# FINAL REPORT

# DIGITAL MULTISPECTRAL VIDEOGRAPHY FOR THE CAPTURE OF ENVIRONMENTAL DATA SETS

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# ABSTRACT

The Virginia Department of Transportation's (VDOT) Environmental Division frequently uses spatial information to analyze and assess a variety of environmental resources. Environmental personnel are constantly looking for faster and more accurate means of collecting and managing these data. Digital multispectral videography (DMSV) is a data collection technology that has shown great potential in other areas where remote sensing data are used. DMSV provides digital frame coverage in four spectral bands for color infrared imaging, allowing for the detection of soils, vegetation, water bodies, chemically contaminated areas, and various other resources. This type of remote sensing differs from traditional methods in that sensor bandpass or wavelengths are typically ≤25 nm wide as opposed to the more typical 100+ nm wavelengths.

The purpose of this research was to test the feasibility of using DMSV for some of VDOT's environmental data acquisition needs. This was accomplished by using the technology to capture imagery-based data sets and then developing a procedure for transforming the image data into geo-referenced vector data sets. The vector data were analyzed spatially, and the advantages and shortcomings of the technology were documented during this process.

DMSV was very effective in identifying and classifying major plant communities in VDOT's wetland mitigation sites. Data were quickly collected, corrected, classified, and imported into an ArcView-based geographic information system. From there, the data sets could be analyzed and stored for further query and manipulation.

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## INTRODUCTION

The Virginia Department of Transportation (VDOT) is continuously looking for ways to modernize and take advantages of new and emerging technologies. Throughout VDOT, greater emphasis is being placed on the capture of spatial data and the use of spatial information as a means of managing its ever-increasing infrastructure. An example is VDOT's ongoing efforts to develop and implement a departmentwide geographic information system (GIS). VDOT's Environmental Division has a variety of applications that require spatial data, ranging from wetland mitigation monitoring to corridor analysis. Because these sites vary tremendously with respect to size and complexity and because the sites are distributed across the state, it is ambitious to think that all of VDOT's resources can be inventoried and analyzed by field personnel alone.

Digital multispectral videography (DMSV) is a data collection technique that provides digital frame coverage in four spectral bands for color infrared imaging, allowing for the detection of soils, vegetation, water bodies, chemically contaminated areas, and various other resources. This type of remote sensing differs from traditional methods in that sensor bandpass or wavelengths are typically $\leq 25$ nm wide. Most aerial photography and satellite sensor data are broad banded ($\pm 100$ nm). These lower spectral resolutions do not permit a great degree of selectivity with particular spectrally subtle phenomena.

Many state departments of transportation are turning to softcopy photogrammetry to generate high-precision, topographic maps for road construction projects. A few have also initiated the use of DMSV for resource monitoring. Advantages of acquiring data by DMSV when compared with conventional film-based photography or typical field methods include:

1. low data acquisition costs compared to yearly field data
2. a digital format that allows for integration into CAD or GIS

3. a large coverage area
4. temporal coverage on demand
5. enhanced spectral sensitivity for detection of environmental attributes.

## PURPOSE AND SCOPE

The purpose of this research was to test the feasibility of using DMSV for some of VDOT's environmental data acquisition needs. Three key environmental issues were targeted for study based on needs expressed by personnel in VDOT's Environmental Division:

1. *The need to monitor mitigation wetland areas previously constructed by VDOT.* Under the regulatory authority of the Army Corps of Engineers and the Environmental Protection Agency, mitigation credit can be realized for constructing wetlands banks to offset the impacts of road construction. VDOT maintains a sizeable wetland mitigation system that requires extensive monitoring for vegetation and hydrology characteristics. Monitoring requirements are site specific but are normally necessary for a minimum of 5 years after construction is completed. VDOT has well over 200 sites throughout the state, with more being constructed each year. These sites vary significantly in size, age, type, and complexity.

2. *The need to detect and characterize acid soils associated with road construction.* Acid-sulfate soils are a chronic problem in Virginia, causing water quality concerns, structural deterioration, and roadside vegetation problems. The Virginia Transportation Research Council (VTRC) and Virginia Tech are conducting an extensive study in order to understand and manage these soils better. Areas identified during the study were included in the sites to be examined by way of DMSV.

3. *The need for corridor analysis.* Personnel from the Environmental Division were interested in determining if DMSV could be used to identify features within proposed corridors that could potentially inhibit their use. Items of interest included endangered plant species, cultural resources, and contaminated areas.

## METHODS

Six tasks were completed to achieve the study objectives:

1. Data collection sites were selected for each of the three priority issues.
2. DMSV was used to capture imagery-based data sets.
3. A procedure was developed for transforming the image data into geo-referenced vector data sets.
4. The vector data were analyzed spatially.
5. The advantages and shortcomings of the technology were documented.
6. Some of the costs associated with this type of collection effort were approximated.

## Site Selection

The researchers and personnel of the Aquatic Ecology Section of VDOT's Environmental Division selected the wetland sites to be studied based on size, anticipated diversity of species present, and proximity to one another.  To ensure that DMSV was a feasible means of collecting data for both large and small sites, wetlands ranging from 0.5 to 16 ha were chosen.  Sites known to have a wide variety of plant species were also selected to test the differentiation capability of DMSV.  All of the sites selected were in the central and eastern parts of the state, which are where the majority of VDOT's mitigation efforts take place.  This also minimized the flying time between sites.

The sites chosen for the acid soils data collection were sites involved in the previously mentioned study for which field data (i.e., pH values) were available.  This allowed for a direct comparison between the data collected in the field and those collected remotely with DMSV.  These sites were also in the central and eastern parts of the state.

Despite repeated attempts, the researchers did not receive the coordinates requested for the corridors of interest to VDOT.  Therefore, data for a single corridor were collected based solely on its proximity to other sites.

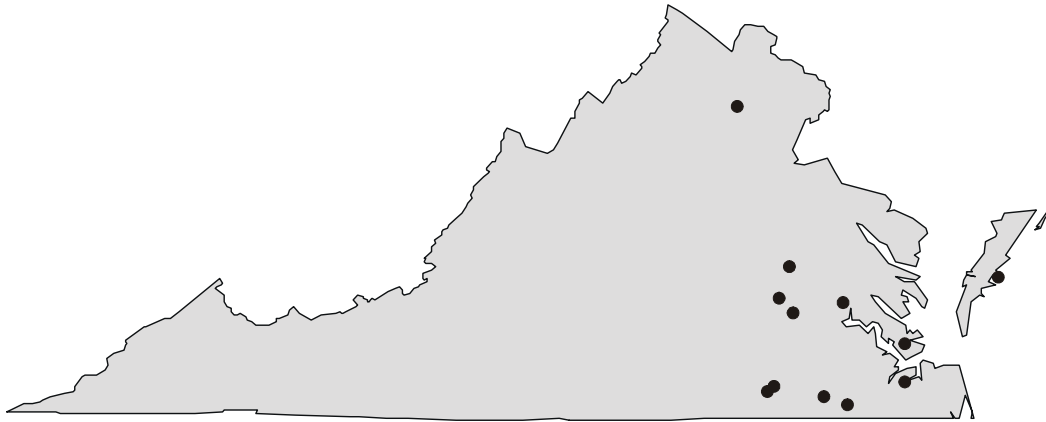Figure 1 shows the sampling locations for the three priority issues.



**Figure 1.  Location of DMSV Study Sites**

## Data Collection

### DMSV System Configuration

To accomplish the remote sensing required for this project, a four-channel multispectral camera system was used.  The digital DMSV is a portable remote sensing system consisting of a matrix of four COHU digital cameras, a Pentium II computer, a flat screen LCD display, and a keyboard.  To detect single-channel information, the spectral wavelengths were controlled by placing bandpass interference filters in front of the camera optics (fore lens).  This permitted the passage of only a single spectral band of data to be captured by the system.  Each camera was

**Figure 2. Three DMSV Wavelengths, (from left to right) 550 nm, 450 nm, 770 nm**

filtered independently, and four single wavelength images were multiplexed via a frame grabber. The result was four panchromatic spectral channels merged into one data file that could be manipulated using computer image processing routines. The individual wavelengths were panchromatic, and an example is shown in Figure 2.

For the VTRC missions, the wavelength band centers were 450 nm (blue), 550 nm (green), 680 nm (red), and 770 nm (near infrared) at a resolution of 25 nm full-wave half-maximum. These band assignments allowed the creation of both natural color and false color infrared composites. This in conjunction with the narrow bands (25 nm) used by the system makes discriminating different soil and vegetation features more effective *(1)*. This is in contrast to film-based imagery and satellite data, which are typically broad banded (100 nm).

The lens architecture of the DMSV incorporates 12-mm focal length lenses fixed at infinity. In addition, each silicon detector for each of the four cameras has a rectangular array size of 740 by 578 pixels. Given the flying height of the aircraft, the pixel size of the CCD arrays in each camera (8 ⇆) and the lens focal length (12 mm), spatial resolution, or ground sample distance (GSD) were computed and are presented in Table 1.

**Table 1. Flying Height and GSD**

| Altitude (m) | Pixel Ground Resolution | Area/Frame |
|---|---|---|
| 740 m | 0.5 m | 106 km$^2$ |
| 1650 m | 1 m | 430 km$^2$ |
| 3000 m | 2 m | 860 km$^2$ |

**Imagery Acquisition**

The VTRC missions (1998 and 1999 seasons) were flown at an altitude of 1650 m. All representative data sets have a GSD of 1 m. The DMSV was configured and installed in a Cessna 172 Skyhawk operated by Airborne Research and Services of Manassas, Virginia. The optical head containing the four cameras was leveled and mounted over the open port in the floor of the aircraft at a nadir view angle. The DMSV was spectrally configured with the filter suite (450 nm, 550 nm, 680 nm, 770 nm) to achieve both natural and false color infrared data in the

final imagery.  As noted, bandpass interference filters (by Corion) were used having full-wave, half-maximum resolutions of 25 nm.

Prior to each mission, coordinates for all sites were taken directly from project files or determined using a mapping grade global positioning system (GPS) receiver by way of ground surveys.  Coordinates were sent to Airborne Research and Services for input into the onboard navigation system via electronic mail.  During data acquisition, the DMSV was triggered by keyboard commands once the target was located using the plane's onboard GPS receiver.  A sequence of frames was captured to the computer at 2-s intervals, and, depending on the coverage needed, flying height, and aircraft speed, stereo images were acquired.  This effectively created data sets having 40 to 60 percent overlap.  For large, complex sites, this capability was important since the frame sequence was mosaicked (tied together digitally) using the common points within each scene.  All flights occurred under nominally clear sky conditions.  Duplicate data sets were achieved of 2-year coverages as indicated in Table 2.

**Table 2.  Location, Acquisition Date, and Coverage**

| SITE | 1998 | 1999 | 2000 | TYPE |
|---|---|---|---|---|
| Rt. 199 | X | | | Wetland |
| Chisman Lakes | X | X | | Wetland/Acid Soils |
| Goose Creek | X | X | | Wetland |
| Ft. Lee | X | X | | Wetland |
| Warrenton Bypass | | X | | Wetland |
| Emporia Bypass | | X | | Wetland |
| Otterdam | X | X | | Acid Soils |
| Franklin Bypass | | X | | Wetland |
| Courtland Bypass | | X | | Wetland |
| Rt. 13 | X | | | Corridor Analysis |
| Swash Bay | | | X | Wetland |
| I-295/Rt. 360 Interchange | | | X | Acid Soils |
| Rt. 288/Rt. 145 Interchange | | | X | Acid Soils |

**Data Format**

Several standard imagery exchange formats were used in the generation and sharing of the DMSV data.  The initial format during data acquisition was band interleaved by pixel (BIP).  This format resulted in a file size of 1.7 mb per frame of four-channel data and included a 512-byte header.  All header data, describing the attributes of the mission and the spectral configuration of the data, were stripped, leaving just the imagery data to be post-processed.  After post-processing, images were stored as band interleaved by line (BIL).  Other exchange formats included JPEG and TIF.  These file types were reserved for products or examples of data where only three bands were used.

**Spectral Data Collection**

To improve the accuracy of the classification of features, spectral reflectance data were collected for several sites using an ASD PS II spectrometer. This instrument collected data used in modeling the radiometric attributes of the DMSV for several of the sites. Spectral reflectance was measured using procedures outlined by Satterwhite and Henley (*1*). Spectralon, a diffuse reflectance standard, was used to calibrate the instrument to reflectance units. An 18° field of view was used to collect spectra at a distance of 1 m above the target (soil, vegetation, or water feature). Ten spectra were collected and averaged to create a representative reflectance spectrum from 350 to 900 nm at a resolution of 3 nm. The digital archive of spectral measurements was stored on a data CD.

Spectral data were post-processed using the radiometer manufacturer software and archived in Excel spreadsheets. For the calibration of the DMSV data, spectral percent reflectance (0 to 100%) was used in conjunction with the imagery digital numbers (0 to 255) to develop a regression equation for each wavelength of interest. The resulting regression *(y = ax + b)* was then used to create a new image corrected to reflectance and having values from 0 to 100% (*2*).

## Data Correction

**Geometric Correction**

Raw DMSV data were corrected for internal geometry by removing the de-interlacing that occurs with the use of non-progressive scan cameras. The 1/60th of a second scan line problem produces an artifact in each band that can be corrected using commercial image processing software. The artifact is created by the image acquisition and motion of the aircraft in the roll direction and is seen as a displacement of lines, particularly at the image margins. The next correction is to co-register the separate spectral frames within less than 1 pixel of each other. This procedure is performed to correct for the displacement of image frames that occurs because of the slightly different viewing geometry for each of the four cameras.

**Radiometric Correction**

The collection of the spectral data allowed the generation of regression equations to calibrate the DMSV imagery to known ground targets. Equations were developed from the solution of digital number values (*x* axis, independent variables) and field reflectance values (*y* axis, dependent variables). Each equation yielded an *r* value of >0.70. The calibration of the imagery improves classification confidence and normalizes the data to reflectance units. The four resulting equations used were

450 nm waveband: 450NEW = 450OLD(0.0816) – 2.6069
550 nm waveband: 550NEW = 550OLD(0.1036) – 3.4358
680 nm waveband: 680NEW = 680OLD(0.1215) – 4.5216
770 nm waveband: 770NEW = 770OLD(0.0961) – 0.4587.

**Image and GIS Rectification**

Raster class maps in Imagine format were used as input to ArcView GIS for geographic rectification and vector processing.  Each image was examined to identify potential ground control locations.  Features such as road intersections, building corners, bridge decks, etc., known to make excellent ground control points because they are not likely to be altered by changing environmental conditions, were identified.  The ground control points were then visited in the field.  The latitude and longitude coordinates for each point were captured using a Trimble GeoExplorer GPS receiver.  A minimum of four control points were captured for each image.  The coordinates were post-processed using correction data from a base station in Charlottesville, Virginia.  Corrected files were then exported from the GPS software package, Pathfinder Office, to ArcView 3.2.  A feature theme was then created for each image using the ground control point locations.

Using ArcView's Image Analysis extension, the unrectified images were combined with the ground control points to transform the image from a pixel coordinate system to a real-world coordinate system.  This multistep process involved matching each control point in the feature theme to the corresponding point in the image.  The first control point allows the two themes to line up.  The second control point adjusts the scale of the image.  The third point allows for an affine transformation to be calculated, altering the image.  The fourth control point allows for the calculation of the root mean square (RMS) error (*3*).  Root mean square is essentially the measurement (in pixels) of the distance between the input points from the uncorrected image to the control points after the polynomial transformation is applied.  A high root mean square error indicates a potential error in ground control location measurement.  Once rectified, the files were renamed and saved.

**Vector Conversion**

Next, the rectified raster images were converted to a vector image using ArcView's Image Analysis module.  To carry out this procedure, the images were first brought into ArcView as an Image Analysis data source.  The image themes were then converted to shapefiles and saved with .shp extensions.  The new themes were added to the view.  The view's projection properties were altered so distance units could be measured in real-world units as opposed to pixels.  All projections were set to Equal Area Cylindrical, and all distance units were set to meters.

## Data Analysis

**Classification**

Images were classified in the raster domain using a minimum distance classification strategy.  Training signatures were selected using ERDAS Imagine for known, field-identified land features.   Following methods described by Jensen (*4*), separation of spectral signatures was tested using statistical transformed divergence.  Signature separations for features such as open water and major plant communities that achieved scores of 1,900 (of 2,000) or better were

retained for classification.  This allowed only highly separable features to be classified, characterizing the major landscape features detected by the DMSV.


**Area Calculations**

Polygon areas were precisely calculated on the new projected .shp files.  An area calculation function is not available on ArcView's standard interface.  The script calcapl.ave was loaded from ESRI's online scripts, compiled, and run in ArcView's active window containing the image that was to be analyzed.  This function calculated the area of each of the previously delineated polygons (in square meters) and stored the values in a newly created field of the theme's existing attribute table.  To view the total area values for each classification in the theme, as opposed to individual polygons, the newly created area field was summarized by clicking the summarize button on the main menu and indicating the specific field and summary function to be used.  This resulted in the creation of a new theme with a consolidated attribute table.


## Cost Comparison

A very simple cost comparison was done for the costs associated with wetland mitigation monitoring.  There are several components of the monitoring requirements for mitigated wetlands.  This study evaluated the potential of using DMSV for the vegetative portion only.  The approximate costs associated with monitoring this portion using standard field methods were calculated using information provided by the Aquatic Ecology Section of VDOT's Environmental Division.  The values were compared with the approximate costs of collecting and analyzing the information by way of DMSV.  These costs were calculated using information from DMSV data collection contracts with Southern States Cooperative, the Virginia State Police, and VDOT.


## RESULTS AND DISCUSSION

### Data Collection

The acquisition of digital multispectral image data for VDOT's environmental resources took 2 years.  The availability of two sensor systems (Specterra DMSV and CAMIS) permitted most of the data to be acquired in the wetlands and acid soils categories.  Only one data set was acquired in the corridor category (Route 13).

Figure 3 shows the results of the raw DMSV files obtained for a single wetland mitigation site.  Raw data were in a raster format with pixel resolutions of approximately 1 m.  These images had no geo-referencing (no direction or distance values) and were not classified (no vegetation assignments were made).  Each pixel simply had a value for each of the four color bands previously described.
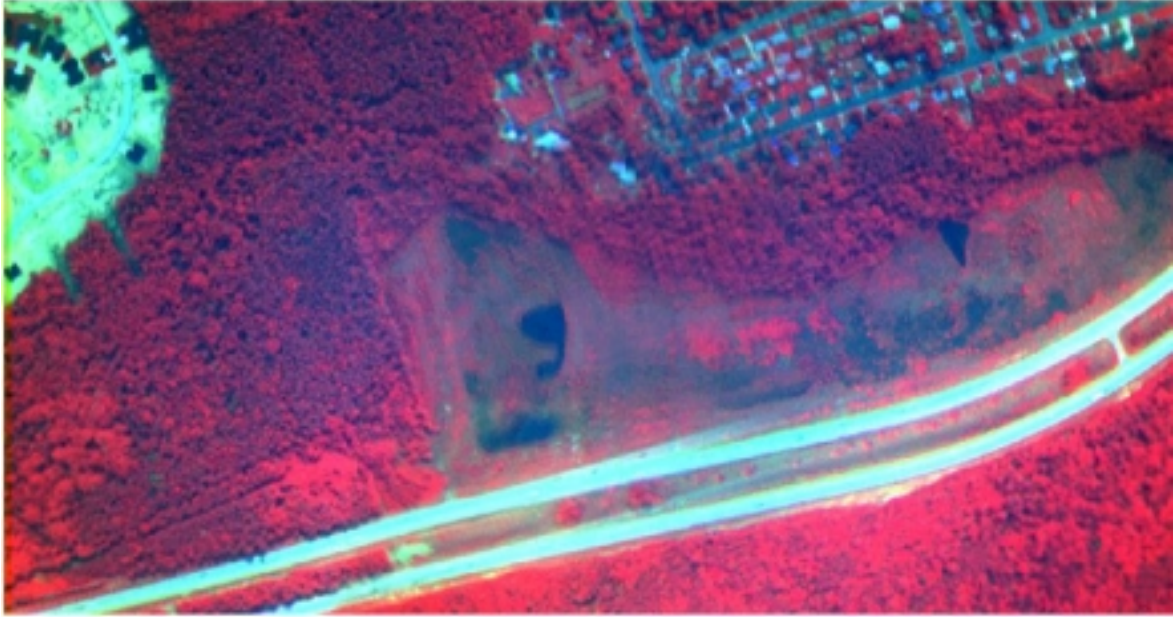
**Figure 3. Uncorrected Image Data for Ft. Lee Wetland Mitigation Site**

Several data collection problems were encountered and overcome as a result of the project. With regard to the wetland mitigation sites, accurate positional data were not available for several key sites. The attempt to acquire data for sites having poor positional data from the air using inaccurate control points resulted in flight delays and uncollected data sets. In addition, to fulfill the contract, these sites were re-flown once the proper coordinates were established. Another problem was the lack of image and data processing resources at VTRC and Virginia Commonwealth University. The establishment of identical computer processing facilities at both institutions allowed the Internet to be used to send files back and fourth. At the conclusion of the project, each institution had ERDAS Imagine for image processing and analysis and the Arc View GIS for geographic correction and vector post-processing.

The graphical results of data collected with the field spectrometer are shown in Figure 4. Each feature (plant species, soil type, etc.) has a unique reflectance value along the wavelength continuum (*x* axis). Large differences can be seen in the signatures for soils when compared with those for the various plant species. The plant species themselves show the greatest separation in the 770 nm (near IR) range. Again, because of the narrow bandwidths being measured by the DMSV, these separations could be distinguished. This information, when combined with the raster imagery previously shown, allowed for the derivation of plant communities and land features.
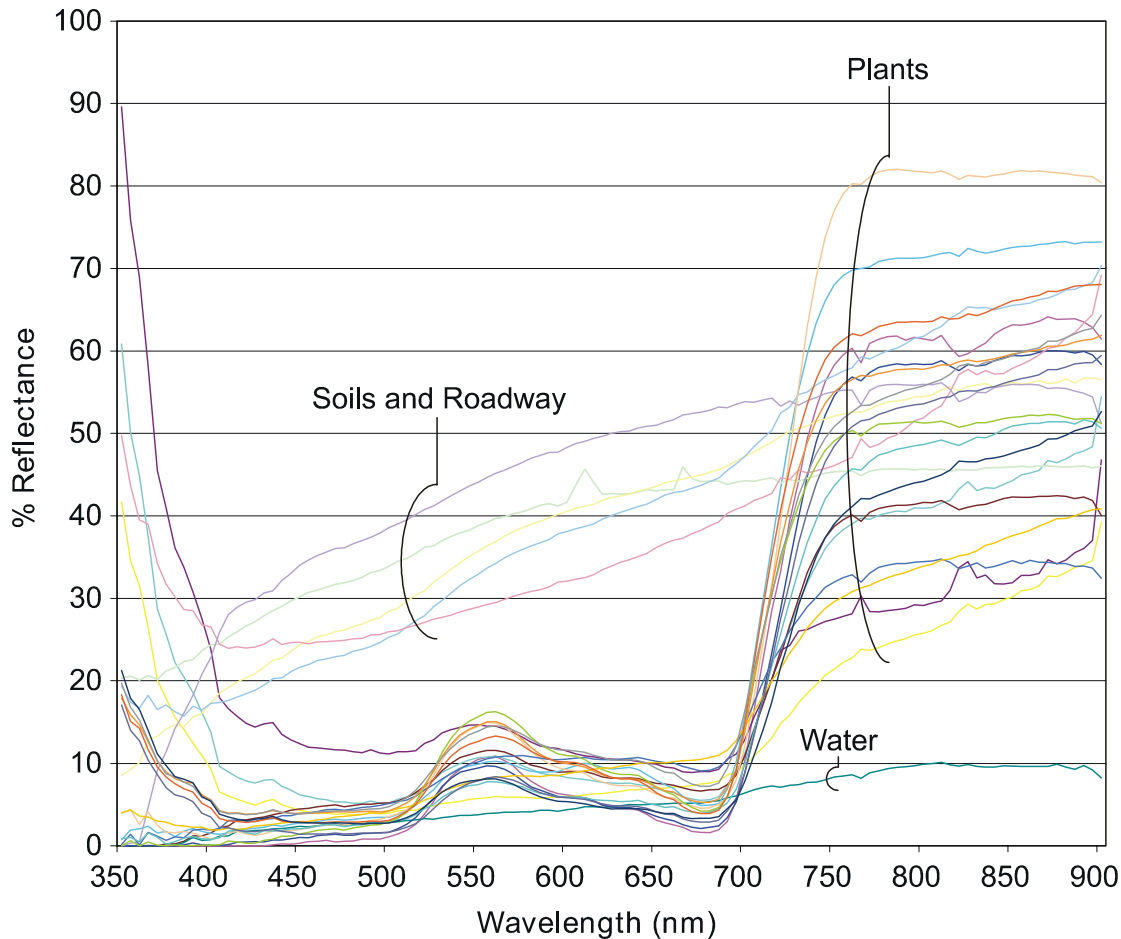
**Figure 4.  Field Spectral Reflectance Data from PSII Radiometer for Calibration**

## Data Correction

### GIS Image Rectification

There were no problems importing the image data into ArcView's Image Analysis extension for geo-rectification.  For some of the more rural sites, it was difficult to collect ground control points at locations that were distinguishable on the image.  In the future, it may be beneficial to place temporary ground control markings near these sites just prior to flying over them.  Coordinates could be obtained for these points and matched to the corresponding points in the image.  One drawback of using these temporary types of ground control points is that they could not be used for multiple images taken over a period of years as they would likely degrade and/or move over time.  This, in turn, would require replacing and reestablishing coordinates for each point prior to each flight.  This would ultimately increase the time requirements and costs related to the data collection effort.

The majority of the images had RMS values well under 3.  This was quite good, considering that the inherent error associated with the GPS receiver used for the collection of the

ground control locations was 3 to 5 m.  Hand-held mapping grade GPS receivers are now able to provide submeter accuracy.  If the accuracy of the ground control points is increased, it would be reasonable to expect a decrease in the RMS values (an increase in the accuracy) as well.

## Vector Conversion

The conversion of the raster images to vector coverages was extremely efficient.  Only a few years ago, this step would have been a major impediment to the utilization of image acquisition technology for applications such as wetland monitoring where vectorization was required, because it would have taken numerous hours of manual digitizing to convert the image.  Converting the data for this study, depending on the processing speed of the computer and the complexity of the image, in most cases took only minutes.  No discernable mistakes were found when converting from raster to vector.  Some blockiness was evident on the delineation of some of the smaller polygons on some of the smaller wetland sites.  This was more a result of the 1-m resolution being too large and not actually related to the raster-to-vector conversion process.

## Data Analysis

## Classification

Four collected files could not be classified.  Instead of distinguishing between features with different spectral signatures, the entire image was classified as a single feature even though individual pixels had visibly different reflectance values.  It was not fully understood by the researchers what caused the problem with the classification request submitted to the ERDAS software, but the resulting data sets were unusable.

All other classifications resulted in accurate delineations of the features of interest.  Major plant communities were distinguishable for the wetland mitigation sites captured.  Along with the plant communities, open water and bare soil were easily identifiable.  For the sites that were collected twice, changes in the vegetation communities were identifiable.

Areas known to contain acid soils were also identified when the soils were visible from the air (i.e., not covered by vegetation or non-acidic soils).  In a related study, the researchers found a good correlation between exposed acid soils and pH testing done on samples in an area known to have highly acidic soils (5).  Although exposed, highly acidic soils were distinguishable, most of VDOT's concerns related to acidic soils are due to soils that do not currently have a low pH because they are not oxidized (i.e., are not exposed at the surface).

## Area Calculations

Despite the fact that the area calculation required minor modifications within the ArcView environment, the process was straightforward and free of errors.  Figure 5 shows the ArcView graphical output for the Ft. Lee mitigation wetland site.  Table 3 shows the attribute table generated for the graphical output.  Included in the table are the total areas (in square meters) for each of the major vegetation communities.  Specific area data are both relatively easy
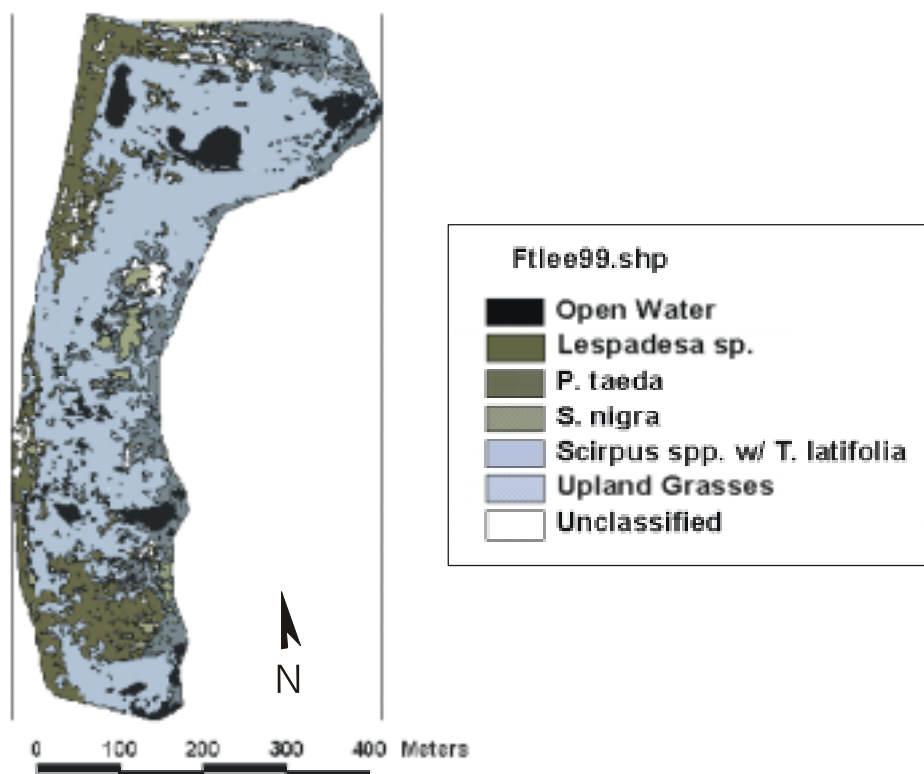
**Figure 5. ArcView Graphical Output for Ft. Lee Wetland Mitigation Site, Showing Major Vegetation Classifications**

**Table 3. ArcView Attribute Table for Ft. Lee Vector Coverage**

| Class Name | Count | Sum Area | Sum Perimeter |
|---|---|---|---|
| Lespadesa sp. | 458 | 25077.494 | 11720.486 |
| Open water | 82 | 8202.984 | 2611.261 |
| P. taeda | 532 | 18989.934 | 12216.397 |
| S. nigra | 140 | 4635.222 | 3017.45 |
| Scirpus spp. w/ T. latifolia | 270 | 81698.297 | 15865.812 |
| Unclassified | 3 | 155050.651 | 4132.304 |
| Upland grasses | 551 | 7215.648 | 8267.507 |

*Note:* Sums are in square meters.

to acquire and extremely beneficial in terms of measuring species diversity, density, and temporal change. The alternative method of cutting a number of transects through a site and then extrapolating the findings to the remainder of the unstudied area is far less accurate and much more labor intensive.

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## Cost Comparison

The approximate costs of the vegetative component for typical wetlands monitoring when conducted using conventional methods were 40 h/ha x $20/h = $800/ha.

The approximate costs for obtaining the vegetation information by way of DMSV (including correction and analysis) were as follows:

Aerial collection: 0.05 h/ha x $500/h = $25/ha
Data correction: 0.25 h/ha x $100/h = $25/ha
Data analysis: 0.3 h/ha x $100/h = $30/ha
DMSV total = $80/ha.

In another study conducted by staff of Virginia Commonwealth University, 1215 ha of cotton were flown over and analyzed for approximately $13.50/ha. This cost estimate was inclusive of 10 h round trip flight time to Tifton, Georgia, at a rate of $500/h. The per hectare price for collection of the data by way of DMSV technology can vary drastically based primarily on the size, complexity, and location of the wetland site. If multiple sites can be flown over during the same mission or if the sites are large, the collection cost per area will be decreased. Conversely, if the sites are small and/or require multiple flights for capture, collection costs will be increased because of the flight time requirements.

Specific monitoring requirements may vary depending on the site and when it was constructed, but it can be assumed that data for the vegetative component should be collected two times per year. The hourly rate used in the conventional method is another variable that could fluctuate significantly from the value used in the calculations here. With respect to the DMSV cost estimates, costs can vary greatly depending on the size and number of sites to be monitored at a given time. Obviously, economies of scale play a part in reducing the costs when using this type of technology.

Additionally, as digital imagery becomes a widely available resource, it is anticipated that the cost of acquiring spectral data will remain competitive. At present, several satellite systems are planned that will provide high-resolution spectral and spatial imagery to customers. Among these will be the IKONOS and OrbImage sensors. These systems will deliver image data similar to or better than those available with DMSV technology. Many aircraft systems have emerged since the initiation of this project that could fulfill much of VDOT's digital imagery requirement needs. Among these are the CAMIS and AAHIS sensors systems that can provide high-spatial and high-spectral resolution data as well as better temporal resolution than the satellite systems offer.

## Digital Image Archive and GIS Data Base

The corrected and classified DMSV data were archived to a CD ROM along with the GIS vector coverages generated in ArcView. The organization of the data falls into two folders that contain 1998 and 1999 year mission data. Additionally, a folder containing the raw field spectral

data is contained on the CD. A "readme" text file provides information on filenames and locations for each dataset.

## CONCLUSIONS

- DMSV is a technically feasible means of capturing data. DMSV could distinguish all major wetland plant communities that were manually identified in the field. Exposed acid soils were also readily identified.

- The data collected with DMSV were successfully corrected, geo-referenced, analyzed, and stored with ERDAS and ArcView software. The steps needed to correct the raw image data and transfer them to a GIS environment were successfully developed.

- Data can be analyzed and manipulated with DMSV in the GIS environment. Once the raster output from the DMSV system is converted to vector format, the datasets can be analyzed and manipulated just as any other vector dataset. Attribute information can be summarized and extracted for further statistical analysis in a spreadsheet or statistical analysis package.

- Several data collection problems were encountered with DMSV. Inaccurate ground coordinates resulted in the collection of the improper data set for two locations, and four files could not be properly classified. Under normal circumstances, this would necessitate recollection of the data.

- Based on the limited cost information available, it appears that the use of DMSV technology is significantly less expensive than the use of more traditional methods of wetland monitoring. It is anticipated that the price of acquiring data with DMSV will remain competitive since new satellite systems are under development and several new aircraft systems have emerged.

## RECOMMENDATIONS

1. *It is recommended that VDOT further pursue the use of DMSV type technology as a means of acquiring wetland mitigation monitoring data.* Specifically, regulatory acceptance needs to be guaranteed before the Environmental Division can rely more heavily on this type of data. The regulators themselves need to become more familiar and confident with the technology and the type of data it can provide.

2. *It is recommended that VDOT begin the use of DMSV data on a pilot basis to satisfy the vegetative monitoring requirements for a subset of the mitigation sites currently requiring monitoring.* This would allow Environmental Division personnel to become more adept at manipulating and analyzing DMSV acquired data while also providing the regulatory agencies additional data and time by which to judge the acceptability of the technology.

3.  *It is recommended that the Environmental Division's Aquatic Ecology Section begin using GIS as a method by which to analyze and store wetland mitigation monitoring data.* At the very least, this will ensure that monitoring data will be able to be compared on a temporal basis to better understand trends and changes related to the success of mitigation sites.

## ACKNOWLEDGMENTS

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