

<table>
<thead>
<tr>
<th>Indicator Status and Code Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Obligate (OBL)</strong> Code Value 10</td>
<td>OBL species, under natural conditions, almost always (probability &gt; 99%) occur in wetlands. Examples of obligate species are bald cypress and water tupelo.</td>
</tr>
<tr>
<td><strong>Facultative Wet (FACW)</strong> Code Value 6</td>
<td>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.</td>
</tr>
<tr>
<td><strong>Facultative (FAC)</strong> Code Value 3</td>
<td>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. Species that are classed FAC normally can be found over a very broad range of habitats.</td>
</tr>
<tr>
<td><strong>Facultative upland (FACU)</strong> Code Value 1</td>
<td>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 &gt;34%. Examples of FACU species are white pine, basswood, redbud, and mountain laurel.</td>
</tr>
<tr>
<td><strong>Obligate Upland (UPL)</strong> Code Value 0</td>
<td>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.</td>
</tr>
</tbody>
</table>
3.1.0 Neighborhood Analysis Techniques

The determination of wetlands is made for an area, typically defined by a minimum mapping unit. Samples are typically 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. 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 area areas adjacent to potential wetland pixels on a classified high-resolution remotely sensed image. The techniques were developed to provide a close surrogate for on-the-ground techniques wherein species are counted and an assessment is made. The techniques assess the most significant vegetative component for the neighboring area around each classified image pixel, the weighted sum of components, and the combined dominants present in the neighboring area.

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 designed to consider the pixels within the ¼ acre neighboring area. This was accomplished by specifying a circular focal neighborhood with a radius of 18 one-meter pixels around each pixel. The resultant area is approximately 1017 square meters or about ¼ of an acre. The exact size of a ¼ acre area would be \( \frac{4047}{4} = 1011.75 \) 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.

**Figure 6.** An “Analysis Development Unit” shown in light red within the study area was selected to develop and test geospatial and remote sensing analysis techniques. The analysis development unit is about 1.9 square miles or 1220 acres in size. 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.
3.1.1 Most Significant Component (MSC): Focal Majority

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). Thus, when considering the wetland indicator status values of 10, 6, 3, 1, and 0, the MSC function returns the most frequently occurring value in the neighborhood. For areas where there are mostly facultative (FAC) species with a wetland indicator status value code of three, but scattered occurrence of FACW species, the MSC serves to filter out the noise of these other minor constituents. The MSC provides a clear picture of the vegetative types (grouped by indicator statues value code) that occupy a majority of the landscape for a given area.

**Figure 7.** The most significant component analysis results for the analysis development unit are shown in various shades. Vegetation with upland indicator status and a resultant value code of 0 dominate the area. The MSC raster is hillshaded by the elevation data for the analysis development unit to highlight topographic relief and features.
3.1.2 Weighted Sum of Components (WSC): Focal Sum

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.

![Image of weighted mixture of components for the analysis development unit](image)

**Figure 8.** The weighted mixture of components for the analysis development unit shows increasing combined weight in increasing shades of blue. Overall patterns of WSC are similar to the patterns seen in the most significant component output. Moreover, as would be expected, areas near focal neighborhoods that had been evaluated as MSC OBL show patterns indicating significant quantity of vegetation with a high wetland indicator status.
3.1.3 Combined Dominants (CD): Combination of Focal Counts

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. Although the remote sensing data used in this project did not provide information to differentiate strata, a determination was made by counting the number of pixels in the neighborhood of each cell that had a wetland indicator status value code of 10, 6, or 3. The CD assessment determined, for each pixel, the count of pixels in the neighborhood that were 10, or 6, or 3. The count of cells that are 10, 6, or 3 was divided by the count of the total number of cells in the focal neighborhood resulting in the percent combined dominance for the focal neighborhood. The CD provide an overall indication of areas likely to meet the vegetative criterion for wetland determination.

Figure 9. The combined dominants results for the analysis development unit shows increasing combined counts of obligate wetland (OBL), facultative wetland (FACW), or facultative (FAC) in increasing shades of orange. Overall patterns of CD are similar to the patterns seen in the MSC and WSC outputs.
3.2 High-Resolution Elevation 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 by the precise timing of thousands of laser pulses striking the ground surface. The surface created shows the “bare earth” surface that is the results of removing natural cover and man-made structures from the raw LIDAR data. The LIDAR data were evaluated for preliminary design as well as cut and fill analyses for roadway construction. Typical DEM products such as USGS 1:24,000 scale DEMs are generally not of sufficient quality for roadway analysis and design analysis. However, the quality of information products that can be developed with LIDAR show much promise for topographic, morphologic, and hydrologic analysis as well as for preliminary roadway design.

Figure 10. A 3D view (with moderate vertical exaggeration) of the analysis development unit created from the LIDAR DEM shows the drainage patterns on the landscape. The DEM was created with 2 meter spacing between elevation points. This spacing is generally called the “posting” interval for the DEM. USGS 1:24,000 scale, level 2 DEMs have posting interval that are typically 30 meters. The vertical accuracy of LIDAR data is typically better than 0.2 meters, which is a dramatic improvement over the vertical accuracy of USGS DEM data.
3.2.0 Generation of Hydrologic Data Derivatives

**Figure 11.** The DEM created for the analysis development unit was used for hydrologic analysis. To conduct hydrologic analysis from a DEM, data derivatives must be generated. These include a filled surface so that water can properly flow on all areas of the surface. From the filled surface several other data sets are generated including flow direction and flow accumulation. From the flow accumulation and flow direction data, watershed boundaries and synthetic stream networks can be generated. Resultant information products may be used in conjunction with other data such as image data for interpretation and analysis. The watersheds and synthetic stream network shown will be discussed further in following sections.
3.2.1 The Filled DEM and Hydrologic Depressions (Sinks)

For hydrologic analysis to work properly, 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 the 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 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 raw DEM was subtracted from the “filled” DEM to create 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 become ponded and stand on the land surface. Such areas are likely flood storage sites and potentially sites for wetland soils and vegetation to develop.

Figure 12. Brown areas that are hydrologic depressions or sinks overlie the gray hillshaded elevation data. The majority of the sinks occur in the vicinity of the stream channel, but some sink areas are present at higher elevation. Many of these depressions are in fact filled or ponded, while others offer the opportunity to store water for undetermined periods of time after a rainfall event.
3.2.2 Flow Accumulation, the Synthetic Stream Network, and Transitional Zones

**Figure 13.** The filled DEM was used to develop flow direction and accumulation information products. Flow direction and accumulation were used to create digital streams on the landscape. Streams occur when 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-interpreted synthetic stream network to the right was buffered to include an 18-meter distance (radius of 1/4 acre circular area) from the theoretical drainage centerline that represents the transitional or riparian zone. Within the study area, wetlands along streams are typically completely hidden by the canopy of trees that thrive in this transitional environment. The figure below shows the buffer zones along the stream network.
3.3 Data Combination Analyses

Wetlands fieldwork typically involves determining whether vegetative, soils, and hydrologic criteria are met. In this analysis digital county soils data were used to form a hydric soils layer and combined with hydrologic and vegetative information products.

3.3.0 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 data may be available as a digital product or may be compiled as such for use in environmental analysis associated with transportation projects and in other application areas. 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 (CE Wetlands Delineation Manual, 1987).

Figure 14. Areas classified by the NRCS as having hydric soils are shown in light-brown/tan and overlay the gray hillshaded elevation data for the analysis development area. Digital data for hydric soils may be available from the NRCS or may be digitally compiled from hardcopy materials provided by the NRCS.
3.3.1 Combining Non-Vegetative Information Products

Quantitatively assessing the likelihood of wetlands occurrence required ranking and combining information layers. For this analysis, the data products were grouped into vegetation and non-vegetation information items. In developing the methodology, equal weight was given to vegetation and non-vegetation information items. Non-vegetation information items contributed a possible 30 points, and vegetation information items contributed a possible 30 points. Soils and hydrology combined to contribute 30 possible points while the vegetation information products that are a result of analysis of remote sensing data received 30 possible points. Other ranking systems are possible, but this method was developed to provide a demonstration of the use of high-resolution hyperspectral data for wetlands identification and as such gives more relative influence to that component in the quantitative determination of wetlands likelihood.

Figure 15. Buffered areas around synthetic streams are shown in blue, hydrologic depressions in brown, and hydric soils are shown in tan. This combination of non-vegetation information products illustrates the spatial overlay of stream and riparian zones, areas likely to pond overland flow, and soils typical of the wetland environment.
3.3.2 Ranking and Combining Vegetation and Non-Vegetation Information

The vegetation information (VI) items generated from the analysis of high spatial resolution hyperspectral classified data provide continuous surfaces of data values that were gradationally ranked and combined. These surfaces are the MSC, the WSC, and the CD surfaces already discussed. For each of these surfaces the entire range of data values was divided into intervals and assigned a ranking from 0 to 10. For the MSC surface, the MSC value code was directly used to provide a pixel rank, but the other surfaces were normalized by the global maximum value, divided into equal intervals of data values, and ranked from 0 to 10. The maximum value indicates for a given pixel in that surface a maximum likelihood that wetland conditions exist for that criterion at that location.

Since VI may contribute a sum of 30 points, the NVI also may contribute a combined sum of 30 points. The non-vegetation information (NVI) products provide a non-continuous surface in which wetland conditions are assessed as being either present or not present. Areas classified as being hydric soils, sinks, and buffered stream riparian zone provide an indication that wetland conditions are present and received a maximum rank of 10 while other areas in these layers received a rank of 0.

The total possible sum (TPS) of ranked information was determined by summing the ranked information for all six layers. Therefore, the maximum total possible sum is 60. A percent of possible sum (PPS) layer was determined by dividing the actual sum of all layers by the maximum possible value of 60. The TPS and PPS layers were used to compare the results of this assessment methodology with the results of tradition NWI wetlands mapping and NC DOT field wetlands determinations.

<table>
<thead>
<tr>
<th>Group</th>
<th>Item</th>
<th>Ranking Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetation Information (VI)</td>
<td>Most Significant Component (MSC)</td>
<td>Wetland Indicator Status Value Code provides ranks from 0 to 10.</td>
</tr>
<tr>
<td></td>
<td>Weighted Sum of Components (WSC)</td>
<td>Values are normalized and ranked from 0 to 10.</td>
</tr>
<tr>
<td></td>
<td>Combined Dominants (CD)</td>
<td>Values are normalized and ranked from 0 to 10.</td>
</tr>
<tr>
<td>Non-Vegetation Items (NVI)</td>
<td>Hydrologic Depressions (Sinks)</td>
<td>Sinks receive a 10 and all non-sink areas are 0.</td>
</tr>
<tr>
<td></td>
<td>Streams and Transitional Riparian Zones</td>
<td>Areas within the buffer zone receive a 10 and all other areas a 0.</td>
</tr>
<tr>
<td></td>
<td>Hydric Soils</td>
<td>Hydric soil areas receive a 10 and other areas a 0.</td>
</tr>
<tr>
<td>Total Possible Sum (TPS) of Ranked Information</td>
<td></td>
<td>60</td>
</tr>
</tbody>
</table>
The algorithm developed was summarized into major workflow elements and analysis components in a data workflow diagram as shown in figure 16.

**Figure 16.** Geospatial and remote sensing analysis work flow diagram for the wetlands assessment algorithm.
3.3.3 Vegetation Information and Non-Vegetation Information

Summing the ranked MSC, WSC, and CD image analysis products generates the VI product.

**Figure 17.** The VI product is shown with increasing values indicated by increasing shades of green. The VI overlays the hillshaded relief of the analysis development unit. VI values range from 0 to 30 with the majority of the area shown having values of 10 or less. The VI product is generated from the high-spatial resolution hyperspectral classified image data analysis products. The MSC, WSC, and CD analysis products are ranked from 0 to 10 and combined to produce the VI information product.
Summing the ranked hydric soils, hydrologic sinks, and riparian zone analysis products generates the NVI product. The NVI may have a maximum possible value of 30.

**Figure 18.** The NVI product is shown with increasing shades of brown indicating increasing value of NVI. The NVI overlays the hillshaded relief of the analysis development unit. The NVI product is generated from the topographic sinks, transitional zones, and hydric soils data layers. Each layers is ranked either as 10 for presence of topographic sinks, transitional zones, and hydric soils or as 0 for absence. The ranked data layers are combined to produce the NVI information product.
3.3.4 Total Possible Sum and Percent Possible Sum

Summing the VI and NVI information products generates the TPS product. The VI and NVI may each contribute a possible value or 30 resulting in a maximum possible value for TPS of 60.

Figure 19. The TPS product is shown in shades from light green to brown with increasing brown indicating increase in combined sum. The TPS overlays the hillshaded relief of the analysis development unit. TPS values range from 0 to 60. Combining the VI and the NVI information products generates the TPS product. The TPS provides information about the combined rank of all data layers used for both vegetation and non-vegetation wetlands analysis.
Dividing the TPS by the maximum possible sum value of 60 generates the PPS product. The PPS provides a good indication of the wetlands relative likelihood.

**Figure 20.** The PPS product is shown with increasing shades of brown indicating increasing value of PPS. The PPS overlays the hillshaded relief of the analysis development unit. The PPS product is generated from the TPS as a percentage of the maximum possible score. Thus, the PPS is simply the TPS divided by 60. The TPS and the PPS are useful for comparison with existing data, for early screening of potential wetland areas, for planning field work, and for generating an alignment that travels the “least cost path” across either the TPS or PPS when used as resistance surfaces.
3.4 Comparison of PPS and NWI Survey Results

The results of a National Wetlands Inventory survey (photo interpretation and field classification) were used to generate a set of wetland line and polygon features. The NWI overlays were scanned and registered to the digital orthophotography. The registered NWI interpretations were “screen digitized” and attributed with the proper NWI classifications. The resultant line and polygon features were then converted to grids to facilitate comparison and area analysis.

When compared to the percent of possible sum (PPS) product it is apparent through visual inspection that the patterns of areas on the landscape predicted as being highly likely of supporting wetlands correspond almost exactly to the NWI survey results.

**Figure 21.** The NWI line and polygon features are shown in blue. The PPS product is shown with increasing shades of brown indicating increasing value of PPS. The PPS overlays the hillshaded relief of the analysis development unit. The general agreement between the PPS patterns and the NWI results are evident through inspection of the spatial overlay of information products.
To estimate the areas that have a high likelihood of being wetlands it is necessary to define a threshold above which will be considered “high likelihood.” For the purposes of this analysis, areas for which the TPS exceeds 20 were considered high likelihood. In these areas it is highly likely that at least one of the criteria for wetlands are met. The value “20” represents one-third of the total possible sum and it is reasonable to assert that areas that exceed 33 percent have a high likelihood of meeting one out of three wetland criteria.

**Figure 22.** The NWI line and polygon features are shown in blue. The areas where the TPS product exceeds 20 points are shown in brown. Of the approximately 200,000 square meters in the analysis development unit that are included in the NWI line and polygon feature, over 87,000 square meters are in areas where the TPS exceeds 20 or one-third of the possible score and over 140,000 (70%) are within 5 meters or one analysis grid cell of the TPS 20 exceedance area (TPS20). The difficulty of working with small areas on emulsion media and the resultant generalization of NWI survey results are part of the non-digital process by which traditional NWI survey results are compiled. The use of digital methods and high-resolution CIR DOQQ media is an area where traditional NWI methods could be enhanced and would likely result in closer agreement with advanced geospatial approaches to wetlands analysis.
To better estimate the degree of agreement between the NWI information and the TPS20 area, a distance grid was generated that shows the distance away from the TPS20 areas. The NWI data was then compared directly to the distance away from the TPS20 areas. The more area of the NWI that directly corresponds 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 wetlands.

**Figure 23.** The TPS20 area is shown in brown with distance away from TPS20 shown in increasing shades of gray. The NWI data are shown in blue. NWI areas directly overlying the TPS20 have 0 distance from TPS20. NWI areas have been tabulated with respect to distance away from TPS20 to demonstrate the close agreement between the traditional NWI mapping and the geospatial and remote sensing analysis approach to assessing likely wetlands areas. Greater than 70% of the NWI areas lie within 1 analysis cell (5 meters) of the TPS20 and over 95% of the NWI areas are within 4 cells (20 meters).

<table>
<thead>
<tr>
<th>NWI Area (sq-m)</th>
<th>Percent of NWI Area</th>
<th>Distance Away from TPS20 in cells (5 meter cells)</th>
</tr>
</thead>
<tbody>
<tr>
<td>87,550</td>
<td>43.78%</td>
<td>0</td>
</tr>
<tr>
<td>140,175</td>
<td>70.09%</td>
<td>Less than 1 cell</td>
</tr>
<tr>
<td>162,250</td>
<td>81.13%</td>
<td>Less than 2 cells</td>
</tr>
<tr>
<td>174,175</td>
<td>87.09%</td>
<td>Less than 3 cells</td>
</tr>
<tr>
<td>191,300</td>
<td>96.65%</td>
<td>Less than 4 cells</td>
</tr>
</tbody>
</table>
3.5 Comparison of PPS and NC DOT Field Wetlands Assessment

The results of an NC DOT Field Wetlands Assessment (FWA) were used to generate a set of polygon features. The polygon features were then converted to grids to facilitate comparison and area analysis. On the analysis grid, approximately 3.37 acres (13,650 square meters) were shown as wetlands (excluding water) in the analysis development area. The large difference between the NWI and the NC DOT wetland mapping results is largely due to the inclusion of water bodies and streams in the NWI result. It should also be noted that there are areas mapped as wetland in the NC DOT assessment that are not included in the NWI result.

When compared to the percent of possible sum (PPS) product it is apparent through visual inspection that the patterns of areas on the landscape predicted as being highly likely of supporting wetlands correspond very well with the NC DOT FWA results and all polygon areas are within or adjacent to areas with high estimated values for likelihood of wetlands.

Figure 24. The wetland polygons from the NC DOT field assessment are shown with in outlines with a light stipple pattern and are seen in the central and upper left areas of the figure. The polygons overlay the PPS with increasing shade of brown indicating increase in TPS. The very close agreement between the PPS patterns and the NCDOT results are evident through inspection of the spatial overlay of information products.
The TPS20 layer was used to illustrate the close agreement between those areas that the NC DOT mapped as wetlands and the estimated likelihood of wetlands. It is visually apparent that the areas mapped by the NC DOT as wetlands are directly on those areas predicted as having a high likelihood of meeting one of the wetlands criteria. The NC DOT FWA covers much less area than the NWI due to the omission in the FWA of water bodies and areas along stream segments that are included in the NWI classification.

**Figure 25.** The NC DOT wetland polygon features are shown in blue. The areas where the TPS product exceeds 20 points are shown in brown. In the analysis development unit, the NC DOT mapped approximately 13,650 square meters as wetlands. The TPS20 product shows areas where there is a very strong likelihood that either the vegetation, soils, or hydrology criteria for wetlands are present. This screening can be used to for preliminary planning, for screening potential wetlands against the impact of roadway construction and for assisting environmental analysts and wetland biologists in planning their field assessment and mapping activities.
To better estimate the degree of agreement between the NC DOT FWA and the TPS20 area, a distance grid was generated that shows the distance away from the TPS20 areas. The FWA data was then compared directly to the distance away from the TPS20 areas. The more area of the FWA that directly corresponds to the TPS20 the better the agreement. The tabulation of percent FWA area versus distance away from the TPS20 provides a good indication of the overall agreement between the NC DOT's FWA and the areas predicted as having a high likelihood of meeting at least one of three wetland criteria.

<table>
<thead>
<tr>
<th>NC DOT FWA Area (sq-m)</th>
<th>Percent of FWA Area</th>
<th>Distance Away from TPS20 in cells (5 meter cells)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11,175</td>
<td>81.87%</td>
<td>0 or Adjacent (1)</td>
</tr>
<tr>
<td>12,225</td>
<td>89.56%</td>
<td>Less than 2 cell</td>
</tr>
<tr>
<td>12,750</td>
<td>93.40%</td>
<td>Less than 3 cells</td>
</tr>
<tr>
<td>13,050</td>
<td>95.60%</td>
<td>Less than 4 cells</td>
</tr>
</tbody>
</table>

**Figure 26.** The TPS20 area is shown in brown with distance away from TPS20 shown in increasing shades of gray. The NC DOT FWA areas are shown in blue. FWA areas directly overlying the TPS20 have 0 distance from TPS20. FWA areas have been tabulated with respect to distance away from TPS20 to demonstrate the close agreement between the FWA and the geospatial and remote sensing analysis approach to assessing likely wetlands areas. Greater than 81% of the FWA areas lie within or adjacent to the TPS20, almost 90% are within 2 cells, and over 95% are within 4 analysis cells of the TPS20.
4.0 Summary and Conclusions

High-spatial resolution, hyperspectral digital data and high-resolution elevation data (in combination with other best available data) can be used to perform analysis of the likelihood of wetlands. By using 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).

High-spatial resolution, hyperspectral digital data can be used to generate detailed land cover and vegetation information. When combined with hydrologic and hydric soils non-vegetation information a more complete analysis of the likelihood of wetland occurrence is possible. Vegetation information products resulting from neighborhood analysis can stratify results, reducing the confusing complexity of and the “noise” in high-spatial resolution hyperspectral classified imagery. Using neighborhood analysis, a series of information products can be developed, each of which provides specific insight as to the likelihood of meeting criterion for wetland vegetation. The most significant component (MSC), the weighted sum of components (WSC), and the combined dominants (CD) information product can be combined to provide a sum of vegetation information for preliminary wetlands determination.

LIDAR-based digital elevation data can be used to create data layers related to hydrologic conditions including filled hydrologic surface, hydrologic sinks surface, and other hydrologic data derivatives such as flow direction and flow accumulation. These data products can then be used to generate synthetic stream networks and watershed drainage boundaries. The synthetic streams can be buffered to develop estimated areas for riparian or transitional zones. Estimation of these transitional zones is an area where the analysis procedures developed for this paper may be further refined 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.

The use of 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 have been compiled over time and from base materials that in most cases lack the spatial and spectral resolution of current high-resolution image data. 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.
The ranking and combining of spatial data layers included in vegetation information and non-vegetation information products results in a total possible sum that can be used to estimate the likelihood of a wetland occurring in a given location. The results of these analyses favorably compare with results of traditional wetland mapping techniques. These digital analyses 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, screening for areas that have a high likelihood of wetland occurrence, and for planning fieldwork in the project areas. The data required to conduct these analysis can be scheduled with data vendors and the methods for conducting the analyses can be accomplished by using most desktop image processing and GIS software with little effort required to develop programs that complete the analysis algorithms for the specific software used.

Further efforts in other study areas are on going to refine the analysis methods presented herein. These efforts will result in an improved understanding of the cost, utility, and limitations of these techniques and of the data products used and described herein. 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 important part of wetland-mapping efforts.
References

Brecher, A., 1999, Summary of the DOT National Forum on Remote Sensing Applications to Transportation, DOT, Transportation Science and Technology, Research and Engineering,
http://scitech.dot.gov/reeng/sensmsrm/rmtsense/sbrsmstr.html


