4.0 SUBSIDENCE ANALYSIS

As a part of the evaluation of forestland health using remote sensing imagery, an analysis of horizontal strains and subsidence that would be expected at the ground surface over longwall panels at the selected study sites was performed. This section of the report provides a general discussion of subsidence effects, the input parameters and modeling software used for the analyses, and the predicted horizontal strains and subsidence displacements obtained from these analyses.

4.1 BACKGROUND AND TECHNICAL APPROACH

When longwall mining is performed, a cavity is created underground that collapses, resulting in a change of the stresses in the surrounding strata. The increased stresses result in deformation and collapse of the rock layers that immediately overlie the cavity. The thickness of collapsed rock strata is usually three to six times the excavated coal thickness. The broken rock debris provides support to other overlying rock beds, which tend to only sag instead of collapse. The rock deformation diminishes in the direction of the ground surface and a trough-shaped depression forms at the surface. The depression at the ground surface is usually larger than the footprint of the longwall panel and is called trough or sag subsidence.

Tensile and compressive stress-strain fields and vertical and horizontal deformations develop at the surface due to the collapse of the longwall cavity. The purpose of the subsidence analysis was to determine locations of relative highs in surface horizontal tensile and compressive strains at undermined study sites for possible correlation to areas of stressed tree canopy observed from the remote sensing imagery.

Surface tensile strains are more likely to cause damage to trees than surface compressive strains because of the possibility of tearing tree roots in tension and/or the potential loss of surface or shallow groundwater into surface cracks. It is estimated that there is potential for damage to forests and woodlands when surface tensile strains exceed 5 to 10 x 10^{-3} ft/ft[15].

As discussed in Section 2.0, two study sites that were undermined by longwall panels were selected at each of three mines in Washington and Greene counties. At each mine one of the study sites had experienced subsidence due to longwall mining prior to or in 1990 and the second site had experienced subsidence due to longwall mining between 1995 and 1999. Each study site was chosen such that it included a valley and/or a stream channel where the thickness of overburden above the extracted coal seam was a minimum and thus subsidence effects at the ground surface would be expected to be a maximum.

4.2 INPUT PARAMETERS AND ANALYSIS

Ground surface displacement resulting from subsidence was modeled at each undermined study site using Version 4 of the Surface Deformation Prediction System (SDPS) software[16], which was developed at Virginia Polytechnic Institute and State University. The software was developed for the purpose of predicting ground movements resulting from underground mining in eastern U.S. coalfields. The analysis methodology is based upon the influence function method, which is widely employed for predicting subsidence in U.S. coalfields.

Predicted subsidence deformations are a function of mining geometry, overburden geology, and other physical parameters. This information, as well as permit documents, reports and drawings for the subject mines, was obtained from DEP files. Where data were lacking, typical data from other mines in Washington and Greene counties were used, if available. Otherwise, relevant published data were used. The input to the subsidence model included the following parameters:

- Extraction thickness
- Overburden depth
- Seam elevation
- Subsidence factor
- Gate extraction ratio
- Average offset distance
- Percent of hard rock
- Strain factor (selected as recommended in the SDPS program manual for the Appalachian coal fields = 0.35)

- Angle of influence (selected as recommended in the SDPS program manual = 62.4 degrees)

While site-specific data were used to the extent available, the intent of the analysis was to determine locations of relatively high tensile and compressive strain, rather than actual magnitudes. The locations of relative maximum tensile and compressive strains were particularly of interest in the image analysis (Section 5.0) and ground truthing of panel boundaries (Section 7.0).

A grid was established to model the ground surface at each study site, and subsidence and horizontal strain were calculated at the grid nodes. The dimensions of the grid for each study site were selected on the basis of a parametric study that accounted for the effects of surface topographic variation and the thickness of overburden from the mine cavity to the surface. The gates between longwall panels were assumed to yield, but the gates at the ends of longwall panels perpendicular to direction of mining were assumed not to yield. Subsidence model input parameters for the six undermined study sites are listed in Table 4.

4.3 RESULTS OF ANALYSIS

Surface deformations including horizontal strains and subsidence displacement due to longwall mining were determined for each study site using the SDPS software. A kriging statistical interpolation technique was applied to the SDPS output data in order to produce contour lines of estimated horizontal strains and subsidence displacement. The Surfer 7.0 software[17] was used for this analysis.

The predicted horizontal strain contours for the ground surface at study site A-1 are shown on Figure 8. The study site boundaries and longwall mine panel boundaries are also shown on the figure. Tensile strains were found to be relatively high in the areas between adjacent longwall panels and were influenced by the overburden thickness. The highest tensile strains were calculated at valley and/or stream crossings, where the overburden thickness was lowest. Maximum tensile strains corresponded to locations near the valley bottoms and along Enlow Fork. Areas with tensile strains in excess of the range estimated to produce damage to forests (5 to 10 x 10^{-3} ft/ft) were noted for detailed review of the remote sensing and for ground truthing observations.

Compressive strains were generally found to be greatest along the longitudinal centerline of longwall panels. A transition zone, where the horizontal strains were relatively small or close to zero, occurred near the edges of panels. However, at study site A-1, the panel width was sufficiently wide relative to the depth of mining that the maximum compressive strains were observed just inside the panel boundaries and the strain near the panel centerline was only slightly negative (compressive). This result is consistent with panel width to mining depth ratios greater than 1.4[16].

The predicted surface subsidence contours at study site A-1 are shown on Figure 9. The study site boundaries and longwall mine panel boundaries are also shown on the figure. The greatest subsidence was predicted to occur at the longitudinal centerline of longwall panels. The predicted subsidence gradually decreased in the direction of the edges and gates of the panel. Maximum subsidence settlements were predicted at valley and/or stream crossings where the overburden thickness was lowest. These locations were noted for detailed review of the remote sensing and for ground observations.

The surface deformation characteristics for the other undermined study sites were analyzed in similar fashion. Predicted magnitudes and locations of relative highs in horizontal strains and subsidence settlement were functions of the geometrical and geological properties of each study site. The surface horizontal strain and subsidence contours for study sites A-2, B-1, B-2, D-1 and D-2 are shown on Figures 10 through 19, as follows:

STUDY SITE	STRAIN	SUBSIDENCE
A-2	Figure 10	Figure 11
B-1	Figure 12	Figure 13
B-2	Figure 14	Figure 15
D-1	Figure 16	Figure 17
D-2	Figure 18	Figure 19

The calculated maximum surface horizontal strains and subsidence settlements for each study site are summarized in Table 5.