# EXECUTIVE SUMMARY

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## REMOTE SENSING OF FORESTLAND ABOVE LONGWALL MINING AREAS WASHINGTON AND GREENE COUNTIES, PENNSYLVANIA

D'Appolonia Engineering Division of Ground Technology, Inc., (D'Appolonia) was contracted (BMR-99-01) by the Pennsylvania Department of Environmental Protection (DEP) Bureau of Mining and Reclamation to conduct remote sensing of forestland above longwall mining areas in Washington and Greene Counties, Pennsylvania. SenSyTech, Inc. Imaging Group (SenSyTech) provided primary technical support for the remote sensing tasks and Dr. Donald D. Davis, Forest Pathologist with The Pennsylvania State University, provided consulting services on forest evaluation and health conditions for the project. In accordance with the November 1999 proposal, the work was planned in the following major tasks comprising:

- Sites Selection
- Remote Sensing
- Imaging Analysis
- Report Preparation

The imaging analysis task included analysis of subsidence at selected sites and evaluation in the field (ground truthing) of sites identified as having potentially stressed tree canopy.

The major tasks relate to identification of field sites with stressed tree canopy and evaluation of these sites in the field. From study sites in the approximate range of 400 to 900 acres, areas of forest canopy distress were identified (typically 1 to 10 acres) on the remote sensing imagery, and ground-based reconnaissance and tree health evaluation surveys were performed within the distressed area. In addition to distressed areas detected from the imagery, selected locations of predicted or observed subsidence effects were also evaluated in the field for canopy distress, and the associated remote sensing imagery was further reviewed.

**SITES SELECTION**

Project work initiated in March 2000. Candidate sites were evaluated at longwall mines in Washington and Greene Counties. The work included a literature survey, review of aerial photography and mine data, and evaluation of numerous forest stands in the field. Candidate mine sites were primarily screened on the basis of (1) extent of forest cover, (2) forest type, density and condition, and (3) ease of access. A number of secondary criteria were also considered. The Sites Selection Report was issued in May 2000 and listed four candidate mines with three study sites each as recommended. The top three recommended candidate mines (Bailey, Blacksville and Humphrey No. 7) were authorized for study by DEP on June 2, 2000. The study sites at each mine were selected on the following basis:

- One site undermined between 1995 and 1999
- One site undermined in or prior to 1990
- One site not undermined by longwall panels

The undermined study sites were chosen such that they covered one or more longwall mine panels and extended well beyond the boundaries of these panels.

**REMOTE SENSING**

Airborne multispectral scanning data were obtained by SenSyTech between June 30 and July 2, 2000. The images included natural color, color infrared, normalized difference vegetation index (NDVI), and day and night thermal. The imagery was collected for the 9 study sites (3 at each of the 3 mines). Additional data were obtained in the form of satellite color infrared imagery (IKONOS I) and digitized aerial color photography for the period between July 20 and September 22, 2000.

**SUBSIDENCE ANALYSIS**

For the two undermined study sites at the Bailey, Blacksville and Humphrey No. 7 Mines, an analysis of subsidence was performed using the Subsidence Deformation Prediction System (SDPS) software developed at Virginia Tech. Relevant mine parameters were determined from data in DEP files and other published data. Generally, the maximum predicted subsidence settlements occurred along the longitudinal centerline of the panels. Maximum compressive strains were found along the longitudinal centerline and maximum tensile strains were found along the boundaries between panels. The results of these analyses facilitated the identification of locations of high tensile strain, which assisted in the analysis of the remote sensing imagery and in conducting the ground truthing.

## IMAGING ANALYSIS

The airborne multispectral scanning imagery provided by SenSyTech was the primary input to the imaging analysis. Additional data in the form of color infrared satellite imagery and color infrared aerial photography were also analyzed. The images were scanned and analyzed using the IMAGINE 8.4 software developed by ERDAS. Multiple images from the multispectral scanning were enlarged and systematically traversed using the software. Areas of potentially stressed tree canopy were identified by characteristic changes in color on the images. For the 9 study sites at the three mines, more than 70 anomalous areas were identified from the imagery. This number was reduced to 48 because the study sites encompassed an area smaller than the images. These areas of potential canopy stress identified from the imagery, termed field sites, were typically between 1 and 10 acres in size.

## GROUND TRUTHING

The study areas were typically between 400 and 900 acres. The forests ranged from early successional stands in former pastures (e.g., black locust) to more mature forests dominated by a mixture of hardwood species such as maple, oak, elm, black cherry, and many others. Throughout much of the forestland on the study sites, the trees were characterized as generally healthy based on general observations while traversing to the specific field sites.

### Areas of Canopy Stress Identified from the Imagery

Areas of potentially stressed canopy identified from the imaging analysis were targeted for field evaluation in order to verify that they were actually stressed and to learn to the extent possible the cause of the stress. The primary cause of the stressed canopy detected in tree surveys at field sites was found to be insect infestation with the black locusts (locust leaf miner) and elms (elm leaf beetle) showing the most severe damage.

Branch dieback accounted for a lesser number of the stressed canopy observations. Generally this was found on oak, maple and aspen trees. The dieback observed in oak trees is believed to be related to past insect infestations, such as the 1996 gypsy moth infestations. Logging slash was responsible for the distress interpreted from the imagery at two field sites, although unrelated branch dieback of maple trees was also noted.

Dieback of aspen trees detected at just one field site was attributed to the short-lived nature of the species. Although ground disturbances (e.g., cracks) associated with subsidence were noted at some field sites, these features were not judged to be the causal factor for the canopy stress, either because insects were clearly implicated, or the actual features were not located close enough to the stressed canopy trees for subsidence to be identified as a causal factor.

**Areas of Observed Subsidence Effects**

Areas where subsidence effects were expected or known to have occurred were evaluated. These areas included subsidence pools along Enlow Fork at the Bailey Mine, select longwall panel boundaries where high tensile strains and ground disturbances were predicted, and a property located just east of one of the study sites at the Humphrey No. 7 Mine where the owner reported subsidence damage to trees.

Six subsidence pools along Enlow Fork and stream segments between the pools at Bailey Mine were evaluated by the field team. The soils around the perimeter of the pools were observed to be wetter than soil adjacent to segments between the pools. For species that were tolerant of wet conditions (e.g., sycamore, black locust, boxelder and elm), no significant differences were observed in the vigor of the trees. Species that are less tolerant to moisture such as maple and black walnut were observed to have healthier crowns in the segments between the pools. The overall impact of the increased soil moisture on the tree crowns in the immediate vicinity of the pools was minor.

Sections of longwall mine panel boundaries at the three mines where relatively high tensile strains and ground disturbances were predicted on the basis of the subsidence analysis were selected for evaluation by the field team. Scarps, slides and trees with moderate to severe root damage were observed at several locations along these panel boundaries. Although subsidence effects were observed, the tree canopies were characterized as generally healthy. No distinctive evidence of canopy distress aligned with the locations of high tensile strain was observed in the remote sensing imagery.

The field team observed ground disturbances associated with subsidence at the Lee property located near one study site at the Humphrey No. 7 mine. Scarps, slides, leaning trees, tree root damage and generally hummocky terrain were observed at the site, and some ash trees on the property were observed to have greater branch dieback or mortality relative to adjacent areas also within the influence of the longwall mine.

**FINDINGS AND CONCLUSIONS**

It was found that use of the remote sensing imagery, particularly the aerial multispectral scanning imagery, was effective for identification of tree crown stress. The technique was most effective for identification of the insect damage that resulted in severe leaf browning and for identification of branch dieback for relatively large trees such as oaks, maples and aspens. Areas with minor, sporadic canopy damage were much more difficult to distinguish from the surrounding conditions.

All of the stressed canopy areas identified from the imagery were found to be suffering from some type of observable stress based upon subsequent field observations. The most prevalent cause for the observed stress was insect infestation, present at both undermined and non-undermined study sites. Most of the insect infestation was related to the effects of the locust leaf miner on black locust trees, which exhibited extensive leaf browning and some defoliation. Branch dieback associated with oak, maple, and aspen was also detected, and was attributed to non-mining causes.

In analyzing the remote sensing imagery, D'Appolonia personnel performing the analysis were aware of the orientation and location of longwall panels at undermined study sites. They were also aware that surface horizontal tensile strains were predicted to be highest along panel boundaries. However, no linear or geometric zones of stressed tree canopy were identified that could be correlated with mine panel boundaries or areas. Areas of potentially stressed tree canopy were found in all types of predicted strain zones. Locations of potentially stressed tree canopy were not found to be associated with high tensile strain zones any more frequently than with zones of compressive or minimal strain.

Some specific areas where effects of longwall mining were known to be present (subsidence pools, panel boundaries, and the Lee property) were also evaluated in the field for forest canopy stress. Throughout areas of predicted high tensile strain and ground disturbance (panel boundaries), no distinctive evidence of canopy distress was observed in the imagery, and the canopy was observed to be generally healthy in the field. Ground disturbances associated with subsidence appeared to impact canopy health in two instances: a slide with wet ground conditions where a stand of ash exhibited dieback and mortality (the Lee property) and two tree types (black walnut and maple) along subsidence pools on Enlow Fork which were less tolerant to the moisture conditions than the numerous other mixed hardwoods populating the stream banks. The slight decline in tree health along the subsidence pools could not be distinguished in the remote sensing imagery, and the severe decline and mortality of the young ash stand was difficult to detect even with extensive scrutiny of the imagery.