If you can see it, you can change it.

30 YEARS OF MOUNTAINTOP REMOVAL MINING:

ANALYSIS USING SATELLITE IMAGES AND DIGITAL TOPOGRAPHIC DATA

Context

SkyTruth used satellite image analysis to document the multi-decade impact of mountaintop removal mining (MTR) over a 59-county area spanning much of the Central Appalachian Coal Region[1] in Kentucky, West Virginia, Tennessee and Virginia (Figure 1). Other researchers have noted significant discrepancies between mine plans, as described in permit documents, and actual mining activity on the ground.[2] In addition, a measurable definition of what constitutes a "mountaintop removal" mine has been lacking. SkyTruth sought an independent and cost-effective method for identifying, mapping, and quantifying landscapes disrupted and altered by MTR that relied on physical characterization of the mine site. Satellite imagery was chosen as the primary land-cover data source for this task, given the relatively low cost per unit area of purchasing, processing and analysis, and the availability of satellite imagery from the early 1970s to present day. A multi-decade analysis was performed to assist in discrimination of surface disturbance associated with MTR versus conventional surface strip-mining operations, and maximize the detection of former mining areas where reclamation and revegetation had been conducted or was in progress.

Data Selection

The primary image data for the study consist of digital multispectral images collected by the Multispectral Scanner (MSS) and Thematic Mapper (TM) sensors carried by the Landsat series of remote-sensing satellites. Historical images in the Landsat archive[3] were reviewed for cloud cover, smog and haze. Mid-summer images were favored to facilitate the identification of disturbed areas and minimize seasonal variations in solar illumination. To ensure detection of mining disturbance since the 1970s while minimizing the total volume of data for analysis, mid-decade imagery was preferred. The

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[1] http://www.eia.doe.gov/cneaf/coal/page/nymex/centralappl.html

[2] Shank, M., 2004. Development of a Mining Fill Inventory from Multi-date Elevation Data. Presented at Advanced Integration of Geospatial Technologies in Mining and Reclamation Conference, December 7-9, 2004, Atlanta.

[3] http://glcf.umiacs.umd.edu/data/landsat/

final dataset of 24 satellite images (Table 1) was acquired through West Virginia View, a non-profit organization for the dissemination of satellite imagery[4].

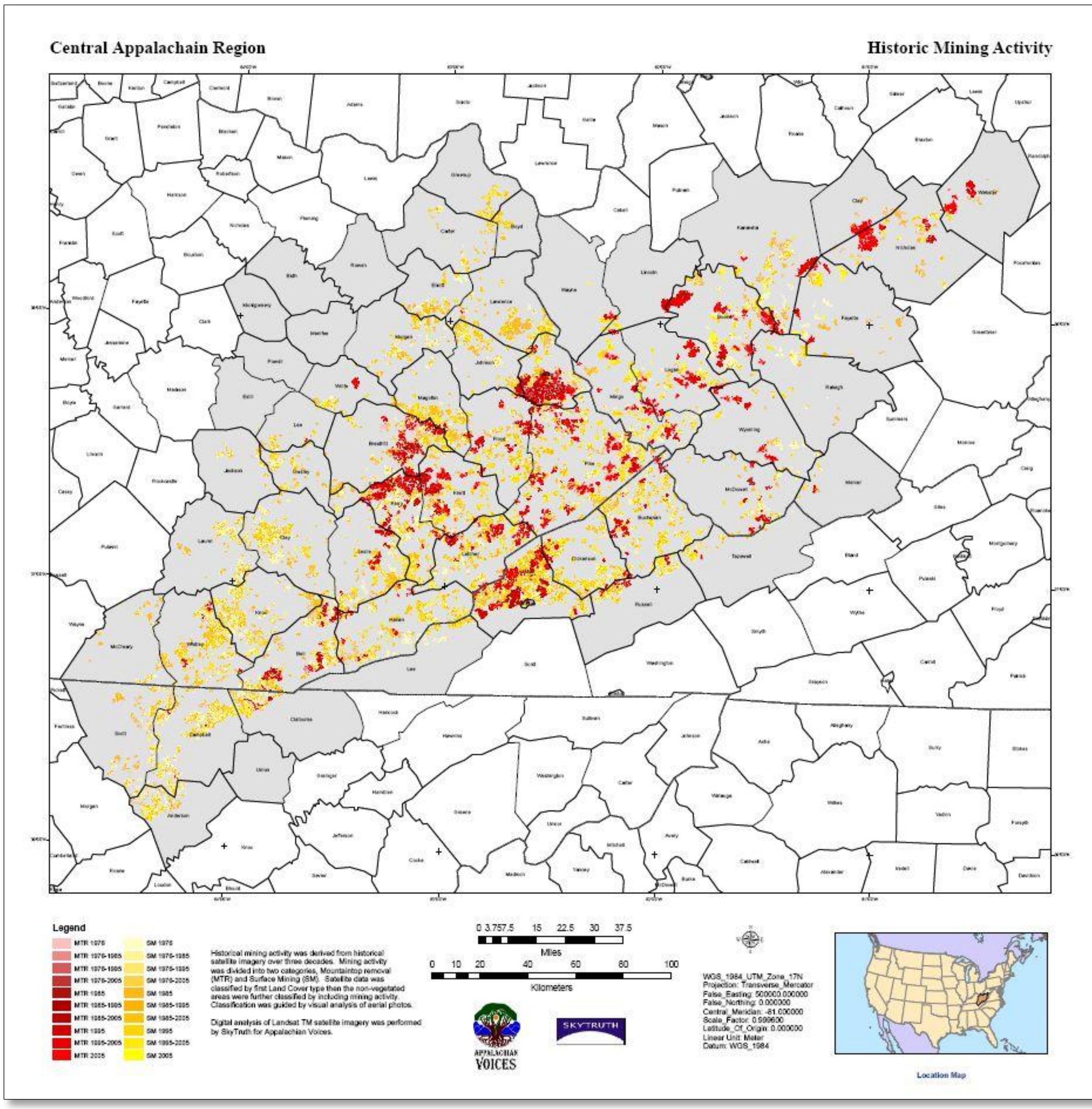

Figure 1. SkyTruth analysis of surface mining disturbance spanning 59-county study area in West Virginia, Kentucky, Tennessee and Virginia.

[4] http://www.wvview.org/

Table 1. Satellite image data used for this study (*p* and *r* refer to path/row location)

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

Digital elevation data were also acquired for topographic analysis, enabling the identification of ridges and mountaintops throughout the study area as a means of discriminating MTR operations from other types of surface mining. We opted to use 3-arc-second (1x1 minute) DEM data compiled by the U.S. Defense Mapping Agency. This series was distributed as 1x1 degree areas that corresponding to the east or west half of the USGS 1:250,000 scale topographic quadrangle map series (DTED® Level 0)[5]. These elevation data are from topographic surveys that mostly pre-date 1976 and therefore provide the best available representation of topography in the study area prior to the advent of mountaintop removal mining. The horizontal position error of this elevation dataset is generally stated to be 100 meters or less[6].

Other supporting digital GIS data acquired from various government sources included detailed transportation features and populated areas derived from USGS 1:24,000-scale topographic maps[7]. The river and stream vectors that comprise regional hydrology were compiled from the 1:24,000-scale National Hydrography dataset[8].

Image Processing

Image processing and analysis was performed by SkyTruth using Erdas IMAGINE© image processing and GIS software on a standard Windows-based workstation. All images were placed into a common map projection (UTM Zone 17 North – WGS84 datum) using standard techniques that included the selection of image-to-map tie points by an experienced operator, and digital resampling of the images using a nearest-neighbor algorithm to preserve the original spectral information. Additional processing included the creation of same-date, path-oriented mosaics to simplify the

[5] https://www1.nga.mil/ProductsServices/TopographicalTerrestrial/DigitalTerrainElevationData/Pages/default.aspx
[6] *Ibid*.
[7] http://edcsns17.cr.usgs.gov/NewEarthExplorer/
[8] http://nhd.usgs.gov/data.html

classification process. The georectified mosaics were then cropped to the study area boundary to reduce computer processing time.

Mining Disturbance Analysis

An iterative, two-stage process was developed to identify and delineate areas disturbed by MTR.

1) Land cover classification was performed for each date of imagery. Classification followed a two-step process: pixel-based spectral signatures of various land-cover types were identified; then a decision-tree analysis was used to classify areas of active surface mining.

Pixel-based classification was performed using the supervised maximum likelihood technique[9]. Given the rugged terrain of the region, the image data were first spectrally enhanced to reduce albedo-related variations in illumination and spectral characteristics using the hyperspherical direction cosine (HSDC) method[10]. Training samples were selected for each date of imagery to yield land-cover classes compatible with the Anderson Level II system[11], such as bare rock, soil, forest, grasses/crops, water, clouds, etc. The results of this procedure were then modified by classifying any bare rock and soil outside of a 400 meter buffer zone around rivers, highways and agricultural areas. This separates areas of bare soil and rock likely attributable to active mining from areas naturally devoid of vegetation, such as river banks and channels, paved surfaces, and plowed or fallow fields.

2) Topographic analysis was performed to subdivide the classified mining areas as “MTR” and “Other Surface Mining.” While the legal definition of MTR as defined by the U.S. Office of Surface Mining[12] is too vague to implement directly into a GIS model, their definition did guide the development of a reproducible, rule-based method by SkyTruth for identifying MTR areas. We started from the perspective that, to qualify as MTR, an individual mining operation had to 1) cross a ridge top or peak, and 2) impact an area significantly larger than a typical conventional strip mine (Figure 2).

Using digital elevation data from the U.S. Geological Survey’s 1x1 degree series, the terrain parameters that characterize ridge tops and peaks, slopes and valleys were calculated. We defined a ridge top or peak as a point that lies on a local convexity that is orthogonal to a line with no convexity or concavity. After ridge tops and peaks were identified and delineated from the

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[9] http://rst.gsfc.nasa.gov/Sect1/Sect1_19.html

[10] 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.

[11] http://landcover.usgs.gov/pdf/anderson.pdf

[12] http://frwebgate.access.gpo.gov/cgi-bin/usc.cgi?ACTION=BROWSE&TITLE=30USCC25

elevation dataset using these criteria, contiguous surface-mined areas encompassing fewer than 40 acres were eliminated to minimize noise in the analysis.

Figure 2. Oblique aerial photograph of large MTR operation near Kayford, West Virginia. Photo courtesy Vivian Stockman/OVEC.

MTR operations were identified in the mining land-cover class by calculating the percentage of ridge top that comprised the mine's total area. We produced two categories of MTR mines: contiguous mining areas spanning more than 320 acres and containing more than 12% (40 acres) ridge top, and contiguous mining areas between 40 and 320 acres that contain at least 25% ridge top in the mined area. This categorization is based on our assumptions that 1) mines larger than 320 acres in size are mature operations, and any significant ridge destruction must be an integral part of the mine plan; and 2) small or incipient MTR mines may be more easily confused with conventional strip mines, so a higher percentage threshold of ridge destruction is required to confidently categorize them as MTR mines. The results are shown in Table 2.

Table 2. Mountaintop Removal Mines – Summary Statistics

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

Digital boundaries delineating the MTR areas, and the other surface mining areas identified by this analysis, were exported in GIS-compatible shapefile format for use by other researchers.