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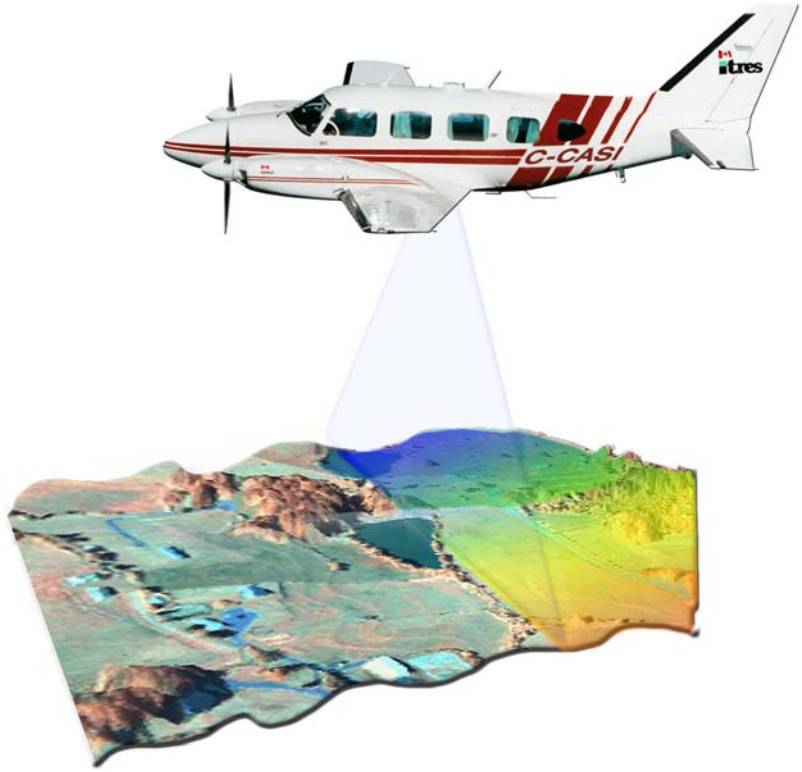
Workshop 7:



Airborne Remote Sensing: A Fast-Track Approach to NEPA Streamlining For Transportation

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Project Objective

The North Carolina Department of Transportation (NCDOT) has a need to know the location and extent of wetlands in order to avoid such areas in infrastructure development.

Airborne hyperspectral digital image data were collected over an area near High Point, North Carolina on 30 June 2000 as part of a project involving EarthData International of North Carolina, the North Carolina Department of Transportation (NCDOT) and the U.S. Department of Transportation (USDOT). The overall project objective was to streamline the process of environmental assessment and permitting for the National Environmental Protection Agency (NEPA). This project investigated the use of aerial photography, airborne hyperspectral imagery and lidar, as well as ground surveys by trained personnel. The hyperspectral image data is used primarily for identification and delineation of wetland areas according to vegetation and drainage characteristics. The project area hosts several varieties of inland terrestrial wetland, including areas modified by urban and agricultural development. The final product from the hyperspectral data was a thematic classification of wetland areas and potential wetland areas.

What Defines a Wetland?

The basis for the classification of the airborne multispectral CASI data for this project is the National Wetlands Inventory (NWI) Classification theme. It uses three criteria that must be examined for a site to be classified as a wetland: vegetation, soil, and hydrology. The area must:

1. Contain a percentage of wetland vegetation;
2. Soils must be hydric; and
3. The area must support a wetland hydrologic regime.

Wetland Vegetation Species

A complete list of vascular plant species that occur in wetlands can be downloaded from the following National Wetlands Inventory web page: www.nwi.fws.gov/bha/.

Hydric Soils

As defined by the USDA – NRCS Soil Survey Division, a hydric soil is:

> *"…a soil that formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part."*

Refer to the website, www.statlab.iastate.edu/soils/hydric/ for further information.

Hydrologic Regime

As defined by the U.S. Army Corps of Engineers, the term wetland hydrology encompasses:

> *"..all hydrological 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."*

Project Design

This hyperspectral project utilized the unique ability of the CASI sensor to collect image data in many narrow spectral bands at high spatial resolution (meter and sub-meter level) and spatial accuracy (meter-level). The objective was to separate vegetation of very similar colors, densities and structures and to pinpoint the spectral behavior of vegetation and land surfaces indicative of wetlands. Once vegetation spectral responses were known, a digital image map was generated pinpointing wetland and potential wetland areas.

Figure 1 provides an overview of the design of this project. The remainder of this section explains this process in further detail.

ITRES acquired image data using the Compact Airborne Spectrographic Imager (CASI) configured with 14 spectral bands across the visible to near infrared wavelengths. Image data were collected at a spatial resolution of 1 meter over a flight block in North Carolina that was 90 km^2 in area on June 30, 2000. On the same day, a smaller subarea was imaged at 60 cm resolution in 11 spectral bands. There were a total of five processed CASI mosaics in the one meter dataset totaling 2.74 gigabytes and one mosaic of 60 cm data which was 612 megabytes.

Airborne lidar data were acquired separately over the same area on June 5, 2000. These data provided a digital elevation model of the area at a nominal spatial resolution of 2 meters. Prior to integration with the CASI data, the lidar data were resampled to a 10 m grid for use in the geocorrection processing, thus minimizing terrain distortions across the imagery and increasing its positional accuracy. The lidar data were included in the output orthorectified CASI data files as an additional co-registered image channel.

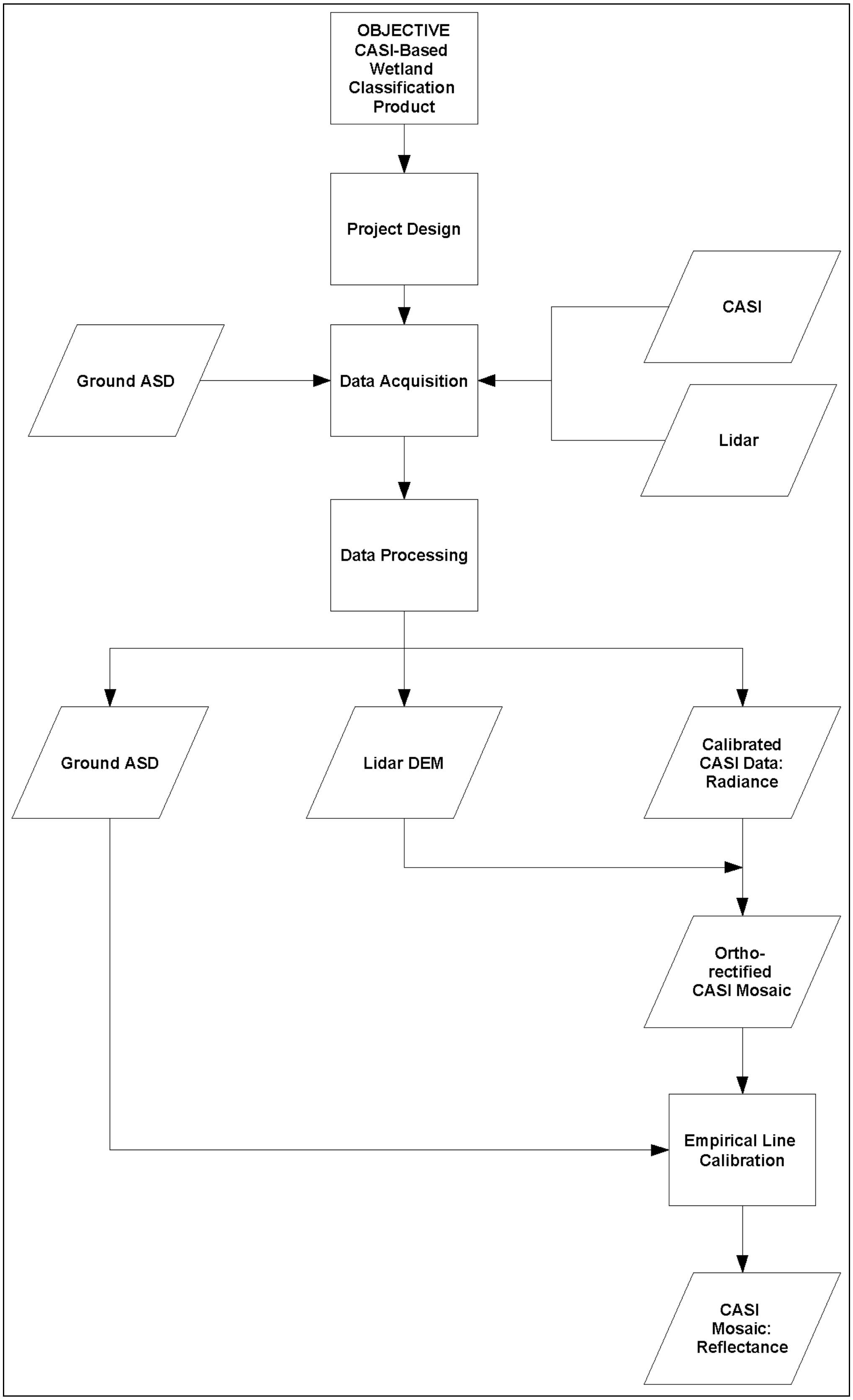
Ground truthing for vegetation location and identification was conducted immediately before airborne data collection in a two day ground truth exercise. Photographs and notes were taken of DOT-identified sites, and GPS coordinates acquired. Most of the visited DOT sites were wetlands, although a couple of sites were “false wetlands”, meaning the site did not meet one of the following criteria: hydric soils, wetland vegetation, or hydrologic regime. Specific information on each site can be located in the Wetland Field Data Sheets associated with this project.

Another ground truth exercise was conducted the following spring in March of 2001, after the wetland classification was nearly complete. This exercise consisted of three days of site visitations. The DOT-identified sites were revisited and judged against the classification. Other sites that were highlighted in the March classification as possible wetlands were also visited. The results of this ground truth exercise are discussed in more detail below.

Previous project reports describe the CASI image collection (Multispectral Acquisition Field Report dated July 2000) and the standard processing of CASI data (Multispectral Field Acquisition Report Revision of November 2000). The procedures and results of these reports are summarized and presented here.

This document describes the general method used to generate the wetland classification. This processing requires hyperspectral image processing software (ENVI is used here) and relies on quality ground truth to guide the classification. The objective was to develop a method that can be easily implemented over a large area using commercially available software and processing techniques.

Figure 1: Project Design Overview



Imaging Technologies Used

CASI (Compact Airborne Spectrographic Imager)

A hyperspectral, CCD-based, programmable pushbroom imaging spectrometer that is sensitive to visible and near-infrared (VNIR) spectral wavelengths (400-1000 nm). Manufactured by ITRES Research Limited, the CASI features a high signal to noise ratio and its data is fully calibrated to traceable standards. The CASI instrument is capable of acquiring information-rich, high spatial and spectral resolution image data that is orthorectified to a high degree of positional accuracy, and may be easily integrated with data from other instruments or georeferenced sources.

The CASI is also equipped with an Incident Light Sensor (ILS), which is used to measure downwelling incident light at the roof of the aircraft using the same chosen spectral bands as used for the image data collection. Data from this sensor is used in the atmospheric correction of CASI image data, permitting its conversion from calibrated radiance units to at-aircraft reflectance.

Figure 2 shows the core CASI system components. From left to right: keyboard, flat panel display, instrument control unit, and sensor head unit.

Figure 2: Primary CASI-2 System Components

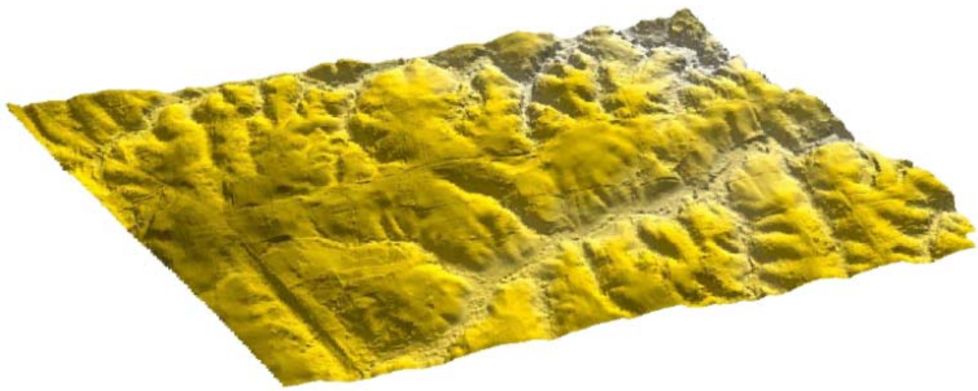
ALTM Lidar (Airborne Laser Terrain Mapper, LIght Detection And Ranging)

The ALTM lidar instrument utilized for this project is manufactured by Optech Incorporated. Based on laser radar technology, lidar is able to generate highly detailed, georeferenced, digital terrain maps of an imaged surface based on measurements of returned pulses or beams of light. These optical pulses are sent by a laser towards the target surface from the aircraft platform. These pulses are reflected off target objects, and the time of arrival of the returned pulses are measured from the start of the pulse to its return. This timing information is then converted to a measure of distance which is then used to build a 3-dimensional image of the terrain below.

The ALTM lidar acquires return pulse data from both the first object encountered (e.g. tree canopy top) as well as the last object (e.g. the ground). As a result, post-processing of this data allows terrain maps to be generated of both the tree tops and the ground topography below.

The lidar system was the source of the digital elevation model (DEM) used as input for the orthorectification of the CASI image data. This DEM was also used as a layer to further refine the initial CASI image classification. A sample portion of the Lidar DEM is shown in Figure 3.

Figure 3: Sample Terrain Map Generated By Lidar (2 m Spacing)



ASD (Analytical Spectral Device)

The ASD is a portable, calibrated, hand-held spectrometer similar in function to the airborne CASI. Manufactured by Analytical Spectral Devices, Incorporated, this VNIR instrument was used to acquire spectral measurements of ground targets that were later used to convert the calibrated CASI image data from units of radiance to reflectance.

Why CASI is Well-Suited For This Application

The VNIR CASI system is ideally suited for this type of application for the following reasons:

1. CASI **sensitivity to visible and near-infrared wavelengths** permits identification of surface types (such as wetlands) based on small differences in their spectral signatures;

2. The sensor's **high signal-to-noise ratio** increases the information content of the acquired data, especially over targets with low reflectance;

3. CASI **data is calibrated** to known standards (NIST), meaning repeatable results;

4. **Operational flexibility** in terms of easily configuring spectral information and spatial resolution. Data may be flown when the user needs, and exactly when weather permits;

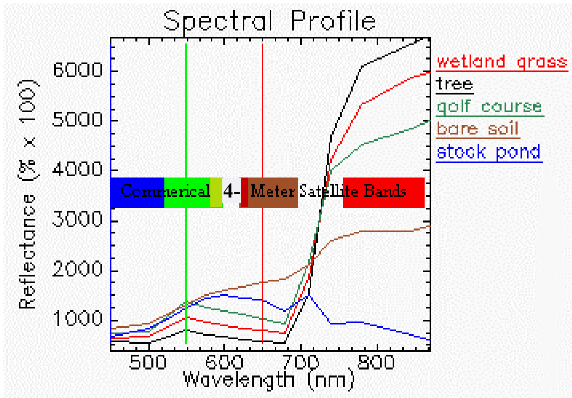
5. The CASI is **easily programmable**. Band placement may be chosen to measure strategic portions of the electromagnetic spectrum where differences between targeted spectral signatures are maximized.

6. CASI spectral bandwidths for this 14 band, 1 m dataset were 12-18 nm, **at least five times finer than commercial satellite technology**;

7. **More spectral bands** means more freedom to sample the spectrum and better ability to differentiate between cover types, especially those that differ in subtle ways. **Figure 4** provides a visual comparison of the number (4), width, and placement of spectral bands

available from the commercial IKONOS satellite at *4 m* spatial resolution versus CASI data acquired at *1 m* resolution. In this example, the CASI has been configured to acquire **14 spectral bands**.

Figure 4: Commercial Satellite Spectral Resolution vs. CASI (CASI Spatial Resolution 1 m; IKONOS 4 m



8. Sensor image data may be converted to at-aircraft **reflectance** using data from its integrated Incident Light Sensor (ILS);

9. **Smaller pixel sizes** (higher spatial resolutions) as compared to commercial satellite systems. This minimizes the spatial "footprint" of an individual pixel on the ground, reducing spectral mixing and increasing the ability to resolve smaller targets. Data was acquired at 1 m and 60 cm for this project. For comparison, the IKONOS satellite can acquire 1 m resolution data, but in *panchromatic mode only* (single band). This sensor's multispectral mode contains four spectral bands (see point number 7 above) at 4 m resolution.

10. **CASI orthorectification accuracy has been independently verified by the DOT as being <2 m;** IKONOS satellite standard accuracy is 12.2 m, precision orthorectification is 4.1 m.

Description of CASI Acquisition

Project mobilization and flight planning took place in Calgary, Alberta, June 16-23, 2000. The CASI system was installed in a Piper Navajo twin engine aircraft. A geometric calibration flight was conducted in Calgary on June 17th before the transit to North Carolina. The data from this flight were used to determine the linear offsets between the CASI sensor and the inertial measurement unit (IMU). These offsets were applied to the North Carolina imagery during geocorrection.

The CASI system hardware utilized for this project is listed in **Table 1**.

Table 1: CASI System Hardware

Hardware	Description / Purpose
CASI sensor	Hyperspectral image collection
Incident Light Sensor (ILS)	Cosine diffuser on top of plane for at-aircraft irradiance measurements
Inertial Measurement Unit (IMU)	Measurement of aircraft motion (roll, pitch, heading)
GPS receiver (embedded in IMU)	Measurement of aircraft position and time
Picodas GPS navigation system	Navigation of aircraft
GPS basestation	Differential correction of aircraft GPS
Processing computer	Field processing of image and attitude data
ASD ground spectrometer	Ground radiance measurements for atmospheric correction

The survey aircraft arrived in Greensboro, North Carolina on June 27.

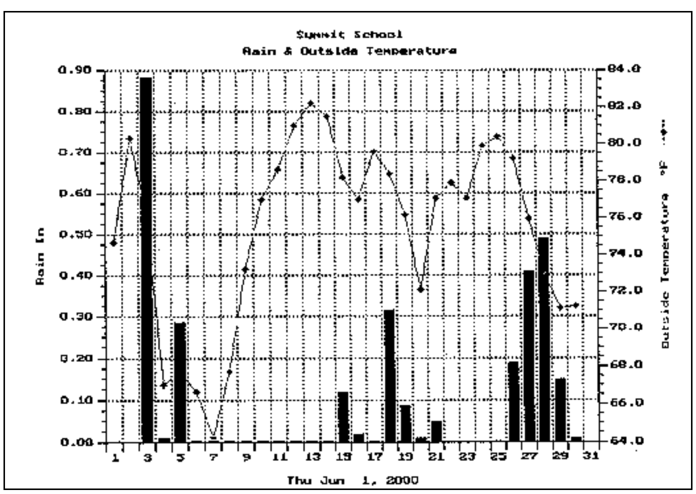
The image acquisition is summarized in **Table 2**. Image data were acquired June 30 from 8:40 am to 11:30 am local time under clear sky conditions with some cirrus cloud at above 20,000 ft. The sun was not obscured by the cirrus layer, although light haze was present in the area. Solar noon occurred at 12:20 am local time. There were three days of rainfall activity preceding the image acquisition, totaling ~1.25 inches, shown in **Figure 5**.

The bandset configuration used for datasets are listed in **Appendix A**, along with a map of the flight track (**Figure 42**).

Table 2: CASI Acquisition Configuration, June 30, 2000

Spatial resolution	Spectral configuration	Number of Image Lines
1.0 meter	14 bands	13
60 cm	11 bands	13

Figure 5: Map of rainfall for area near High Point, North Caroline, June 2000. CASI image data acquired June 30, 2000.



Description of Ground Truthing

Ground Truth 1, June 2000

A ground truth survey was conducted by a certified wetland biologist accompanied by ITRES personnel June 27-28, just prior to the airborne data acquisition. Sites previously identified by the NCDOT were visited (ground truth sites 1-12). Notes on vegetation, drainage, and soil type were recorded, along with a representative site photo and an autonomous GPS position (accurate to ± 5 meters). A ground spectrometer was used on June 30 after the acquisition flight to obtain spectral reflectance measurements of willow, bare soil, and kudzu, an invasive climbing vine.

A sample completed field survey form can be found in **Appendix B**.This form corresponds to ground site number 14, visited on June 27, 2000.

There were a total of twelve ground truth sites visited in June 2000. Of these, two were not considered to be true wetlands, failing to meet the three established criteria of vegetation, hydric soils and /or hydrology (Sites 1 and 2). Of the remaining ten wetland sites, four were located in grazing fields (Sites 4, 6, 8, and 11), one was located in a mowed field (Site 9), one site under willow and shrub (Site 3) and four sites were located under mature tree canopy (Sites 5, 7, 10 and 12).

With the exception of the treed sites, all the visited wetland sites have had their vegetation and/or drainage altered from the original state, and exhibited heterogeneous vegetation assemblages. The stream channel and vegetation at Site 11 had been so altered by cattle grazing that there was debate about its status as a true wetland; as a result, this site was removed from the analysis.

Ground truth sites are plotted in Figure 6 and summarized in **Table 3**.

Table 3: Wetland Sites Catalogued June 2000

Site #	Mosaic #	***Description***	Wetland? Y or N	Classified Correctly? Y or N	Notes
1	4	Drainage feature in agricultural field.	N	N	Small deciduous trees, ground cover dominated upland grasses
2	3	Drainage feature in cornfield	N	Y	Willow tree and upland grasses. Some pixels classified as wetland vegetation
3	3	Wetland dominated by willow	Y	Y	Willow, sedge, rush and cattail present, dominated by the willow.
4	4	Drainage ditch in grazing field, part of a farm located in a topographic basin.	No at GPS point, possibly north of stock pond	Y	Wetland vegetation not present at GPS point. Some *Juncus sp*. in drainage ditch. North of stock pond fields contain *Juncus sp*. and sedge
5	4	Narrow wetland under mature tree	Y	N	Large deciduous tree, no wetland visible.
6	3	Wetland in grazing field	Y	Y	Mixed wetland and non-wetland vegetation. Small willow and deciduous. Juncus *sp*. only in narrow drainage channels and isolated tufts.
7	5	Narrow wetland under mature tree	Y	N	Mature deciduous, no wetland visible at GPS point. Possible wetland identified directly west.
8	3	Wetland drainage through grazed field	Y	Y	*Juncus sp*. mixed in with non-wetland grasses.
9	3	Natural spring in mowed field (one of two).	Y	Y	Deciduous trees, willow and shrub covering spring. Ground vegetation is mixed grasses, sedges and rush.

10	3	Wetland area under mature tree canopy	Y	N	Water source is from springs in Site 9. Image map does not detect the wetland under tree canopy. Lidar detects drainage.
11	3	Small stream through grazed field			Cattle have destroyed creek channel structure, very little wetland vegetation present. Some debate among DOT personnel. This site removed from analysis
12	3	Stream channel under mature tree canopy	Y	N	Kudzu vine not spectrally separable from trees. Stream not classified in imagery.
14	1	Wetland in cut block	Y	Y	Large amount of mixed vegetation in regenerating cut block. Wetland extends west across the road. Site reserved as test for final classification.
15	1	Wetland in grazed field	Y	Y	*Juncus sp*. and *Carex sp*. present, disturbed by grazing. Site reserved as test for final classification.

Ground Truth 2, March 2001

A second ground truth trip was conducted in March 2001 to evaluate the preliminary CASI image classification. Classified imagery was reviewed and sites of interest were selected. Some sites were thought to be potential wetland areas, some sites were selected simply for clarification. The sites visited during this trip are plotted in **Figure 6**, identified alphabetically, and summarized in **Table 4**.

After visiting a few of the sites in **Table 4**, it became clear there were two main sources of confusion in the classification:

1. Saturated grasses on downhill slopes were erroneously classified as wetlands. This was thought to be related to the heavy rains that occurred in the days before the flight (see Figure 6). This problem was subsequently addressed in the next classification by adding spectra from misclassified saturated grasses to the spectral library.
2. The mixed vegetation commonly found in cut blocks was incorrectly classified as wetland vegetation. This situation was harder to resolve since the vegetation assemblage was not homogenous, either spectrally or structurally. There was no one representative spectra for slash vegetation.

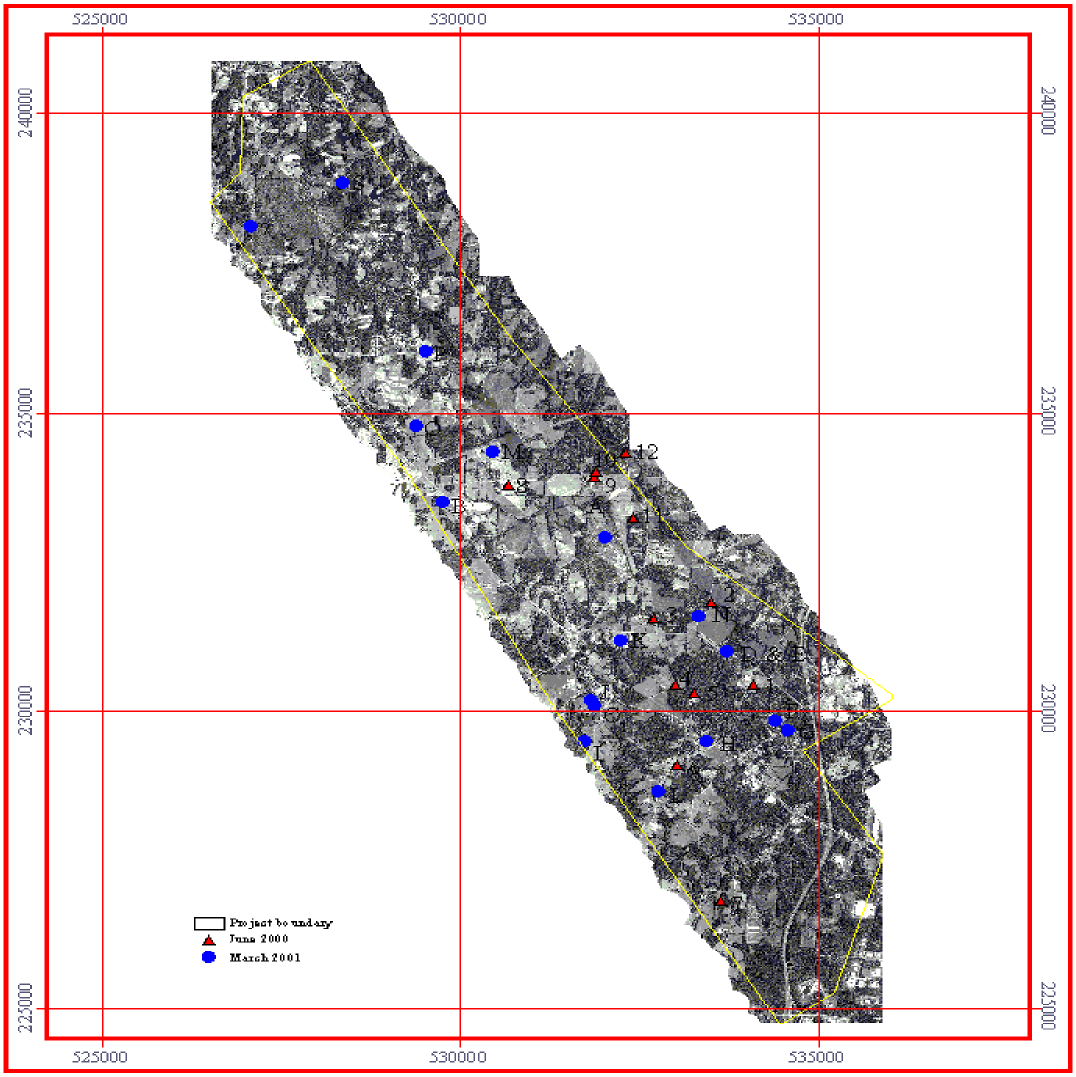
The final thematic maps have incorporated signatures from Site B, where a concentration of *Juncus sp*. was found, and Site N, where dense upland grass had been misclassified as wetland.

Two sites were removed from the accuracy assessment because of uncertainty as to their correct classification. These two sites were areas that drained directly into nearby wetlands. To eliminate this uncertainty, these sites were removed from statistical analysis.

Table 4: Sites Identified by Preliminary Classification to be Wetlands or Sites of Interest, Visited During March 2001 Field Visit

Site #	Mosaic #	Description	Presence of Wetland Indicators? Y or N	Correctly Classified In Final Map Y or N
A	3	Wetland stream in regenerating cut block	Y	Y
B	3	Drainage with wetland vegetation	Y	Y
C	4	Willow, sedge and rush at head of pond	Y	Y
D	4	Willow, sedge and rush wetland across from site E	Y	Y
E	4	Grazed wetland dominated by rush	Y	Y
F	4	Willow, cattail, sedge and rush around pond	Y	Y
G	4	Sedges and drainage in topographic depression	Y	Y
H	4	Upland grasses on slope to pond	N	N
I	4	Drainage ditch and small stock pond	N	N
J	4	Drainage to wetland site C, but likely not true wetland. *Juncus sp*. in drainage ditch		Removed from accuracy assessment.
K	4	Treed spring in agricultural field. No appreciable wetland vegetation		Removed from accuracy assessment.
L	4	Saturated upland grasses	N	N
M	3	Regenerating cut block	N	N
N	3	Saturated upland grasses	N	Y
O	2	Drainage ditch in field, some *Juncus sp*. in ditch (few pixels classify as OBL and FACW)	N	Y
P	2	Saturated upland grass (few pixels classify as OBL and FACW)	N	Y
Q	1	Grassy slope down to stock pond	N	N

Figure 6: Five CASI Mosaics (panchromatic, 550 nm) With Project Boundary Overlay. Ground Truth for June 2000 Plotted by Number; March 2001 Sites Plotted by Letter



CASI Standard Processing

To accomplish mapping from digital image data, these data must be calibrated to a radiometric standard and assigned a specific map coordinate system. The following section describes the steps involved in transforming raw CASI data to an image map.

Radiometric, Geometric and Atmospheric Corrections

Standard processing of CASI data is designed to produce georeferenced orthorectified imagery suitable for use as a map. This involves five basic steps:

a. Raw CASI digital values are calibrated to spectral radiance units (SRU's) which are traceable to accepted standards (NIST).
b. Differential correction of aircraft GPS data (DGPS).

c. Blended solution of DGPS positions with aircraft attitude data from the Inertial Measurement Unit (IMU).
d. Application of optimized position and attitude data to CASI image data.
e. Application of digital elevation model in final geocorrection and orthorectification of CASI imagery.

The following is an expansion of the five steps, and includes the atmospheric correction as an additional step:

a. CASI image calibration involves the removal of measured system offsets (electronic offset, dark current, scattered light) and the application of calibration coefficients to the image digital values. Calibration coefficients are determined in the lab using a calibration sphere. After measured system offsets are removed and the calibration coefficients are applied, the CASI imagery is in spectral radiance units ($\mu W\ cm^{-2}\ sr^{-1}\ nm^{-1}$).

b. Differential GPS positions accurate to the meter and sub-meter level are achieved in post-processing by collecting GPS basestation data over a known point coincident with collection of aircraft GPS. For this dataset, the basestation data were supplied by the city of High Point, North Carolina, at a one second data rate. The DGPS solution was output in UTM Zone 17 coordinates with a horizontal datum of NAD83 and a vertical datum of Mean Sea Level based on the Geoid99 geoid model.

c. DGPS positions are blended with the aircraft attitude measurements from the IMU to achieve an optimized position and attitude measurements. The typical accuracy of the post-processed solution are within the following error:

   Position accuracy: 5 cm to 50 cm
   Roll and pitch accuracy: 0.003° to 0.05°
   Heading accuracy: 0.01° to 0.1°

   The position and attitude solution is output at 200 Hz. This means the GPS positions are interpolated from a 1 Hz rate to a 200 Hz rate. Please note the above accuracy can be reduced when position and attitude data are time synchronized with the CASI data. The best estimate of final accuracy is achieved by comparing ground control points to the final geocorrected CASI image (See Section 4.2).

d. The optimized position and attitude measurements are linked to the CASI by use of a GPS Pulse per Second (PPS) which is logged in the CASI data stream during data acquisition. Each CASI scan line receives position and attitude measurements. During this procedure, the positions are translated from UTM Zone 17 coordinates to State Plane Coordinates, Zone 3200. The vertical datum of Mean Sea Level is retained. Geocorrection of CASI imagery uses the position and attitude measurements for each scan line to map the imagery to a final projection.

e. Orthorectification is achieved by application of a digital elevation model during geocorrection to account for terrain height variations. The digital elevation models were generated from lidar data provided by EarthData International. The lidar data were provided in State Plane Coordinates, Zone 3200, horizontal datum NAD83, with a vertical datum of Mean Sea Level based on the Geoid 99 geoid model. Lidar data were collected at a nominal two meter resolution but for CASI geocorrection all lidar were resampled to 10 meters due to the sheer volume of lidar data. There were two lidar datasets provided: A “canopy” DEM which was used to orthocorrect the 1 m CASI data and a “bare earth” DEM which was used to orthocorrect the 60 cm CASI data.

In the final geocorrected and orthocorrected CASI image mosaics, the lidar used in the geocorrection (resampled to 10 meters) is included as an extra image channel in the mosaic files.

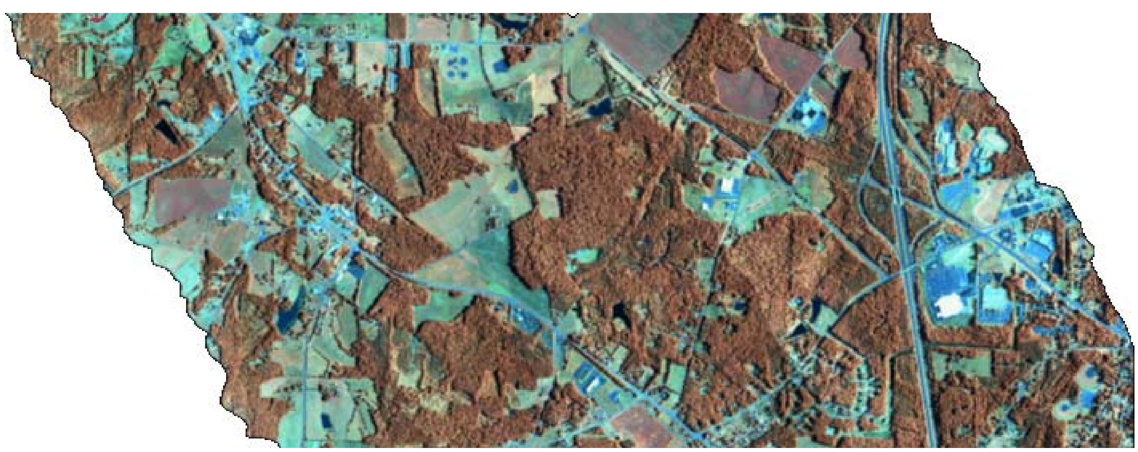
The final standard processing products, based on the above processing steps, were six CASI mosaics. The area covered by one meter CASI data was divided into five mosaics. These mosaics are summarized in **Table 5** below:

Table 5: CASI Mosaics

CASI mosaic file name	**Northwest coordinates** (SPCS Zone 3200, Units=meters)	**Southeast coordinates** (SPCS Zone 3200, Units=meters)	**Spatial resolution** (meters)
DOTmos1.pix	241295 N 525778 E	237500 N 530000 E	1.0
DOTmos2.pix	237500 N 526440 E	234500 N 532250 E	1.0
DOTmos3.pix	234500 N 528450 E	231500 N 535150 E	1.0
DOTmos4.pix	231500 N 530000 E	228500 N 536350 E	1.0
DOTmos5.pix	228500 N 531700 E	224500 N 536300 E	1.0
60cm_mos.pix	234798.6 N 528075 E	232950 N 533040 E	0.6

The false color image seen in Figure 7 is a small subset from one of the processed CASI 1 m resolution mosaic files. This data is in units of radiance, before atmospheric correction. Variations in brightness seen between adjacent flight lines are caused by temporal changes in viewing geometry and the atmosphere that took place during their acquisition. This effect is addressed during the next stage of the processing (atmospheric correction).

Figure 7: Sample Section of Orthorectified CASI Mosaic (False Color)



A sample section from a 1 m orthorectified CASI flight line is shown in Figure 8.

Figure 8: Sample Orthorectified CASI Single Flight Line (True Color)

f. The Empirical Line method was employed to provide a first order atmospheric correction of CASI image data. This procedure is considered somewhat experimental and outside the standard processing procedure. However, atmospheric correction is desired to convert CASI radiance (μW cm^{-2} sr^{-1} nm^{-1}) to measured reflectance, which is a unitless expression of the following:

$$R = E_d / E_u$$

Where:
R = % reflectance
E_d = downwelling irradiance
E_u = upwelling irradiance

The benefit of reflectance units is that, reflectance does not contain any signal except for the signal from the target. Because reflectance is unitless, it can be compared to reflectance values from other datasets, including spectral libraries.

Prior to flight, ITRES crew identified light and dark targets to be utilized in the Empirical Line Correction (ELC). The dark and light targets were located at a school in the town of Randleman. These targets were covered by flight line 13 (easternmost line) of the 1 meter flight plan. At the beginning and end of the airborne image acquisition, line 13 was imaged at 1 meter resolution while simultaneous spectra of the targets were acquired on the ground with a handheld spectrometer. Theoretically, when comparing the radiance of the targets in the image with the radiance collected on the ground, the difference between the airborne and ground spectra should amount to the interference of the atmosphere. The atmospheric influence can then be subtracted from the airborne image data.

Ground spectra collected coincident with aircraft image data are required in the Empirical Line Correction. Because ground data only exists for the one meter data, only one meter data have been atmospherically corrected. The 60 cm data have not been atmospherically corrected.

Spatial Accuracy Assessment

An independent accuracy assessment was performed by the North Carolina Department of Transportation. Before image acquisition, 40 photogrammetric ground control points were deployed in the area and a GPS position was collected. The NCDOT were able to locate and digitize 36 of the 40 targets in the 1 meter GSD imagery using ArcView. One survey point was found to be in error; therefore 35 points were used to evaluate the horizontal accuracy of the multispectral data. The summary statistics are listed below:

X-coordinate (Easting)
mean = -0.67 m
stdev = 1.55 m
rmse = 1.67 m

Y-coordinate (Northing)
mean = -0.52 m
stdev = 1.90 m
rmse = 1.95 m

Classification Analysis

Classification Scheme

The objective was to create a classification scheme that would correlate with the National Wetlands Inventory (NWI) classification scheme, which can be found at http://www.nwi.fws.gov/atx/atx.html. The portion of the NWI classification scheme relevant to the CASI image classification is listed in **Appendix C**. The wetlands presented here are mostly Palustrine System, either classed as Emergent or Forested, with one Riverine System (Site 12).

The thematic classes derived from hyperspectral digital imagery differ from the NWI scheme. Feature extraction from hyperspectral imagery is dictated by chlorophyll and other vegetation pigments (which determine the color of a plant), vegetation canopy density, the size of the vegetation patch, and the surrounding background material. The key to the thematic classification was the attempt to classify indicator vegetation species associated with wetlands. These vegetation included sedges, rushes and willows. Indicator species were divided into Obligate wetland species (OBL) and Facultative wetland species (FACW). An attempt was made to separate OBL from FACW, but because of the small spatial extent and mixed species character of the wetland vegetation concentrations, it was difficult to absolutely determine if this has been successful.

The next two figures provide an example of a CASI image mosaic from flight block 1A (**Figure 9**) and the corresponding wetland classification derived from it (**Figure 10**). The final thematic classes used in the classification are listed in **Table 6**.

Note that there was no separate class for agriculture.

Figure 9: Sample 1 m CASI Mosaic (Panchromatic Single Band) Block 1A

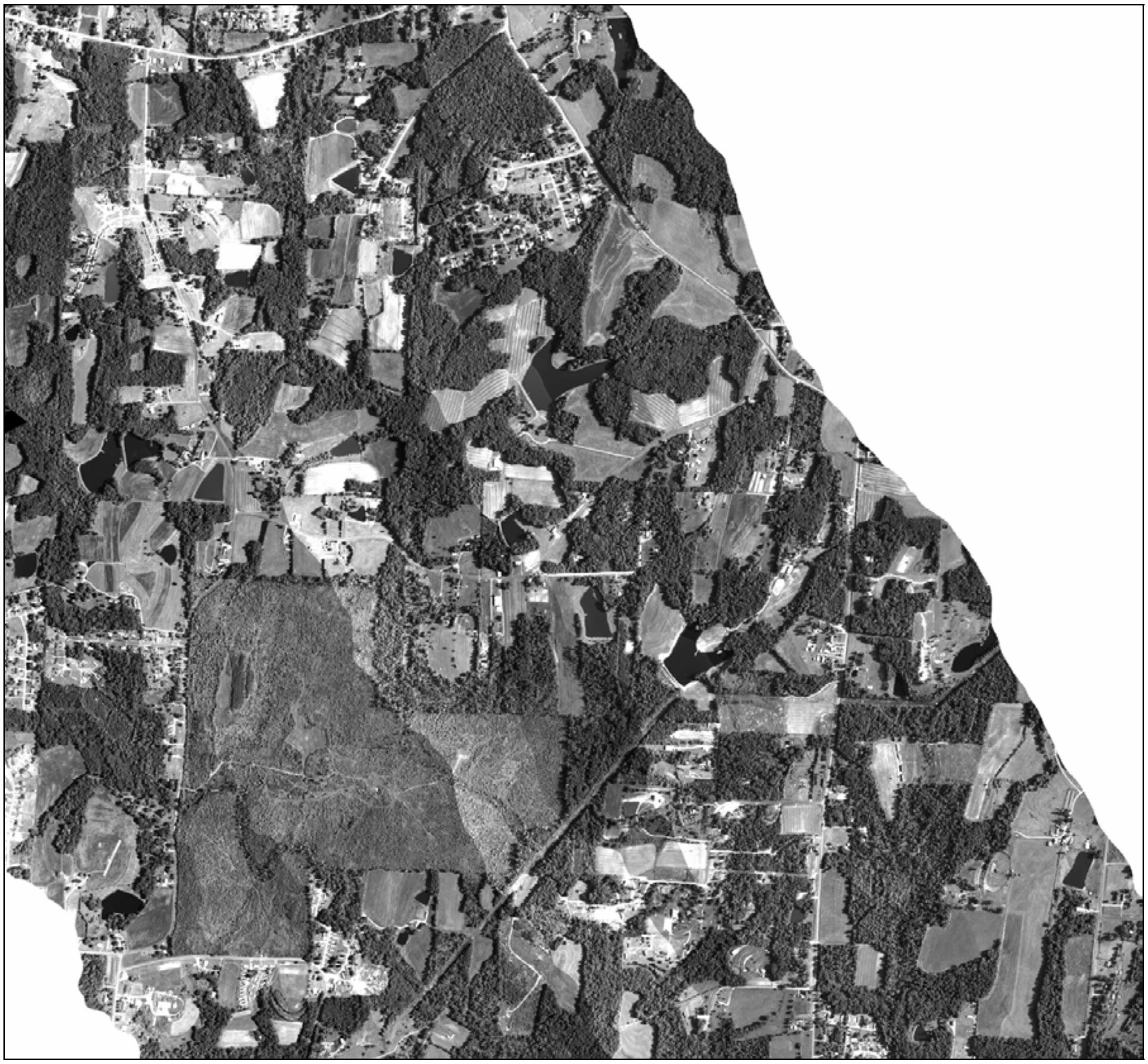


Figure 10: Wetland Classification Derived From 1 m CASI Mosaic Block 1A

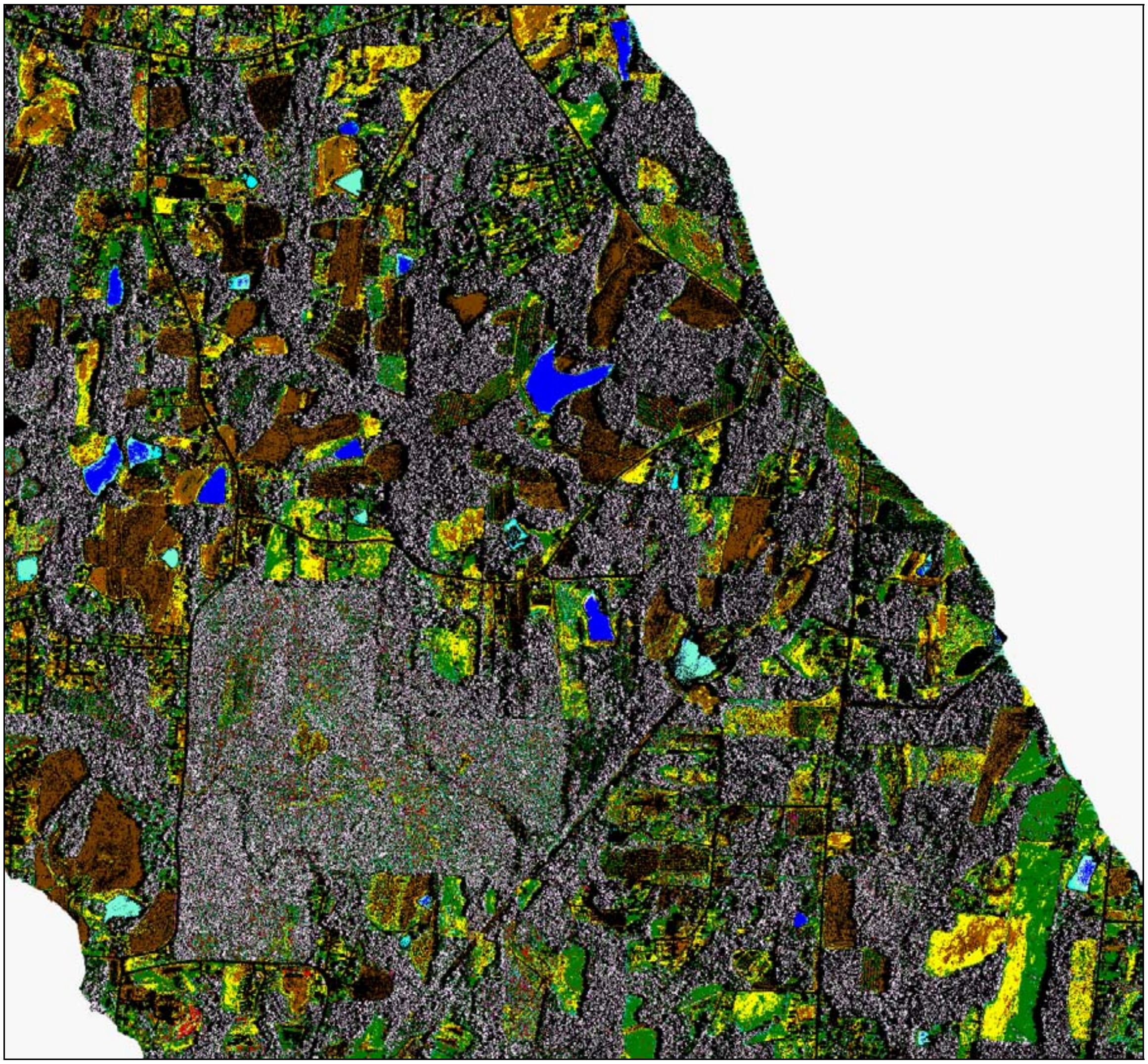


Table 6: Wetland Classification Scheme

Class	Description	Classification Color
Wetland Vegetation Class Obligate Wetland (OBL) Faculative (FACW)	*Juncus sp.* (rushes), *Carex sp.* (sedges) and, rarely, *Typha sp.* (cattail) *Impatiens capensis* (forget-me-not) *Saggitaria latifolia* (arrowhead) *Polygonum sp.* (smartweed) Some members of Poaceae grass family Under tree cover: *Microsteris gracilis* Wetland vegetation types are often mixed with each other and with non-wetland vegetation.	RED (mostly sedges and rushes found at lowest point in terrestrial hydrologic regime) CYAN (mostly sedges found at slightly higher elevations)
Willow Class Obligate Wetland (OBL) Facultative (FACW)	*Salix nigra* (black willow) *Rosa palustris* (swamp rose) *Sambucus Canadensis* (elderberry) *Fraxinus pennsylvanica* (green ash) *Alnus serrulata* (tag alder) Sometimes associated with wetlands, sometimes found in upland	MAGENTA
Tree and Scrub / Shrub Facultative (FAC and FACU) Upland (U)	*Acer rubrum* (red maple) *Liquidimbar styraciflura* (sweetgum) *Liriodendron tulipifera* (yellow poplar) *Lagustrum sinese* (Chinese privit) Mostly deciduous tree, some conifer stands of varying height. Conifer classification shows spectral confusion with sedges and grasses	THISTLE (light pink)
Sparse grass (non-wetland) Facultative (FAC) Facultative Upland (FACU)	Members of Poacae family *Lollium multiflorum* Often associated with agriculture and urban development in this area	YELLOW
Dense grass (non-wetland) Facultative (FAC) and Facultative Upland (FACU)	Often associated with agriculture and urban development in this area. Considered to be similar to sparse grass FAC but more dense.	DARK GREEN
Bare soil	Little or no vegetation present	BROWN

Classification Procedure

A supervised image classification was used in this study. Supervised classifications rely on the identification of known ground cover types in the imagery and the extraction of reflectance spectra for those known areas. The larger the number of spectral bands in the dataset the more distinctly the reflectance spectra can be defined. Datasets of high spatial resolution are desirable to ensure extraction of pure reflectance spectra representing a specific ground cover, thus reducing the effects of mixed pixels. Once reflectance spectra for the land cover types of interest have been identified and extracted, these spectra are compared to spectra for each pixel in the entire image. If the spectra match to a specified accuracy threshold, a class will be assigned to that pixel. If not, the pixel remains unclassified (and is left black in the classified map).

In this dataset, identified land cover types included the ground truthed wetlands, agricultural fields, trees, water bodies, and unvegetated surfaces. Spectra were compiled in a library of land cover types and applied to the rest of the digital imagery. The quality of the resulting classification depended on the quality of these representative spectra and of the radiometric calibration of the imaging instrument.

Figure 11 provides an overview of the procedure used in performing this wetland classification using CASI imagery. The text that follows explains these steps in more detail.

Specific data processing techniques used before the supervised classification involved two steps. The first step was to minimize the noise in the imagery. This is done by a Minimum Noise Fraction (MNF) rotation. The MNF is essentially two iterations of a Principal Components Analysis (PCA). The first PCA decorrelates the noise between the spectral bands and rescales the noise values. The second PCA examined the eigenvalues produced from the first PCA and separated noise from image data. The resulting spectral channels contained spatially coherent image data with a minimum of noise. Further information on the MNF transformation can be found in Green *et al*. (1988).

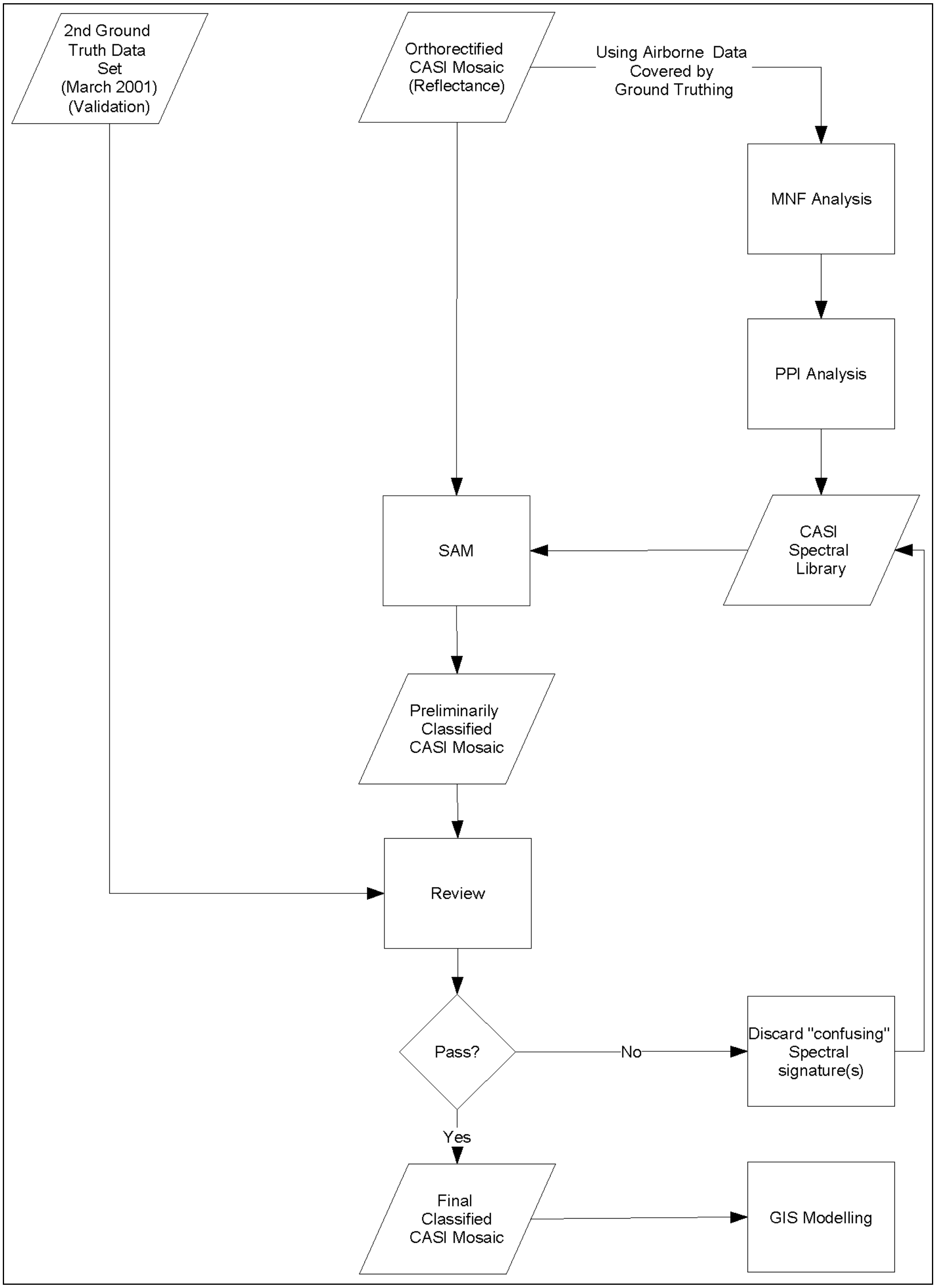
The second step in pre-classification processing was to isolate those image pixels in a ground truthed area that had the purest spectra (meaning the least amount of spectral mixing with adjacent land cover types). The most unique or “pure” spectra were then highlighted using a procedure called the Pixel Purity Index (PPI). PPI operates on the noise-minimized data output from the MNF procedure. When spectrally pure pixels were identified in ground truthed areas, the spectra from these pixels were extracted and included in the spectral library and used to classify of the entire image.

After the spectral library was assembled and each thematic class had its own representative spectra, a supervised classification was performed on each of the five CASI image mosaics. The spectra from each image pixel were compared to the thematic spectra contained in the assembled library. If a match was found within a certain standard deviation, the pixel was assigned to a given class. Otherwise the pixel was left unclassified. Different algorithms may used for supervised classifications; the one used for these classifications was the ENVI's Spectral Angle Mapper (SAM). SAM relies on an angular comparison between the representative spectra and each pixel’s spectra. This method, when applied to calibrated data, is relatively insensitive to illumination differences.

> *Note that the creation of a spectral library is a time consuming and iterative procedure. Not all ground truthed targets translate into a robust spectral signature. The first step in assembling a spectral library is to review notes and ground photos in conjunction with the image map. The second step is to run MNF and PPI on areas where ground data is available and so produce a bitmap of spectrally pure pixels. The desired outcome is that a pure pixel will occur within a wetland plot. If so, the spectra for that pixel is extracted and added to the library. After all the available pure pixels have been extracted in this way, they are used in the SAM classification. The resulting classified map is reviewed and the spectral library revised based on the results. Spectra that are omitted either do not classify any pixels or produce results that do not match the ground data. For every spectra retained in the spectral library, far more are omitted during the library development process. Because every spectra “competes” with other spectra in the library, the success of any one spectra will depend in part on the inclusion or omission of similar spectra.*

The resultant thematic image map was examined and particular attention was paid to results in ground truthed areas. Specifically, misclassified and unclassified pixels were looked for. Based on this review, signatures were omitted from the library and new signatures were added before the classification was run again. Signatures used in the classification presented here are shown in **Figure 12** to **Figure 15** (The spectral bandsets are provided in **Appendix A**).

Figure 11: CASI Classification Procedure Overview



Spectral Signature Analysis

In order to classify an image pixel as a particular vegetation class, a spectral signature for that class is required. Spectral signatures are represented in a plot showing the amount of light reflected in each spectral band of the imagery for a given pixel. Ground data helps to determine what an image pixel really represents so a name can be assigned to the reflectance values. To classify the CASI imagery at least one spectral signature is required for each thematic class. There are often multiple signatures for a single class, owing to natural variations in the environment. The spectral signatures used in this classification are shown in the graphs below.

Figure 12: Wetland Vegetation Signatures

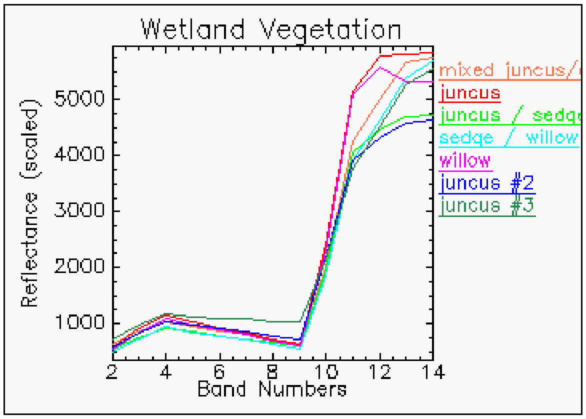


Figure 13: Grass Signatures

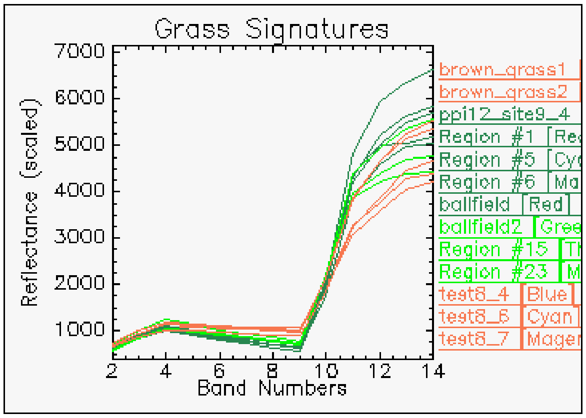


Figure 14: Tree Signatures

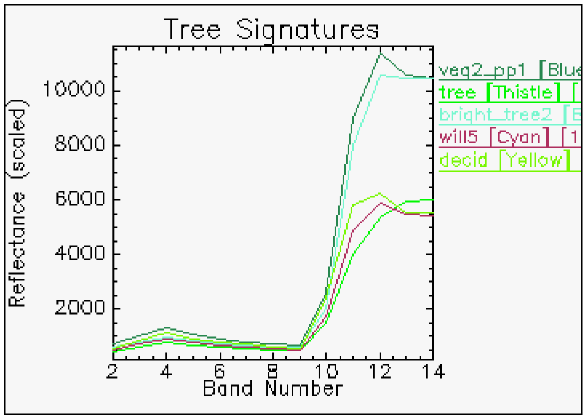
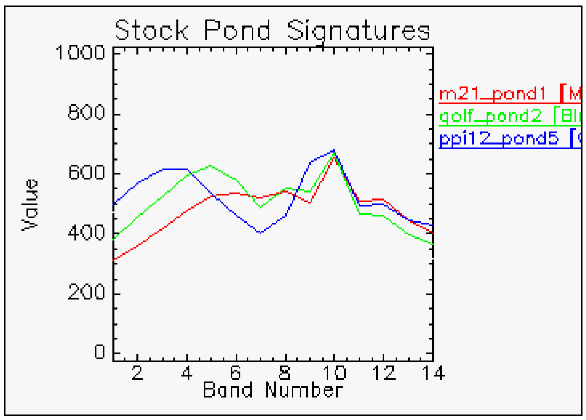


Figure 15: Stock Pond Signatures



Results

The results of the analysis were five thematically classified image mosaics. The ground truthed areas and the sites visited in March 2001 are assessed in the thematic maps in this section.

The decision as to whether or not a site has been correctly classified is somewhat arbitrary at this time. Classification accuracy assessments have traditionally relied on the use of a confusion matrix that reports omission and comission errors. Most of the spectral signatures used in this project were extracted from a single "pure" pixel and in this case a confusion matrix will only report whether or not the single pixel classified correctly. The confusion matrix was used in the analysis and spectra that did not classify in their intended class were eliminated. Thus the confusion matrix will appear at close to 100% accuracy, which is not a reasonable estimation of the accuracy of the classified image as a whole. Alternatively, the confusion matrix could be run on areas not used in the initial development of the classification. But to do this, the spatial boundary of these areas would have to be decided upon, as would the specific percentage of the region that would have to be classified as wetland in order to be correct. Some sites, as discussed below, have very small concentrations of true wetland vegetation and a 25% wetland classification of a determined region may indeed be correct.

The assessment made here relied on whether wetland vegetation appears in the classified image at or near the GPS point. A more accurate assessment could have been made if a region were identified instead of a single point. It was recognized that some latitude is made in determining a successful classification.

Of the ground truth sites listed in **Table 3**, two were removed from calculation. Site 4 was removed because although the GPS point represented a non-wetland site, a potential wetland existed just north of the point on the other side of the stock pond. Site 11 was removed because grazing had destroyed the vegetation and stream channel and there was some debate among DOT personnel as to its functionality as a wetland. Of the remaining twelve sites, 7 of 12 were considered to be correctly classified, for an accuracy of 58%. If the non-wetland sites are removed from the list, the accuracy is 6 of 10 sites correct, or 60%. If the treed sites are removed, the accuracy of the remaining wetland and non-wetland sites improves to 7 of 8 sites correct, or 88%. The results are summarized in **Table 7**.

Table 7: Accuracy Assessment of Ground Truth Sites

Total accuracy, wetland and non-wetland sites	7 / 12	58%
Accuracy of wetland sites	6 / 10	60%
Accuracy of non-treed sites, wetland and non-wetland	7 / 8	88%

The sites visited in during the second ground truth trip in March 2001 were treated as the validation sites. Two sites were removed from assessment because of some debate over their status as wetland or non-wetland. Site J was removed because although it was a drainage ditch through a field at point J, it drained directly into a wetland under the trees between Site J and the stock pond. Other reasons for removing it were the visually identified presence of *Juncus sp*. in the drainage ditch and the inability to gain access to point J due to a fence. Site K was removed because although it does not contain any appreciable wetland vegetation it was a spring that drained into a wetland area under the trees to the southeast.

The results from the comparison with the March 2001 ground sites were similar to those from comparison with the first ground dataset. The wetland areas were successfully identified but several non-wetland areas incorrectly classified as wetland. These results are summarized in **Table 8**.

Table 8: Accuracy Assessment Using March 2001 Sites

Total accuracy, wetland and non-wetland sites	10 / 15	67%
Accuracy of wetland sites	7 / 7	100%
Accuracy of non-wetland sites	3 / 8	38%

The inference made was that wetland areas were detectable by the CASI unless obscured from the view of the CASI by a tree canopy. The weakness in this classification is that the wetland signature was being over-classified and included non-wetland vegetation, notably in artificially drained areas, cut blocks, and saturated slopes. The next step in the thematic classification was to characterize the misclassified non-wetland vegetation. Because of this misclassification, further interpretation is necessary for sites where no ground information is available. In these instances, the lidar data was beneficial for first identifying drainage patterns and low-lying areas. Although these areas often matched the image classification, at times areas classified as wetlands in the CASI data did not match the depressions in the lidar data and so were incorrectly classified.

Recommendations for improving the accuracy of wetland classification using the CASI are discussed under the Results section.

Site Discussions

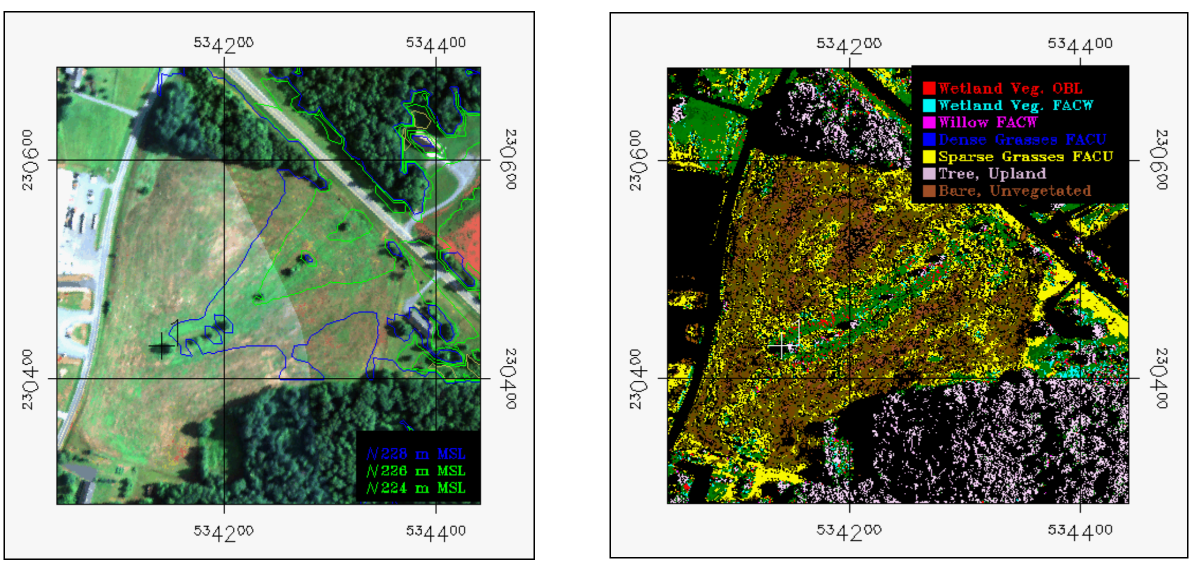
The following is a discussion of results in selected ground truthed sites. The discussion focuses on the strengths and weakness of the classification scheme and illustrates the results outlined in the Results section.

Deciduous and Upland Grasses in Agricultural Field, False Wetland

This site was a fallow agricultural field containing a yellow poplar and sweetgum tree; the grasses are predominantly upland and facultative upland species. **Figure 16** provides a ground photo. Three of the six OBL wetland signatures classified at this site, resulting in a misclassification of the vegetation. The lidar data indicated this area to be a depression. The original CASI imagery and classification are shown in **Figure 17.**

Figure 16: Site 1, a False Wetland. Photo Courtesy of John Anderson

Figure 17: Site 1, Depression in Fallow Agricultural Field, False Wetland

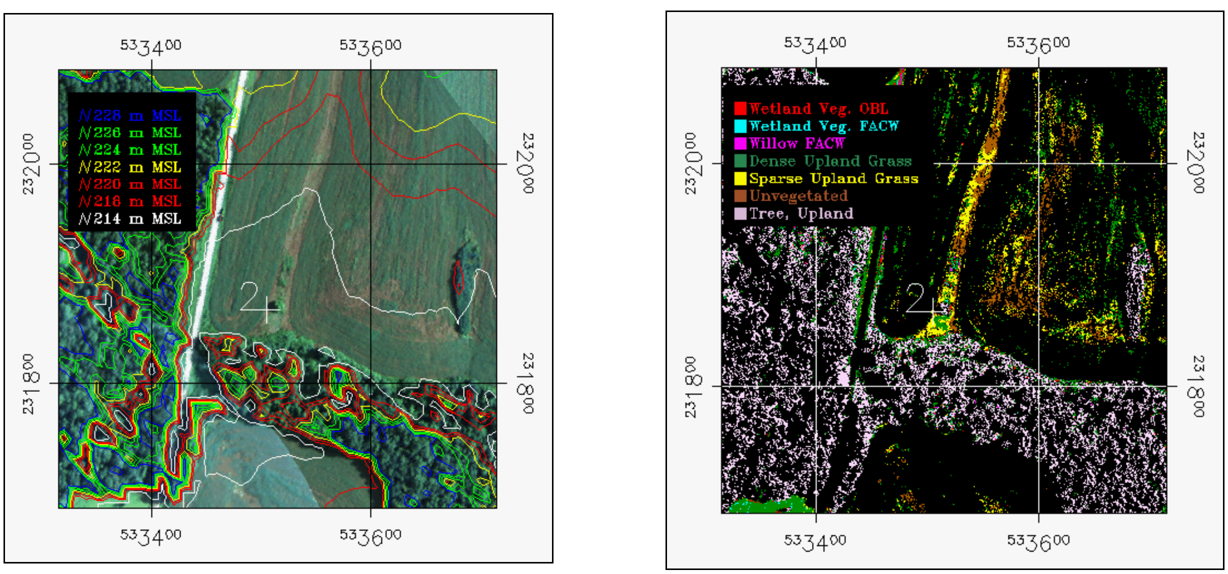


Site 2, Willow in Agricultural Field, False Wetland.

This site was a drainage feature in an agricultural field and was not a true wetland. The drainage contained a willow and the ground cover was dominated by *Lollium multiflorum*, an upland grass species (**Figure 18**). In the image classification the willow tree was classified as a deciduous tree instead of specifically willow. As well, there was some confusion between one patch of vegetation north of the tree that was classified as OBL wetland vegetation, shown in **Figure 19**. Lidar contours identified this site as a depression. Despite the confusion of one vegetation concentration, the original classification of this site does not indicate a wetland.

Figure 18: Willow in a Drainage Feature Located in a Corn Field

Figure 19: Site 2, Willow in a Corn Field, False Wetland

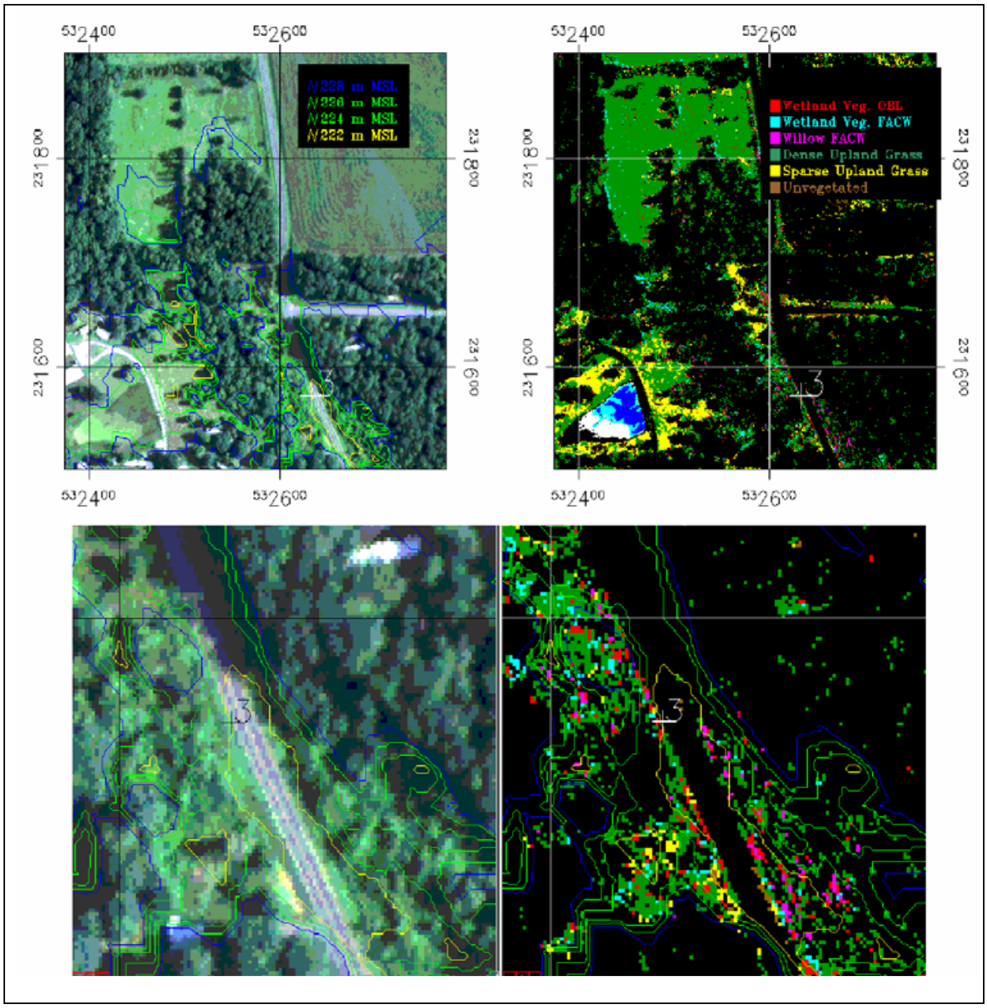


Site 3, Wetland Dominated by Willow

This site was a low lying drainage area that continued across a road. The dominant vegetation was willow, although sedges, rushes and a small amount of cattail are mixed with non-wetland grasses (**Figure 20**). The classification shown in **Figure 21** was able to detect scattered pixels of sedge and rush and willow. The lidar contours indicate a low-lying area and can trace the drainage pattern from north and west of Site 3. Note that this site has been altered since June 2000 on the western side of the road. The underbrush in the photograph has been cleared to allow for grazing. The eastern side of the road remains the same.

Figure 20: Wetland Area Dominated by Willow and Mixed Vegetation

Figure 21: Site 3, Roadside Wetland. True Color CASI With Lidar Overlay, Upper Left and Image Classification With the Trees Removed For Clarity, Upper Right. Lower Images are Close Ups of Site 3.

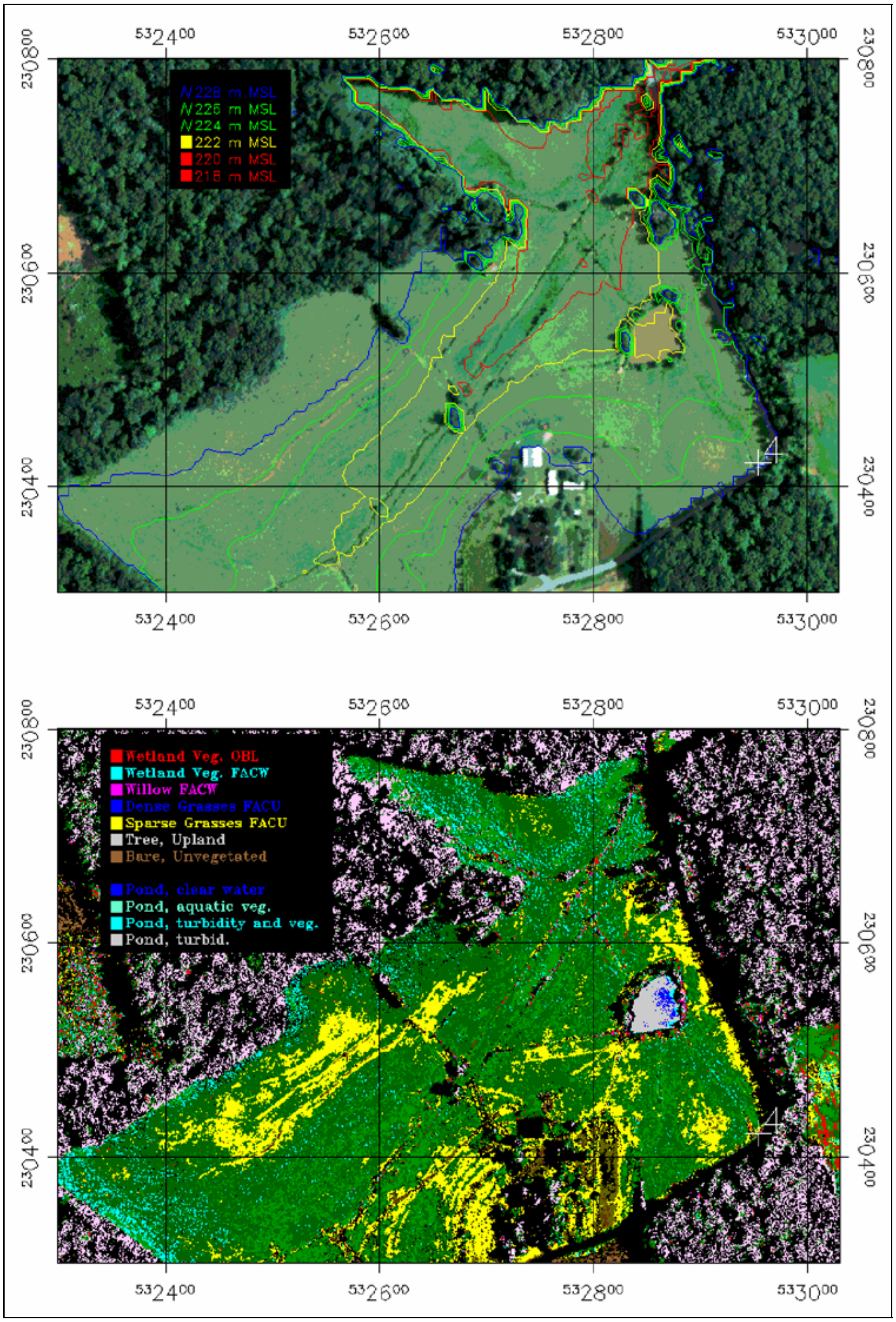


Site 4, Agricultural Area in Drainage Basin

The GPS position for this site defined a drainage ditch that ran from a road to a stock pond through an agricultural field (**Figure 22**). There was *Juncus sp*. in the ditch, but the soil was not hydric and the ditch was artificially formed. The classification shown in Figure 23 indicated the presence of wetland vegetation, both OBL and FACW. To the north of the GPS position, however, was an area used for grazing that contained drainage and larger amounts of wetland vegetation. The soil type in this area was not known. This area was classified correctly based on visual ground truth of the existing vegetation. Whether this is a true wetland area was not known and a test on the soil would have to be performed.

Figure 22: Site 4, Ditch Leading to a Stock Pond

Figure 23: Site 4, Wetland Vegetation in Agricultural Field



Treed Wetlands (Sites 5, 7, 10, 12)

Treed wetland sites did not classify well in the CASI imagery. If the wetland was not visible, it was difficult to detect. The date of image collection complicated the problem because the deciduous trees were in full leaf. Notes made during the March 2001 trip indicate that wetland vegetation begins to green before the deciduous trees are in full leaf and this problem may be reduced if imagery is acquired earlier in the season.

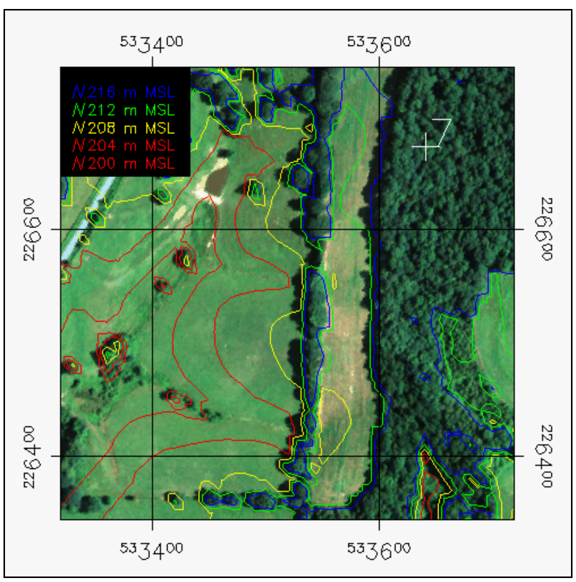
Figure 24 is a ground photo from Site 7, an example of treed wetland sites. This was a small wetland stream under deciduous tree canopy; the stream was less than one meter in width. The hyperspectral data did not correctly identify small wetlands under tree canopy. If there is no drainage from an open wetland into the treed area, it will likely remain unclassified unless lidar contours indicate a strong depression or sub-canopy channel. At Site 7, lidar contours indicated a drainage area to the west of the GPS point and the image classification also showed a potential wetland to the west (**Figure 26**).

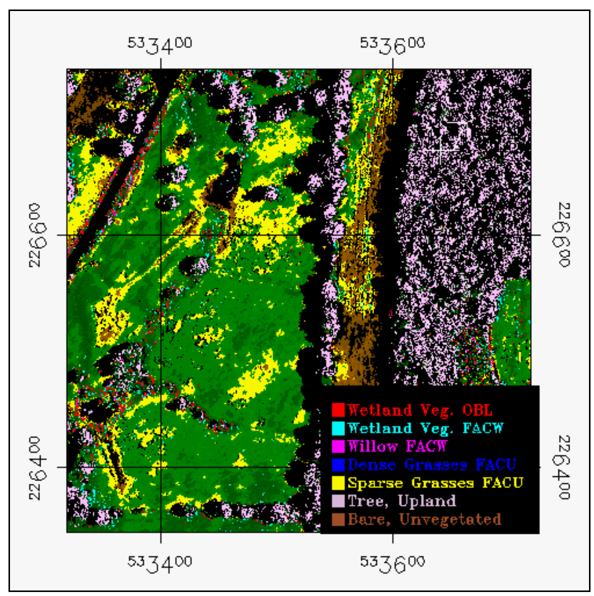
At Site 5, there was no definite classification of wetland and no lidar contours indicating a wetland. Site 10, a treed wetland and Site 12, a heavily treed stream, did not classify as wetlands in the hyperspectral imagery. Lidar contours indicated drainage channels were present at Site 10. Lidar was not available for Site 12, which was characterized by a heavy concentration of kudzu. This is an invasive vine species, seen at the bottom of the picture in **Figure 25**. Ground spectra taken of the kudzu growth was collected but the spectra were too heavily correlated with deciduous trees at the time of image collection and could not reliably be separated in the imagery, despite its high concentration in the area. The confusion with deciduous tree species was too high to retain the kudzu signature in the spectral library.

Figure 24: Site 7, Small Stream Under Tree Canopy

Figure 25: Site 12: Established Stream Under Tree Canopy

Figure 26: Site 7, a Treed Wetland, and Potential Wetland to the West





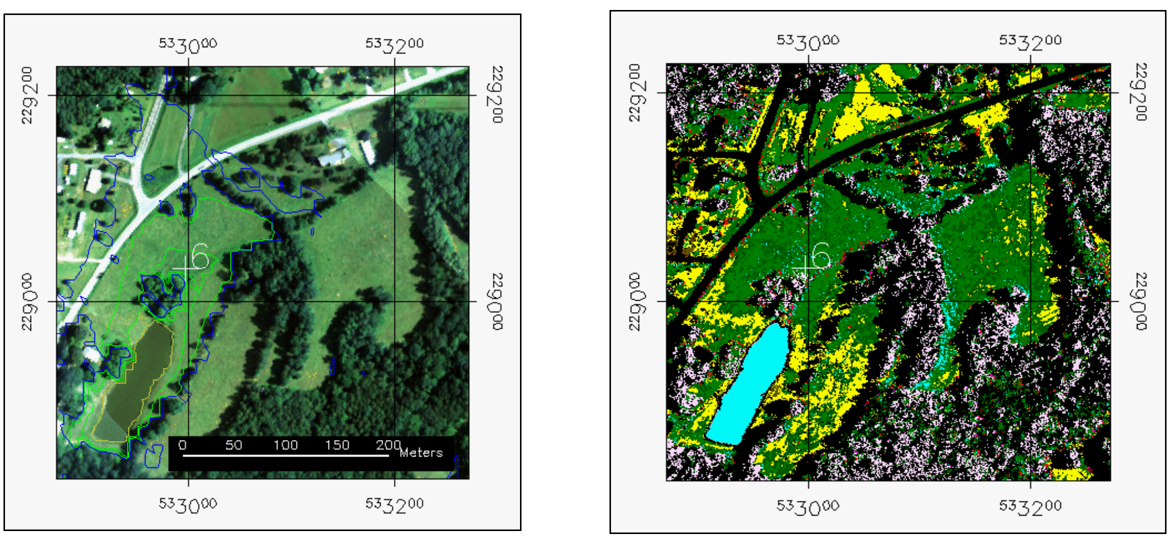
Sites 6, 8, and 11, Grazed Wetlands

Grazed wetlands were easier to identify in the airborne imagery due to the lack of tree cover. Grazing by animals contributed to the hummocky appearance of the soil, making a surface that is easier to separate from upland grasses. However, grazing can also increase the amount of soil in the field of view, making the spectral signature of *Juncus sp.*, which has an affinity for moist soil, appear like the soil background. In addition, cattle can destroy stream structures and vegetation, rendering a site a questionable wetland.

Site 6 was a small wetland associated with a stock pond, shown in **Figure 27**. Again, the true wetland species were mostly confined to the drainage channels with some scattered hummocks of *Juncus sp*. in the field. Most concentrations of wetland vegetation were pixel to sub-pixel in size (meter or sub-meter). The corresponding classification is shown in **Figure 28**.

Figure 27: Site 6, Wetland in a Grazed Field

Figure 28: Site 6, Wetland in a Grazed Field



Site 8 was featured a wetland drainage through a grazed field. There was a significant portion of mixed wetland and non-wetland vegetation with *Juncus sp*. found in the drainage channel (**Figure 29**). The classified map of Site 8 is shown in **Figure 30**.

Figure 29: Site 8, a Grazed Wetland

Figure 30: Site 8, Wetland in Grazed Field

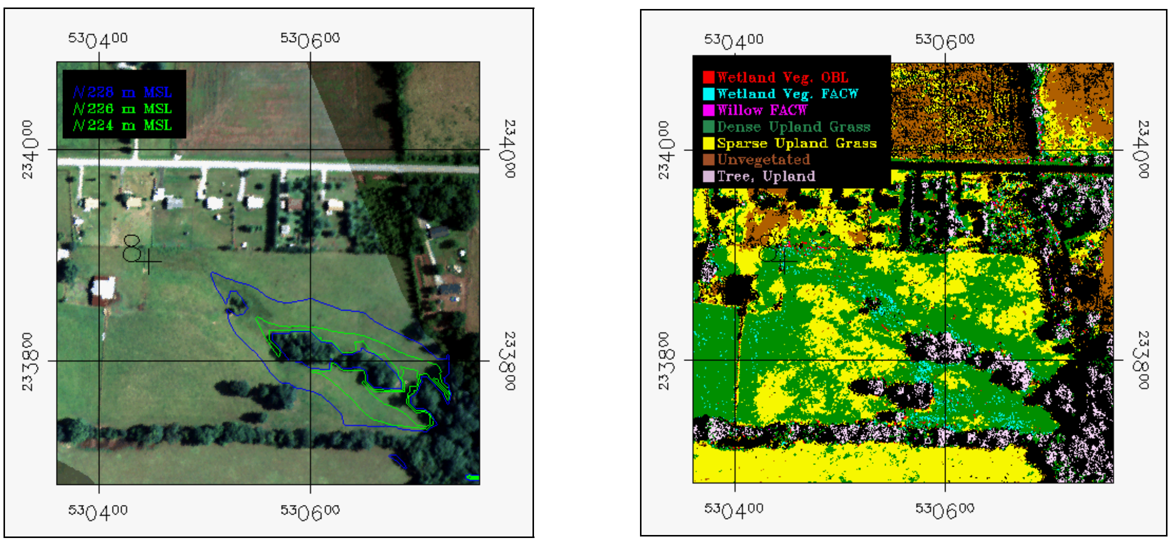


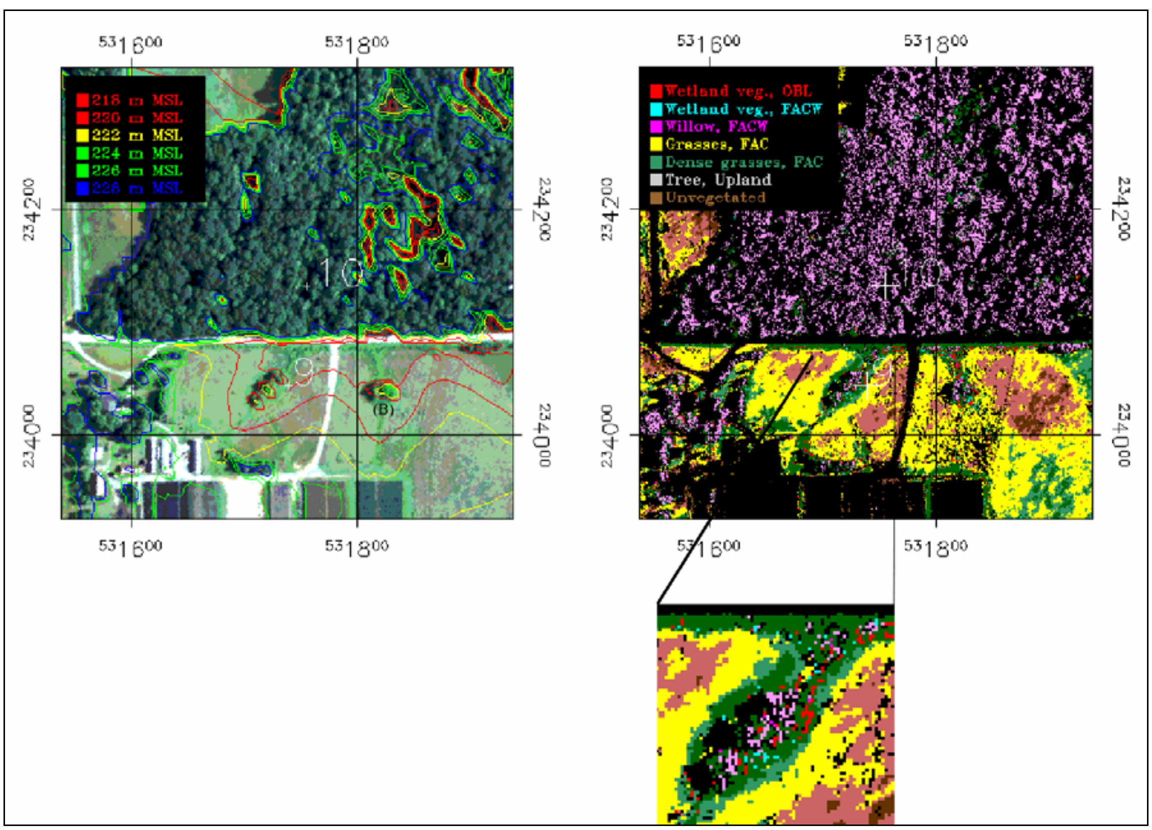
Figure 31: Site 11, a Ravaged Stream in a Grazed Field.

Site 9, a Natural Spring and Site 10, Treed Wetland

This site demonstrated the small size of the wetlands to be detected, the mixed nature of the vegetation, and the use of lidar to show drainage under trees. Site 9 was a natural spring located in a mowed field, shown in **Figure 32**. There was another spring several meters to the east. Both springs drained into Site 10 to the north across the road. The spring was covered with deciduous and willow trees and had mixed wetland and non-wetland vegetation on the ground. The classified map in **Figure 33** detected willow and wetland vegetation at Site 9. The classification was not successful at Site 10 due to its dense tree canopy. The lidar contours, shown at 2 m intervals, show the drainage pattern in the area and indicate the presence of Site 10 under the trees as an extension of Site 9.

Figure 32: Site 9, Natural Spring in Mowed Field

Figure 33: Sites 9 and 10, Two Natural Springs Draining Into a Treed Wetland



Blind or Test Truth (Sites 14 and 15)

These sites were originally identified by DOT personnel but were not visited by ITRES in June of 2000 and were not used in developing the classification. The two sites were visited in March 2001 when a GPS reading was taken. The validation results using these two sites are presented below.

Site 14 was a stream complex that ran through an area that had been forested and is now chiefly populated by mixed vegetation and immature trees. The photograph of Site 14, shown in **Figure 34**, indicates the mixed nature of the wetland vegetation in this area. Both the lidar and the image classification indicated a wetland area, shown in the classification in **Figure 35**. Both lidar and imagery also classified an area to the west of the Site 14 GPS point (across the road) as a wetland, marked by a cross in **Figure 35**.

Figure 34: Site 14, Wetland in a Regenerating Cut Block

Figure 35: Site 14, Wetland in Regenerating Cut Block

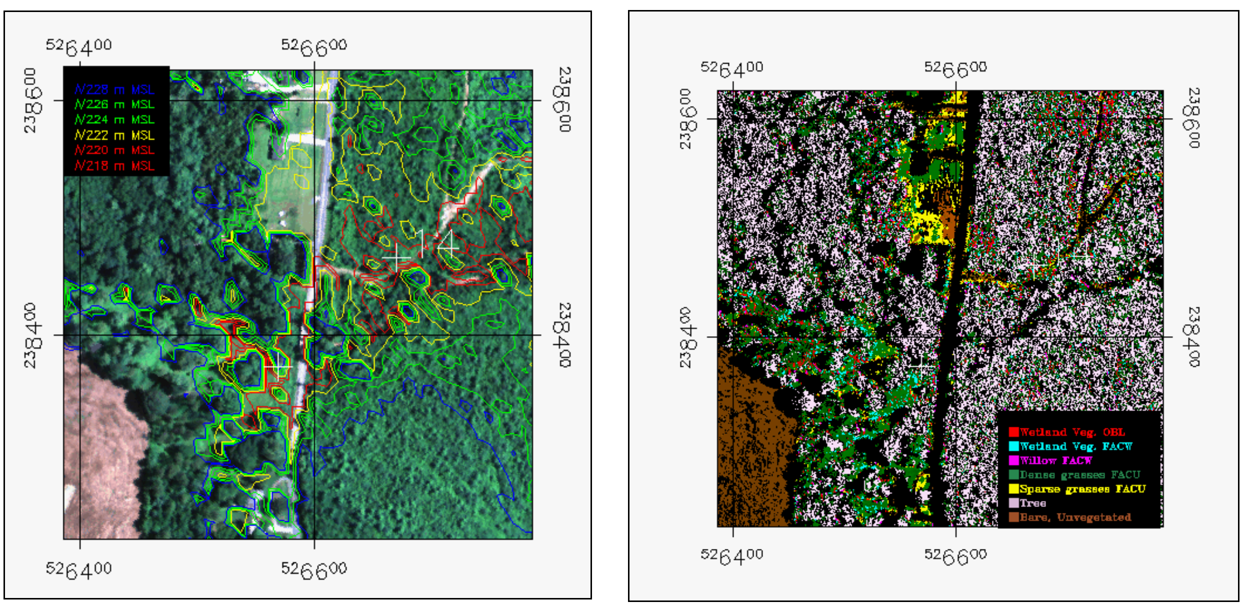
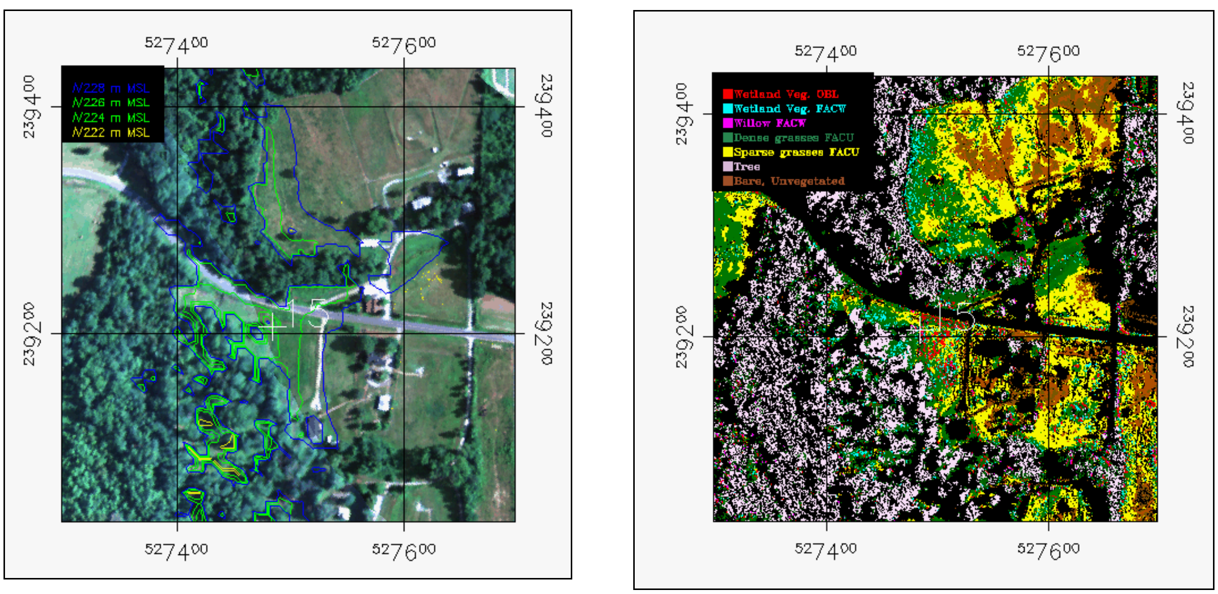


Figure 36: Site 15, Wetland in Grazed Area

Site 15 had a drainage channel bisecting a grazed field, shown in **Figure 36**. The classification indicated wetland vegetation in this area (**Figure 37**). The obligate wetland vegetation classified at Site 15 may not be entirely correct. There was a fence at the GPS position and vegetation on the eastern side of the fence may not be dominated by wetland vegetation. However, the facultative wetland vegetation in the classification was correctly classified.

Figure 37: Site 15, Wetland in Grazed Field



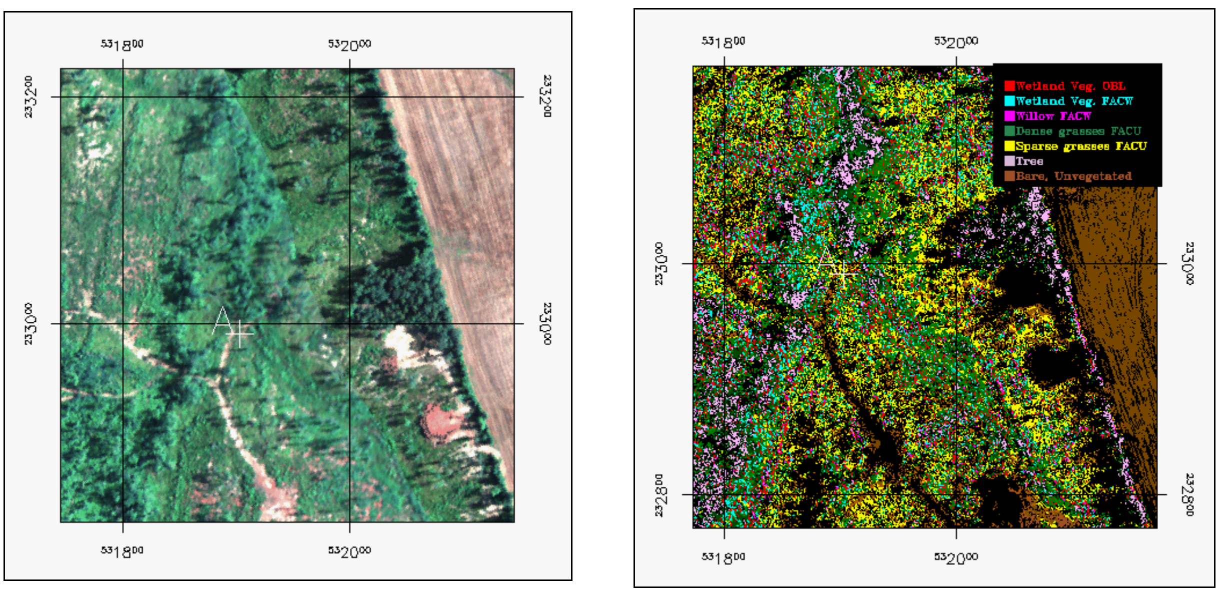
March 2001 visit – Selected Sites

The following is a summary of sites visited in March 2001. Most sites were visited because the preliminary classification showed them to have wetland characteristics. Dense grasses growing on a slope, which had been misclassified as wetlands, covered several sites. The hypothesis is that these slopes had been saturated by the recent rains, which may have contributed to the misclassification. After the March ground truth trip signatures of saturated grasses were added to the spectral library, reducing the confusion in the classification. Another source of confusion occurred in forested areas that had been recently harvested. The resulting slash made up of small trees, shrubs, and grasses were classified in several categories, including willow, wetland, and non-wetland grasses.

Site A

This site was visited because it contained a large amount of slash vegetation and because the classification indicated the presence of a wetland. **Figure 38** shows the true color CASI and corresponding classified image. The stream channel referenced by GPS point A was dominated by mixed grasses and shrubs but interspersed with small pools and small (<1 m^2) stands of sedges, rushes, willow, and cattail. The lidar contours indicated a bifurcated stream channel that meandered through the cut block (the contours are not plotted for clarity).

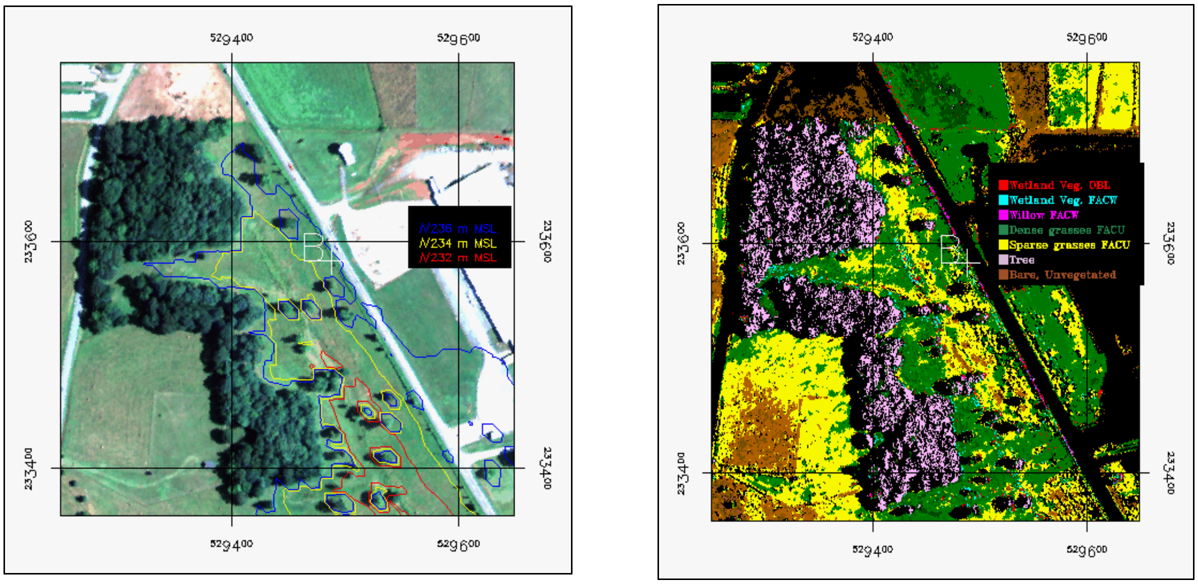
Figure 38: Site A, Wetland in a Cut Block Located From Preliminary Classification and Visited in March 2001



Site B

This site was another narrow wetland drainage located in a grazed field. The vegetation in the drainage channel was sedge and rush mixed with other grasses. The lidar contours indicated drainage at this site, but at a higher elevation than the other wetland sites in the area.

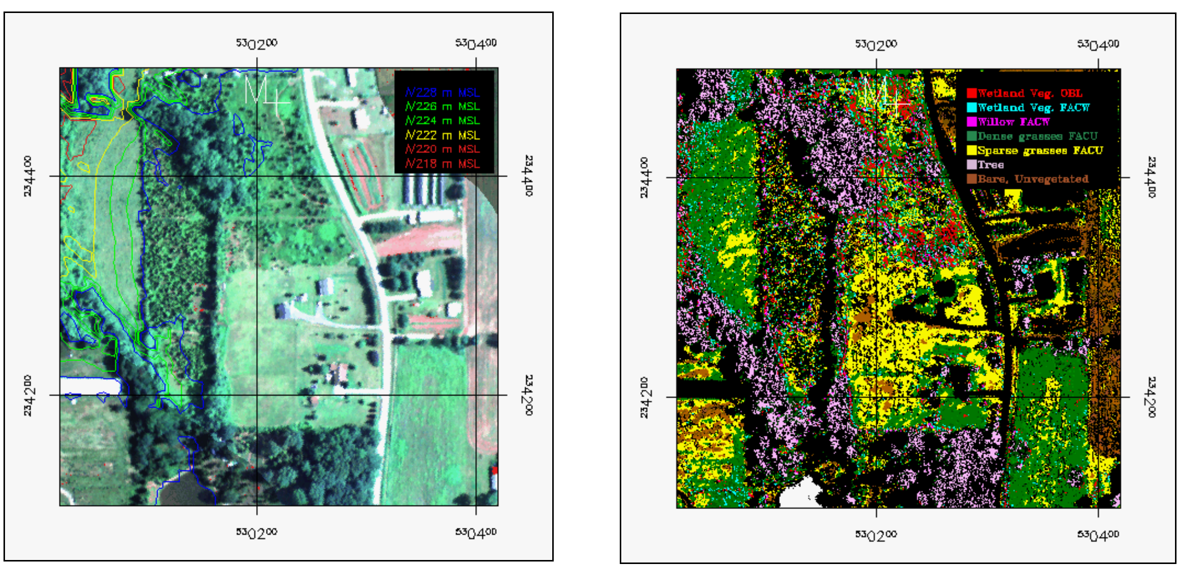
Figure 39: Site B, Drainage Located From Preliminary Classification, Visited in March 2001



Site M, Regenerating Cut Block, Not a Wetland.

This site provided an example of confusion in the classification created by the wide variety of grasses and shrubs found in this regenerating cut block. Despite attempts to characterize non-wetland grasses, there were populations that were spectrally very similar to actual wetland signatures (**Figure 40**). Further development of the classification must widen the spectral library to accommodate more non-wetland grasses. Doing so does not guarantee the desired result however. The inclusion of additional non-wetland grass signatures may in fact reduce the wetland classification in actual wetland areas.

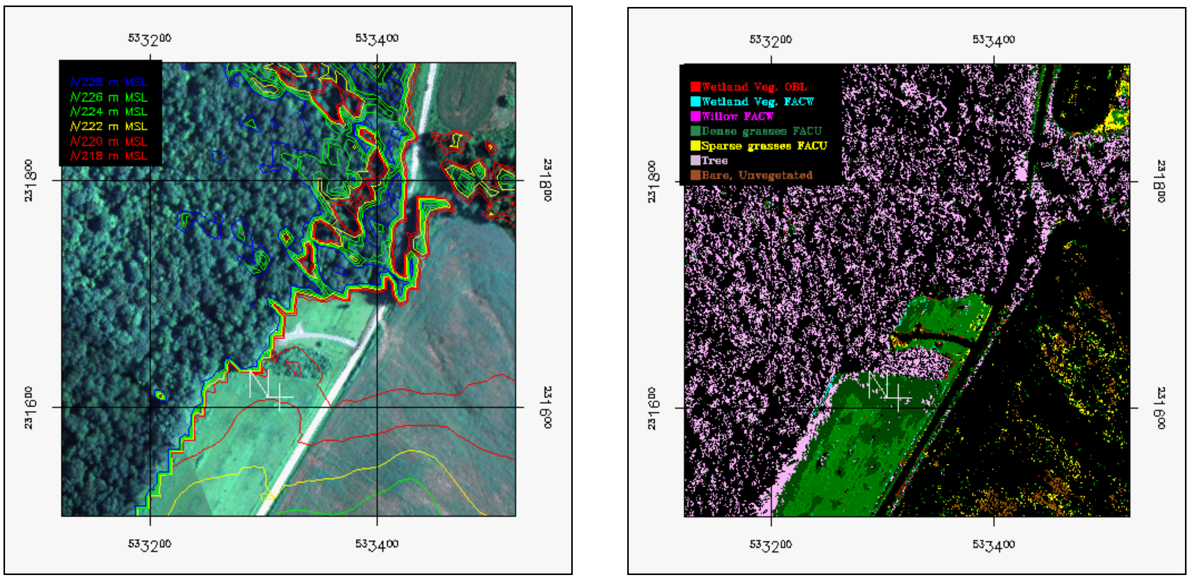
Figure 40: Site M, Mixed Grass, Shrub, and Small Tree in Regenerating Cut Block. Not a Wetland



<u>Site N, Dense Saturated Grass, Not a Wetland.</u>

This site was originally classified as obligate wetland species when it was actually a dense concentration of upland grass on a slight slope. Three spectral signatures were collected from this site after the March 2001 visit and added to the spectral library. The signatures subsequently reduced the confusion between saturated pasture grass and wetland vegetation in the final classification, shown in **Figure 41**.

Figure 41: Dense Saturated Grass That Classified as Wetland Vegetation in Preliminary Classification



Conclusions

1. It is possible to delineate small wetland areas by their drainage and vegetation characteristics using high spatial hyperspectral imagery and lidar data. The image pixel size of one meter is large enough to make data collection over large areas feasible, yet small enough to resolve most cover types in the area. It appears that we are able to find non-treed wetlands, the challenge now is to further separate wetlands from non-wetlands with similar vegetation and drainage characteristics.

2. The wetland classification misclassified and included non-wetland cover in three types of areas:
    a. Artificially drained areas, such as stock ponds and drainage ditches which may or may not host some wetland vegetation;
    b. Regenerating cut blocks where a profusion of vegetation species can be found; and
    c. Grasses on saturated slopes, often found in pastures.

3. The wetland classification omits wetlands under dense tree canopy. Lidar contours have proven beneficial to track drainage channels under treed areas. The airborne image data and Lidar data for this project were collected June 2000, when all foliage was in full development. Flying in early spring when wetland vegetation begins to turn green but before the deciduous trees leaf out would likely increase the wetland detection ability of the CASI alone, particularly in forested areas. Removing deciduous cover from the classification will also decrease confusion between spectral reflectance of wetland vegetation and the reflectance of deciduous tree crowns and forward scattering from deciduous tree crowns. Finally, the absence of dense tree foliage will reduce tree shadow and subsequent loss of data.

4. The detection problem is compounded by the small size of the wetlands, human disturbance, and mixed vegetation. The small areal extents and wide variety of the wetlands in this area made extraction of pure spectra difficult. There are not many homogenous stands of wetland vegetation that are at least one meter in diameter. The problem of "mixed pixels" where the spectra from more than one land cover type contributes to the measured signal from a single pixel is very relevant to this classification. Reducing the spatial pixel size may help detection, but will increase the number of flight lines required to cover a given flight block.

5. Airborne hyperspectral data is required for this approach due to the spectral similarity of the land cover types and the small size of the wetlands. Commercial satellite imagery currently does not have the spatial resolution or accuracy, or the spectral resolution to perform this analysis to the same level of accuracy.

6. The land cover classification is "tuned" for the wetland vegetation. The allowable standard deviation is very small to reduce confusion with non-wetland grass and shrub. Therefore, there is a larger than normal percentage of unclassified pixels in treed areas. As well, no attempt was made to isolate agricultural signatures or those between grass and conifer species in this classification.

7. Water bodies can be delineated and different types of water bodies discriminated according to their vegetation and suspended sediment content. Because no ground truth was available specifically for water bodies, no assessment was made of the accuracy of the water classification.

8. Ground spectra of vegetation that were collected using the hand-held spectrometer were not used. It is difficult to get a pure reading from mixed vegetation without putting the ground spectrometer on a crane to view the target from above.

9. Properly referenced site data, notes, and photographs were very useful in the development of the classification. For future reference, GPS points are helpful but only identify a single pixel. Walking the boundary of a stand of vegetation to provide a polygon may help in future accuracy assessments. Because of the precise nature of the classification where a single pixel represents a wetland area, differential GPS positions should be used in the future so that GPS accuracy is improved to the sub-meter (and sub-pixel) level.

10. Interpretation of the thematic maps is still needed; however the maps are beneficial in greatly reducing the area to be interpreted and in providing a map of all land cover types.

11. Our analysis method focused on the differences in spectral signatures of various wetland communities. Alternate analysis methods should be evaluated. These methods can include using neural networks and contextual-based classifiers. These neural networks take advantage of ground-truth and hyperspectral data as inputs to iterate the final classification. Contextual classifiers take advantage of spectral and spatial relationships in creating the classification.

12. GIS modeling techniques to collate and incorporate the Lidar terrain variables with the classified imagery should be examined to predict and model potential wetland zones.

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.

Green, A., M. Berman, P. Switzer, and M. Craig, 1988. A transformation for ordering multispectral data in terms of image quality with implications for noise removal. IEEE Transactions on Geoscience and Remote Sensing, Vol. 26, No. I, pp. 65-74.

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Appendix A: CASI Spectral Bandsets

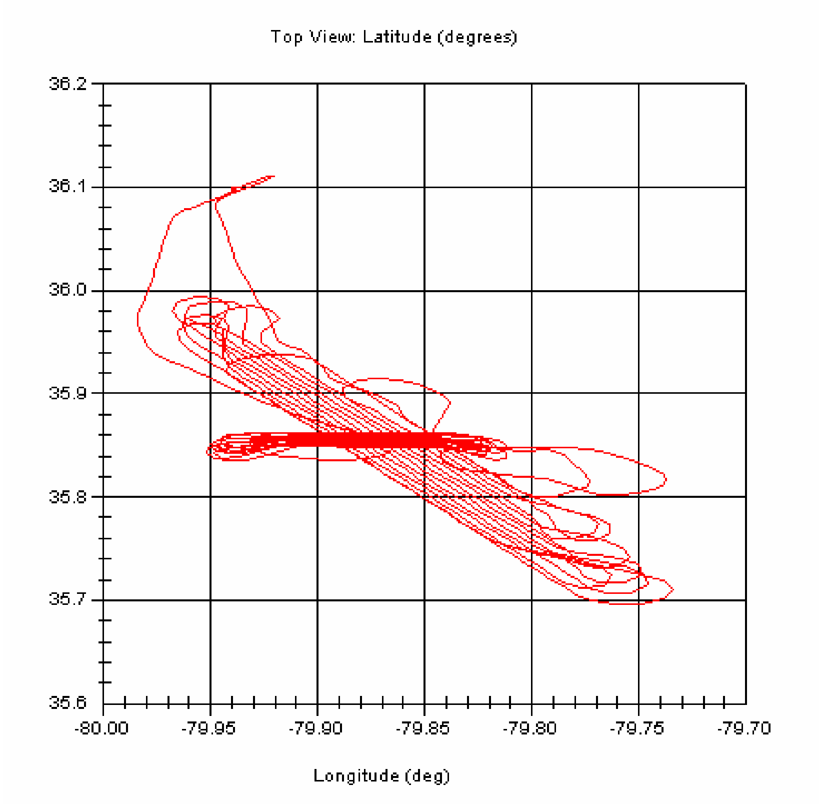
Table A-1. Spectral bands for the one meter data collection.

Band #	Band start and end (FWHM)	Center wavelength (nm)	Band-width (nm)
1	428.9-470.1	449.5	41.2
2	492.2-509.4	500.8	17.2
3	516.6-533.8	525.2	17.2
4	541.1-558.3	549.7	17.2
5	567.5-582.9	575.2	15.4
6	592.1-607.5	599.8	15.4
7	616.7-632.3	624.5	15.6
8	641.5-658.9	650.2	17.4
9	672.1-685.7	678.9	13.6
10	704.5-716.3	710.4	11.8
11	733.3-747.1	740.2	13.8
12	773.7-785.5	779.6	11.8
13	837.2-853.0	845.1	15.8
14	862.4-878.2	870.3	15.8

Table A-2. Spectral bands for the 60 cm data collection.

Band #	Band start and end (FWHM)	Center wavelength (nm)	Band-width (nm)
1	458.6-509.4	484.0	50.8
2	509.1-550.7	529.9	41.6
3	550.5-586.7	568.6	36.2
4	590.2-622.8	606.5	32.6
5	622.4-653.2	637.8	30.8
6	658.6-683.8	671.2	25.2
7	685.4-710.6	698.0	25.2
8	712.2-729.8	721.0	17.6
9	729.5-745.1	737.3	15.6
10	769.8-799.0	784.4	29.2
11	845.0-876.2	860.6	31.2

Figure 42: Flight path from CASI data collection, 30 June 2000.



Lines trending NW to SE represent 1 meter data collection with flight line 1 as the westernmost line. East-west trending lines represent 60 cm data collection, with line 1 being the most northern line.

Appendix B: Wetlands Ground Survey Field Form (2 Pages)

WETLAND FIELD DATA SHEET

REPORT No.: 14 Photo No.:10738-25 Date: 6/27/00
Reported By: John Anderson, EnviroData, Inc., St. Louis Park, MN
OTHER FIELD PARTY MEMBERS: Tondra Scheton, EarthData International

1. LOCATION: 1:100.000 MAP: Raleigh NW
   STATE: North Carolina COUNTY: Randolph
   TOWN/TOWNSHIP: N/A U.S.G.S QUAD: High Point East
   WATERSHED: Deep River ECOREGION: Southeastern Plains (Bailey)
   COORDINATES: N/A

2. WETLAND CLASSIFICATION PER COWARDIN (NWI) SYSTEM:

Site No.: 14
System: P
Subsystem:
Class: SS
Subclass: 1
Water Regime: A
Special Modifiers:

3. DESCRIPTION OF PLANT COMMUNITY:
Dominant Plant spp. (<20% aerial coverage):

Forested:	Indicator	%	Emergent:	Indicator	%
1			1. *Juncus effusis*	OBL	50
2.			2. *Carex* sp.	FAC toOBL	25
3.			3. *Juncus* sp.	FAC to OBL	25
4.			4.		
5.			5.		
Scrub (saplings)/Shrub:	**Indicator**	**%**	**Aquatic Bed:**	**Indicator**	**%**
1. Salix nigra	OBL	50	1.		
2. Sambucus canadensis	FACW	50	2.		
3.			3.		
4.			4.		
5.			5.		

Is the vegetation criteria met? Y N

4. DESCRIPTION OF SOILS
Classification Per Soil Survey:
Map Unit Name (Series/Phase): Wynott-Enon Complex
Taxonomy: N/A
Drainage Class: well
On NRCS list: Y N

Per COE 1987 Wetland Delineation Manual:
Observations:
Profile Description: * not determined as investigator is not certified soil scientist

Depth	Horizon*	Matrix	Mottle Colors	Abundance/Contrast	Texture, Structure Concretions
0" – 18"		10YR 5/1	10YR4/6	105/Prominent	sandy loam

Gleyed, Low Chroma, and Low Chroma Mottled Soils:x Oxidized Rhizosheres:

Is hydric Soil Criterion met? Y N

5. DESCRIPTION OF SURFACE HYDROLOGY:
Primary Indicators: Inundated: Y <u>N</u> Depth: Saturated: Y <u>N</u> Depth:
Secondary Indicators: Water marks: Buttressed tree trunks: Drift lines: Shallow roots: Windthrows:
Multiple trunks: Sediment deposits: Drainage pattern in wetlands: :x
Other observations: drainage way
Is the Hydrology Criteria met? <u>Y</u> N

5. AERIAL PHOTOGRAPHY/IMAGERY: Program: National Aerial Photography Program (NAPP)
Date: 2/15/00 Scale: 1:40,000 Emulsion: Color Infrared

6. PHOTOSIGNATURE CHARACTERISTICS (Color/Tone, Texture, Pattern, Topographic Location, Vertical Exaggeration (vegetation/landscape), Shape, Size): Light gray tone, rough texture, linear polygon

Evidence of disturbance: Evidence of recent logging, slash present

Other observations:

7. COLATERAL DATA:
Rainfall Data: Recording Station: Summit School, Greensboro, NC
Prior to photo date (2/15/99): # Days: 21 Inches: 2.15
3 months prior to photo date: Above Below <u>Average</u>

Prior to field check (6/26/00): # Days 23 Inches: .88
3 months prior to field check date date: N/A Above Below <u>Average</u>

National Wetland Inventory (NWI) Map Classification: U (upland)

U.S.G.S. 1:24,000 Topographic Map:

Stream Gage Data: N/A Flood Elevation: Date:

Other Aerial Photography: NCDOT #3-62 Emulsion: Panchromatic Date: 3-11-96 Scale:
Signature: Dark gray linear in light tone area

Appendix C: NWI Classification Scheme

The following is a subset of the NWI Classification Scheme relevant to the land cover types in the High Point, North Carolina area. This scheme provided the basis for the wetland classification of the multispectral CASI imagery. The complete classification can be found on the National Wetland Inventory website at: http://www.nwi.fws.gov

```
                    WETLANDS AND DEEPWATER HABITATS CLASSIFICATION (Subset)

SYSTEM                  SUBSYSTEM        CLASS                      SUBCLASS

                                      |- RB=Rock Bottom             1=Bedrock
                                      |                             2=Rubble
                                      |
                                      |- UB=Unconsolidated Bottom   1=Cobble-Gravel
                                      |                             2=Sand
                                      |                             3=Mud
                                      |                             4=Organic
                                      |
                                      |- AB=Aquatic Bed             1=Algal
                                      |                             2=Aquatic Moss
                                      |                             3=Rooted Vascular
                                      |                             4=Floating
                                      |                               Vascular
                                      |                             5=Unknown
                                      |                               Submergent
                                      |                             6=Unknown Surface
                                      |
                                      |- US=Unconsolidated Shore    1=Cobble-Gravel
                                      |                             2=Sand
                                      |                             3=Mud
                                      |                             4=Organic
                                      |                             5=Vegetated
                                      |
                                      |- ML=Moss-Lichen             1=Moss
                                      |                             2=Lichen
                                      |
P=PALUSTRINE--------------------------|- EM=Emergent                1=Persistent
                                      |                             2=Nonpersistent
                                      |
                                      |- SS=Scrub-Shrub             1=Broad-Leaved
                                      |                               Deciduous
                                      |                             2=Needle-Leaved
                                      |                               Deciduous
                                      |                             3=Broad-Leaved
                                      |                               Evergreen
                                      |                             4=Needle-Leaved
                                      |                               Evergreen
                                      |                             5=Dead
                                      |                             6=Indeterminate
                                      |                               Deciduous
                                      |                             7=Indeterminate
                                      |                               Evergreen
                                      |
                                      |- FO=Forested                1=Broad-Leaved
                                      |                               Deciduous
                                      |                             2=Needle-Leaved
                                      |                               Deciduous
                                      |                             3=Broad-Leaved
                                      |                               Evergreen
                                      |                             4=Needle-Leaved
                                      |                               Evergreen
                                      |                             5=Dead
                                      |                             6=Indeterminate
                                      |                               Deciduous
                                      |                             7=Indeterminate
```

```
                                    |                              Evergreen
                                    |
                                    |- OW=Open Water/Unknown Bottom (used on older
                                                                  maps)

                                     MODIFIERS

                                    |- A=Temporarily Flooded
                                    |- B=Saturated
                                    |- C=Seasonally Flooded
                                    |- D=Seasonally Flooded/Well Drained
                                    |- E=Seasonally Flooded/Saturated
                                    |- F=Semipermanently Flooded
                 |--Non-Tidal------|- G=Intermittently Exposed
                 |                  |- H=Permanently Flooded
                 |                  |- J=Intermittently Flooded
                 |                  |- K=Artificially Flooded
                 |                  |- W=Intermittently Flooded/Temporary (used on
                 |                  |                                    older maps)
                 |                  |- Y=Saturated/Semipermanent/Seasonal (used on
                 |                  |                                    older maps)
                 |                  |- Z=Intermittently Exposed/Permanent (used on
                 |                  |                                    older maps)
WATER REGIME----|                  |- U=Unknown
                 |
                 |
                 |                  |- K=Artificially Flooded
                 |                  |- L=Subtidal
                 |                  |- M=Irregularly Exposed
                 |                  |- N=Regularly Flooded
                 |--Tidal----------|- P=Irregularly Flooded
                                    |-*S=Temporary-Tidal
                                    |-*R=Seasonal-Tidal
                                    |-*T=Semipermanent-Tidal
                                    |-*V=Permanent-Tidal
                                    |- U=Unknown
                                    |
                                    |-*These water regimes are only used in
                                    |  tidally influenced, freshwater systems.

                                    |- 1=Hyperhaline
                                    |- 2=Euhaline
                 |--Coastal         |- 3=Mixohaline (Brackish)
                 |  Halinity-------|- 4-Polyhaline
                 |                  |- 5=Mesohaline
                 |                  |- 6=Oligohaline
                 |                  |- 0=Fresh
                 |
WATER CHEMISTRY-|
                 |                  |- 7=Hypersaline
                 |--Inland          |- 8=Eusaline
                 |  Salinity-------|- 9=Mixosaline
                 |                  |- 0=Fresh
                 |
                 |
                 |--pH Modifiers    |- a=Acid
                    for all         |- t=Circumneutral
                    Fresh Water----|- i=Alkaline

SOIL------------------------------|- g=Organic
                                    |- n=Mineral

                                    |- b=Beaver
                                    |- d=Partially Drained/Ditched
SPECIAL MODIFIERS-----------------|- f=Farmed
                                    |- h=Diked/Impounded
                                    |- r=Artificial Substrate
                                    |- s=Spoil
                                    |- x=Excavated

U = Uplands
```