3.0 REMOTE SENSING TECHNIQUES

3.1 AIRBORNE MULTISPECTRAL SCANNING IMAGERY

Use of remote sensing to evaluate vegetative distress including forest canopy conditions is well established. Measurement of reflectance spectra in the visible, near-infrared and thermal infrared range has been used in agriculture and more recently in forestry applications to assess health and growth(9). Spectral measurement of pigment content in higher plants, such as trees, has produced correlations with leaf area, canopy cover, and the concentration of chlorophyll content. Spectral ranges in the green, red, and near infrared wavelengths can correlate with chlorophyll content and permit measurement of the rate of photosynthesis and monitoring of plant stress(10). Thermal infrared data has been found to be particularly well suited for correlation with vegetation transpiration rate and crop water-stress detection(11). Application of multispectral remote sensing has demonstrated capabilities for detecting stresses associated with cropland(12) and forest damage(13). With the advent of hyperspectral sensors, which can simultaneously record up to 200 or more separate spectral bands, tree type classifications can be performed(14).

The airborne multispectral scanner (AMS) is available in several variations, but the most useful is one that incorporates visible, near infrared, and thermal infrared capabilities simultaneously with all spectral bands co-registered so that digital image processing techniques can be applied. Digital processing allows enhancement to highlight chlorophyll production, canopy temperature and moisture content as a measure of forestland distress. The normalized difference vegetation index (NDVI) is widely used to estimate changes in vegetation state(10) and can be prepared from the multispectral image processing to assist in detecting vegetative stress.

The following remote sensing images were proposed for this evaluation of forestland distress:

- Natural color, which provides a depiction of the extent and general density of forestland and the identification of cultural features.

- Color infrared, which has been a traditional method of determining the vigor of vegetation, because healthy vegetation displays very high near-infrared reflectance.

- NDVI, which reveals variations in leaf chlorophyll content, and, when used in combination with color infrared imagery, assists in evaluation of vegetation composition, density and health.

- Thermal infrared to measure daytime and nighttime forest canopy temperatures, which provides a measure of vegetative transpiration.

3.1.1 Sensor Characteristics

D'Appolonia and SenSyTech selected AMS as the primary remote sensing methodology for the project. Specifications for the SenSyTech AMS are provided in Appendix C to this report. The SenSyTech AMS has the capability for simultaneously recording six spectral bands of visible, near-infrared and thermal infrared data during daylight operation and has the capability of accurately measuring canopy temperatures in either daylight or nighttime operations. All spectral bands are co-registered so that spectral combinations as well as ratios can be created with available digital image processing software. Moreover, with the SenSyTech AMS, the thermal infrared data are calibrated and converted to degrees Centigrade for accurate measurement of the tree canopy temperatures. The AMS scanner used for the project was equipped with 1.25-milliradian (mrad) detectors and had a minimum total field of view of 86 degrees.

The following six spectral bands were collected during daylight operations:

AMS Channel (Band)	Wavelength (μm)	Color
2	0.45 – 0.52	Blue
3	0.52 – 0.60	Green
5	0.63 – 0.69	Red
7	0.76 – 0.90	Near-IR
8	0.91 – 1.05	Near-IR
10	8.5 – 12.5	Thermal IR

The data obtained during daylight operations were collected at 8-bit digital resolution. Night coverage of the sites comprised only Band 10 (Thermal IR) data collected at 12-bit digital resolution.

3.1.2 Flight Plans and Data Collection

Data were collected for each of the three study sites at the three mines selected for the study. As discussed in Section 2.0, two study sites associated with each mine were undermined by longwall panels in the recent (1 to 5 years) and older (10 or more years) time frames. A third study site at each mine without longwall undermining was chosen as a control. The undermined study sites were chosen such that they covered one or more longwall panels. The approximate dimensions and areas of the study sites are provided in Table 3.

3.1.2.1 Flight Plans

SenSyTech personnel created a flight plan to provide airborne multispectral image coverage of each site with nominal one-meter ground resolution. The site boundaries and image coverage were plotted on USGS topographic maps of each site, and the end coordinates of each flight line were determined for GPS navigation of the flight lines for both daylight and night coverage. The initial plan called for a single flight line to cover each site, but a second flight line was added to study site D-2 at the Humphrey No. 7 Mine because the 4,300-foot width of this site was considered to be too close to the 4,700-foot swath width of the scanner coverage.

3.1.2.2 Data Collection

The collection of data was scheduled to commence during the last week of June 2000, when the tree canopy was fully leafed out. The flight work was carried out by Woolpert Consultants (Woolpert) under a subcontract to SenSyTech. The AMS equipment was installed in Woolpert's Cessna 404 aircraft in Ann Arbor, Michigan and was tested on June 30, 2000. The plane was then flown to Wheeling, West Virginia, where it was based during the data collection.

The sky and air temperature conditions were favorable on the night of June 30, 2000, and night thermal infrared data were collected at all nine study sites between the hours of 10:45 p.m. and midnight. The air temperature was approximately 70 degrees Fahrenheit at takeoff with clear skies and calm winds. This flight and subsequent flights were flown at an elevation of approximately 2600 feet above the ground surface, which corresponds to a ground pixel resolution of about three feet (one meter).

On July 1, 2000, the skies were clear in the morning with calm winds and the aircraft departed at 10:40 a.m. However, cloud cover in the range of 50 to 70 percent was encountered and, as a result, data could not be obtained. On July 2, 2000, the sky was relatively clear with a few scattered clouds and calm winds. The aircraft was mobilized about 9:45 a.m. and successfully collected multispectral data over all of the study sites by 11:45 a.m. The aircraft then returned to Ann Arbor for demobilization of the AMS equipment. Details on the flight parameters and time of coverage for each study site are indicated on the flight logs, which are presented in Appendix C.

3.1.3 Data Processing and Image Production

Upon return of the aircraft to the SenSyTech facility in Ann Arbor, the data from the 8-mm recording tapes was imported into the ERDAS IMAGINE software for processing. This processing included corrections for scanner geometry and nominal scaling using the actual flight parameters for each flight line. In addition, the thermal infrared data for both daylight and night flights were corrected to apparent temperature in degrees Centigrade using the internal blackbody reference data recorded in flight for calibration purposes. The multispectral images for each site were displayed in order to check site coverage. These images were then cropped so that they closely corresponded to the site boundaries shown on Figures 4 through 6.

Special processing was performed in order to create NDVI image for each site. NDVI images are produced by ratioing a near-infrared (NIR) spectral band and a red or green spectral band as follows:

Red NDVI: $R_{NIR} – R_{red}/R_{NIR} + R_{red}$
Green NDVI: $R_{NIR} – R_{green}/R_{NIR} + R_{green}$

It has been found that these images are particularly useful for the detection of stressed or dead vegetation, as the ratio detects changes in leaf chlorophyll content. Both classical red and the newer green ratio images were produced and evaluated for purposes of this study.

A comparison of the two types of NDVI images is provided on Figure 7. The figure shows both red and green NDVI images along with a natural color image for study site A-1 at the Bailey Mine. Some minor differences in the red and green NDVI images are apparent, as indicated on the figure, but these differences are associated with generally bare areas, i.e., areas with minimal tree canopy. Note that the areas designated as "A" and "B" on the two images are much darker on the green NDVI. These areas are mostly bare, as can be seen on the natural color image.

Several areas of stressed tree canopy determined from the imaging analysis (Section 5.0) are also indicated on the figure for comparison purposes. As shown on Figure 7, the stressed tree canopy areas (A-1-1, A-1-4, A-1-6 and A-1-8) are very similar on the two images. In general, these stressed tree canopy areas show up as dark gray on the NDVI images. Interestingly, the top portion of A-1-1 is almost black on the red NDVI, but only dark gray on the green NDVI. This portion of A-1-1 has the densest concentration of stressed trees observed during the project.

Based upon comparison of the two types of images, it was determined that there was not a significant difference in information content with respect to the tree canopy, so only the red ratio images were analyzed for the sites in this study. All subsequent discussion of NDVI in this report refers only to red NDVI images.

3.1.4 Geometric Correction of Multispectral Images

3.1.4.1 Color Digital Orthophotos

Digital orthophotos were collected and produced for each study site to serve as a base template for matching to mine maps and for displaying analysis results from the multi-spectral data analysis. This work was performed by Woolpert under subcontract from SenSyTech. A single photograph was planned for each site. Due to the range of study site dimensions, a scale of 1:19,200 (1" = 1,600') was selected so that the largest study site could be imaged on a single photograph. This scale corresponds to a flight altitude of 9,600 feet. SenSyTech provided the corner coordinates for each study site to Woolpert, which then prepared a flight plan for the data collection. Because cloud-free and minimum haze conditions were necessary, several attempts were required for Woolpert to collect adequate data for all of the study sites. The data collection was completed on July 7, 2000.

Upon completion of the data acquisition, Woolpert performed a series of operations to convert the raw photographs into digital orthophotos. The first step involved digitizing the photographs using a scanner with 24-µm spot to produce a digital version with approximately 2-foot pixel resolution. The digitized photographs were then registered to the USGS digital ortho quadrangle data for each site using the NAD83 datum for horizontal control and NAD88 datum for vertical control. The coordinate system for these orthophotos was Pennsylvania State Plane (Zone 5151) with units of U.S. feet.

3.1.4.2 Geometric Correction with Digital Orthophotos

The multispectral scanner images were geometrically corrected using the ERDAS IMAGINE(6) software. This was accomplished by displaying a digital orthophoto and a multispectral scanner image of each site simultaneously and then manually selecting a minimum of 12 control points identifiable on both images. The control points were used as a reference for resampling of the digital multispectral images to obtain a “best fit” to the digital orthophoto for the site.

Upon completion of these processing steps, the corrected and calibrated multispectral data for each site were transcribed to CD-ROMs in ERDAS IMAGINE (*.img) format and delivered to D’Appolonia for image analysis. SenSyTech worked with D’Appolonia staff in the image analysis, as discussed in Section 5.0 of this report. The digital orthophotos were transcribed to CD-ROMs in TIFF (*.tif) format and were also delivered to D’Appolonia.

Figures were prepared for each study site showing the five types of images: natural color, color infrared, NDVI, day thermal and night thermal. The figures also show the study site boundaries and longwall mine panel locations. The figures (A-1 through A-18) are provided in Appendix A.

3.2 SATELLITE COLOR INFRARED IMAGERY

D'Appolonia included the use of a satellite platform in the scope of work in order to obtain redundant color infrared images over the 2000 growing season and to complement the airborne multispectral scanning remote sensing performed by SenSyTech. As indicated above, color infrared imagery provides a ready means of detecting distressed vegetation. Use of a satellite platform is an effective means to obtain color infrared imagery over large areas, and satellite imagery is becoming more available in high resolution in orthorectified form. Collection of replicate imagery over the growing season provided a means of monitoring the development or progression of distress and provided additional data on forestland health over the growing season.

Satellite color infrared images were collected by Space Imaging LLC (Space Imaging) through BAE Systems ADR, Inc., their local representative. The IKONOS I Satellite with a multispectral sensor was utilized to collect 1-meter-resolution, orthorectified, color infrared imagery. Two rectangular shaped areas of interest (AOIs) that enveloped the three mine sites were selected: AOI-1 encompassed approximately 200 square kilometers that included the Blacksville and Humphrey No. 7 Mine sites, and AOI-2 encompassed approximately 84 square kilometers that included the Bailey Mine site. The images were delivered to D'Appolonia on CD-ROM in State Plane projection (NAD83 datum). The 11-bit (and sometimes 8-bit) 3-band color infrared data files were in GeoTIFF format. The three bands were as follows:

Band	**Wave Length (μm)**	**Color**
2	0.53-0.61	Green
3	0.64-0.72	Red
4	0.77-0.86	Near-IR

Three collection periods were planned for the satellite data: late spring/early summer, mid summer, and late summer. Weather and the availability of the satellite resulted in a delay in obtaining the first acquisition. The first satellite acquisition for the two AOIs was achieved on July 20 and 25, 2000, with some cloud interference. Weather (cloud cover) can limit the imagery acquisition, and Space Imaging may not acquire the data if the AOI is obscured by more than 20 percent. Satellite availability is dictated by a flight path and priority system, which affects scheduling. The satellite path and tasking generally limit the ability to collect data at a specific AOI to once every three to five days.

The second acquisition for AOI-1 occurred, with some cloud interference, on August 30, 2000; however, the second collection for AOI-2 was not acquired within the stipulated timeframe due to weather and satellite availability. Similarly, the third collection was not achieved by September 18, 2000 because of weather and satellite availability, at which point D'Appolonia, with DEP's approval, requested the collection of color infrared aerial photography from BAE Systems ADR, as discussed in Section 3.3.

The image data files for the study sites were partitioned from the GeoTIFF files for the AOIs using the ERDAS IMAGINE software. Color and contrast were adjusted using the software in order to provide the color infrared images for figures presented in this report.

3.3 AIRBORNE COLOR INFRARED PHOTOGRAPHY

Airborne color infrared photographs for the two AOIs were requisitioned in order to complete the late summer imagery collection. BAE Systems ADR developed the flight paths and performed the airborne collection over the two AOIs to obtain color infrared photographs with a negative scale of 1" = 2500'. Color infrared prints were prepared and digitized by scanning at 22.5 microns and were delivered in TIFF format. Unlike the satellite and airborne multispectral scanning images, the aerial photographs were not orthorectified, and, as a result, some distortion is present in the images due to the terrain collection geometry. However, physical features within the photographs allowed determination of the approximate location of detected vegetation distress.

The airborne color infrared photography was performed on September 22, 2000 for the Bailey and Blacksville study sites. The Humphrey No. 7 study sites were inadvertently omitted by BAE Systems ADR. By the time the problem was identified, it was too late to obtain the Humphrey No. 7 data because of the onset of fall foliage conditions.

The scanned photographs for each site were partitioned and color and contrast adjustments were made using the ERDAS IMAGINE software as part of the preparation of the color infrared images used in figures for this report.

3.4 SUMMARY OF SATELLITE IMAGERY AND AIRBORNE PHOTOGRAPHY

Redundant color infrared images for each site were obtained as follows:

Mine	First Period	Second Period	Third Period

Bailey Mine	July 20, 2000	No Data	Sept. 22, 2000
Blacksville Mine	July 25, 2000	Aug. 30, 2000	Sept. 22, 2000
Humphrey No. 7 Mine	July 25, 2000	Aug. 30, 2000	No Data

Figures showing color infrared imagery from the multispectral scanner and satellite and airborne photography for the periods above at each study site were prepared. These figures (B-1 through B-9) are presented in Appendix B to this report.