Mapping Mountaintop Removal Mining in Appalachia Using Satellite Imagery and Aerial Photography

Data and Methodology

SkyTruth, in partnership with Appalachian Voices, conducted a project to document the impact of Mountaintop Removal Mining (MTR) for coal over a 59-county area in Kentucky, West Virginia, Tennessee and Virginia. The primary goal of the project was to map and measure the total land surface impact of MTR and other surface coal mining over a 30-year period (1976 to 2006). The size and time span of the study area, a desire to minimize the subjectivity of manual photointerpretation, and the need to generate reproducible results lead us to choose semi-automated analysis of satellite imagery as the most cost-effective approach. Aerial survey photographs were used to validate accuracy during the analysis.

Data

The primary image data for the study consist of images acquired by the Thematic Mapper (TM) and Multispectral Scanner (MSS) sensors carried by the US government-operated Landsat series of earth-imaging satellites. Six Landsat frames were required to cover the study area. We evaluated the archive of Landsat imagery to identify a set of optimal scenes meeting these criteria:

- Cloud-free
- Minimal fog, smog or haze
- Acquired during leaf-on conditions (late May – early October) to maximize the contrast between active mining operations and undisturbed land
- Acquired at or near the midpoint of each decade to provide equal time intervals allowing decade-by-decade comparison

A total of 24 images were purchased through West Virginia View, a non-profit organization promoting the use and dissemination of satellite imagery (Table 1).

Table 1 - Landsat satellite images used in this study

Landsat 5 (TM)							
p19r35	p19r34	p19r33		p18r34	p18r33		p17r33
7/3/2006	7/3/2006	7/3/2006		9/11/2005	9/11/2005		5/31/2005
9/7/1995	9/7/1995	9/7/1995		8/31/1995	8/31/1995		10/11/1995
9/8/1984	9/8/1984	9/8/1984		9/17/1984	9/17/1984		7/8/1984
Landsats 1-2 (MSS)							
p21r35		p20r35	p20r34	p20r33		p19r34	p19r33
8/20/1976		8/19/1976	8/19/1976	9/6/1976		6/7/1976	5/20/1976

Image pre-processing included the creation of path-oriented mosaics, followed by co-registration of the mosaics to a common map projection (Universal Transverse Mercator, WGS84 datum). The georectified mosaics were cropped to the 59 county area of interest to reduce processing time.

Digital topographic (elevation) data were also needed for the identification of ridges and mountaintops. We opted to use the 3-arc-second (1x1 minute) DEM data compiled by the U.S. Defense Mapping Agency. These data were distributed as a series of 1x1 degree areas that correspond to the east or west half of the relevant USGS 1:250,000 scale topographic quadrangle map. We used this elevation dataset because it was mostly compiled from maps that pre-dated 1976, providing key information about the pre-mining topography. The horizontal accuracy in these older elevation data is generally given as 100m, comparable to the georegistration accuracy of the Landsat images. Given that a typical mountaintop removal mine spans an area exceeding 500,000m^2, the horizontal positional accuracy of the DEM was deemed adequate.

Other supporting digital GIS data we acquired from various government agencies include roads and populated areas, derived from USGS 1:24,000-scale topographic maps. The river and stream vectors that make up the study area's hydrology were compiled from the 1:24,000-scale National Hydrography dataset.

Methodology

MTR areas were identified and delineated through a multi-stage procedure. The first stage was to conduct a basic land cover classification for each decade. Classification was a two-step process: the pixel-based spectral signatures of various land cover types were identified; then the mined areas were classified as either MTR or "other surface mines" based on a decision-tree analysis. We were only interested in capturing the total land surface impacted by mining, so we made no effort to discriminate mine cuts and valley fills.

The pixel-based classification was performed using a supervised maximum likehood classification algorithm. Given the rugged terrain of the region, the image data were first spectrally processed to reduce the albedo-related effect of illumination using the hyperspherical direction cosine method (Pouch and Campagna, 1990). Training

samples were then compiled for each path-oriented image mosaic to characterize Anderson Level II-style classes such as bare rock, soil, forest, grasses/crops, water, etc. The results of this basic classification were then modified by classifying as active mining any bare rock and soil outside of a 400m buffer zone around major rivers, highways and agricultural areas. This separates areas disturbed by active mining from other areas that may be naturally devoid of vegetation during the growing season, such as river banks and channel deposits, plowed fields, and road surfaces.

The next step was to classify these potential mine areas as "MTR" and "Other Surface Mining." While the legal definition of MTR, as put forth by the U.S. Office of Surface Mining, is too vague to implement directly into a GIS model, it did guide the development of a reproducible, rules-based method to classify the mines. We used the concept that the mining had to cross ridges or mountain peaks, and had to impact a significant area of the ridge or peak.

We used digital elevation data to calculate terrain parameters that characterize ridges, slopes and valleys. A ridge is defined as a point that lies on a local convexity that is orthogonal to a line with no convexity/concavity. After ridges and peaks were delineated those covering less than 40 acres were eliminated from consideration.

MTR areas were identified by calculating the percentage of ridge top that comprised the mine's total area. MTR included mines over 320 acres in size that impacted at least 40 acres of ridge top, and mines between 40 and 320 acres that impacted at least 10 - 40 acres of ridge top. The results are shown in Table 2.

Table 2 - Mountaintop Removal Mines

Total MTR Mined Area since 1976	445,792 Acres
Largest Single Mined Area	10,410 Acres
Median Mined Area	128 Acres
Average Mined Area	406 Acres
Number of Ridges Mined	2,789
Total Acres of Impacted Ridges	130,655 Acres
Largest Ridge Removed	504 Acres

References

Pouch, GW, and Campagna, DJ, 1990, Hyperspherical direction cosine transformation for separation of spectral and illumination information in digital scanner data. Photogrammetric Engineering and Remote Sensing, 56, 475-479.