Assessing the Extent of Mountaintop Removal in Appalachia: an Analysis Using Vector Data

Report Submitted to Appalachian Voices, Boone, NC
by Ross Geredien[t], GIS Consultant

Introduction

It is well known that mountaintop removal mining (MTR) in Appalachia has been occurring at accelerated rates over the last two decades. Yet quantifying the total acreage of and accurately mapping surface mining in the region has proved challenging. Until 2006, virtually all estimates of MTR and surface mining area and extent had been made using existing permit data. Many of these data are misleading, incomplete, and in some cases, erroneous and fail to present an accurate while comprehensive, spatially explicit picture of Appalachian surface mining. In some states, such as Kentucky, permit data consist only of attributed point features located at the beginning of haul roads (Kentucky Division of Mine Permits, 2009). Even when polygonal GIS permit data are available and relatively complete, for many reasons they do not always accurately represent areas of mining (WVDEP, 2009).

Previous studies by Appalachian Voices in 2006 and 2007 and Skytruth in 2007 resulted in total surface mining figures ranging from 764,000-793,000 acres. Skytruth's study used remote sensing, relying exclusively on satellite imagery (Campagna, 2007). The Appalachian Voices study used a combination of satellite imagery and medium to high-resolution aerial imagery to digitize mine polygons (Appalachian Voices, 2006). Quality assessment of these studies revealed that both missed a significant proportion of mining, the former most likely due to the inability of remote sensing to detect many reclaimed mine lands, and the latter due to a combination of factors including old, out-dated imagery, inadequate digitizing scale, and human error.

These studies have done much to illuminate the extent of MTR in Appalachia, however. For example, the polygon data from the 2006 Appalachian Voices study have been featured in Google Earth™ and have been used widely in informational materials. However, the data do not seem to be robust enough for rigorous scientific analysis, as revealed by an ecological study of MTR impacts to rare, threatened, and endangered species (Geredien, 2008).

The recent availability of new, up-to-date, high-resolution imagery from the National Aerial Imagery Program (NAIP) has led Appalachian Voices to revisit these studies with increased scrutiny. These new datasets, particularly for Tennessee and Virginia, have created the opportunity for a much-needed quantitative accuracy assessment of these datasets and potentially for the development of a new, highly accurate map of MTR surface mining. Could a quantitative approach through intensive sampling be taken to assess mine polygon accuracy? Could these samples be extrapolated to arrive at a more accurate total surface mining acreage estimate? And is it possible to develop a highly accurate polygon dataset of surface mining? It is these questions that this assessment attempts to answer.

[t] Current contact: 1617 Hilltop Rd., Edgewater, MD 21037; goodmigrations@yahoo.com

METHODS

Data Used

As mentioned previously, the availability of high resolution NAIP imagery was the primary factor that led to this study, which otherwise would have required extensive flyovers or ground-truthing, both of which are extremely costly and/or impracticable. The four NAIP imagery datasets used were:

West Virginia - 2007 NAIP natural color, 1-meter resolution

Tennessee - 2006 NAIP natural color, 1-meter resolution

Virginia - 2008 NAIP natural color and Color IR, 1-meter resolution

Kentucky - 2006 NAIP natural color, 2-foot resolution

The above datasets were used as the primary digitizing bases for the vast majority of surface mine features. In addition, USGS digital topographic maps were used to identify older mine activity, including some reclaimed mines where the visual scars on the landscape were otherwise very difficult to detect. The digital topos served to supplement the aerial imagery as a digitizing base in these cases. All data were georeferenced and reprojected in UTM NAD83 Zone 17N.

Study Area and Sample Selection

The MTR Study area was defined by two polygonal regions which encompassed the vast majority of known coal surface mine polygon features from the previous studies. The study area measures 10,155,352 acres in total and extends from central WV southward through eastern KY, southwestern VA, and into the Cumberland Plateau of Tennessee.

A vector dataset of hexagonal “grid” cells, each 5km in diameter, covering the entire study area was generated using an Avenue script in ArcView 3.3 software. A total of 2162 cells were generated as part of this hexagonal grid index. 1,654 hex grid cells are contained completely within the study area. Using a random numerical function, 60 hex grid cells were randomly selected from this subset as sample plots for high-accuracy digitizing. Each grid cell measured approximately 5,350 acres in area, totaling 320,998 acres, or 3.16% of the total project area. See **Figure 1** for a map of the study area and sample plots.

ESRI ArcGIS 9.3 Desktop software was used to digitize the mine sample. Digitizing methodology remained consistent throughout the process. A scale of 1:5,000 or larger was adhered to for the vast majority of mine polygons. In some cases, it was necessary to use very fine (large)-scale digitizing to 1:1,500, but this was relatively infrequent.

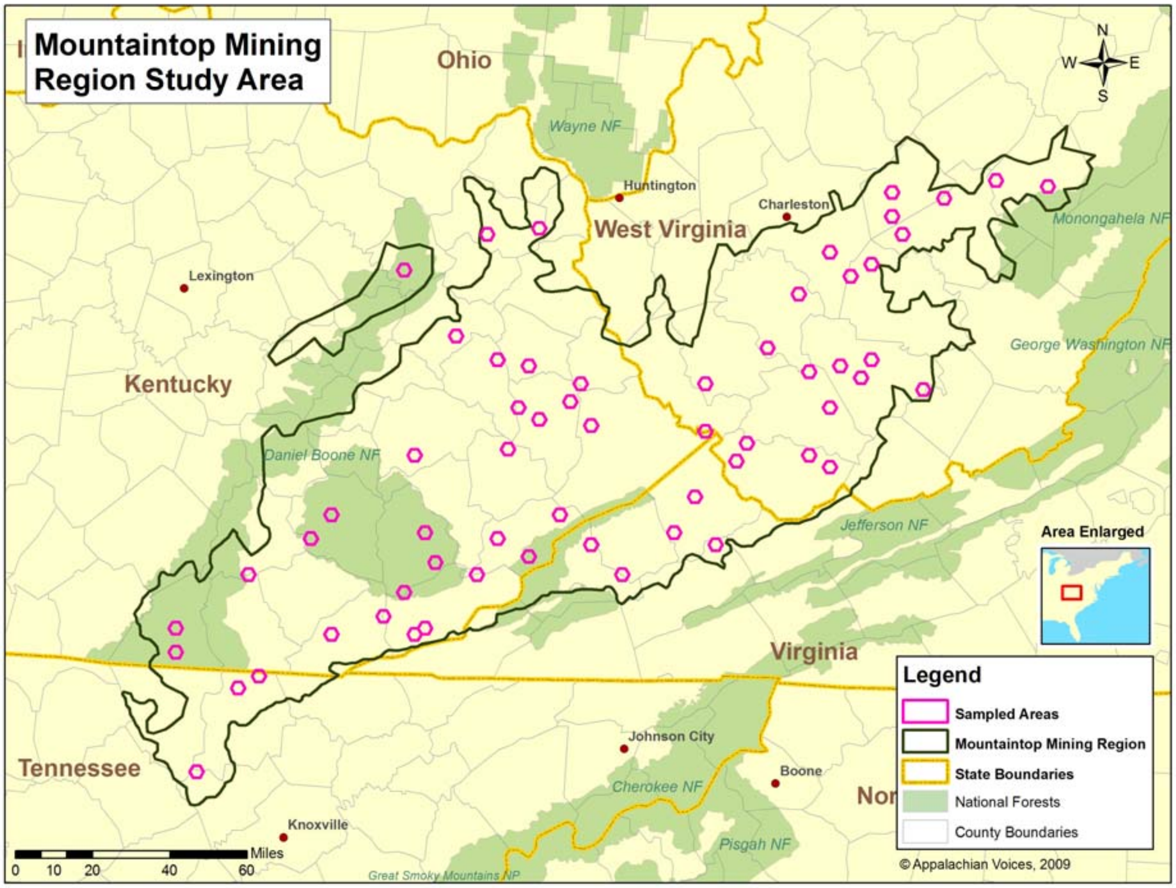


Figure 1. Map diagram of the Mountaintop Mining Region Study Area and Sample Plots

Decision rules were established to determine which areas should be included within mine polygons. The minimum mapping unit was set to 10 meters. Using the minimum mapping unit, a feature was required to be at least 10 meters long/wide on at least one axis. For example, mine roads that were less than 10 meters in width were not digitized, but those that were at least 10 meters wide were in included within existing features or as independent features. Likewise isolated patches of surface mining activity generally had to be at least 10 meters in diameter in order to be mapped. Similarly a feature needed to be separated by at least 10 meters of in-tact forest vegetation in order to be considered distinct. However, if vegetation was determined to be new, post-mining growth or reclaimed vegetation, such features were "lumped" and included as part of the mine feature. "Islands" of native, in-tact patches of forest were assumed to be un-mined and were excluded from mine polygons using the same mapping unit standards outlined above. The "Cut polygon" tool was used to exclude these features. Polygon edge tolerance was set at 5-10 meters. Whenever possible, digital polygon boundaries were to remain within 5 meters of "hard" surface mine feature edges (see **Figure 2**). Where edges were "soft", or less distinct due to vegetation gradients, 10-meter edge tolerance was adhered to. These rules were developed based on the previous Appalachian Voices studies and were expected to result in at least 95% accuracy for spatially explicit mapping of surface mines (Appalachian Voices, 2006).

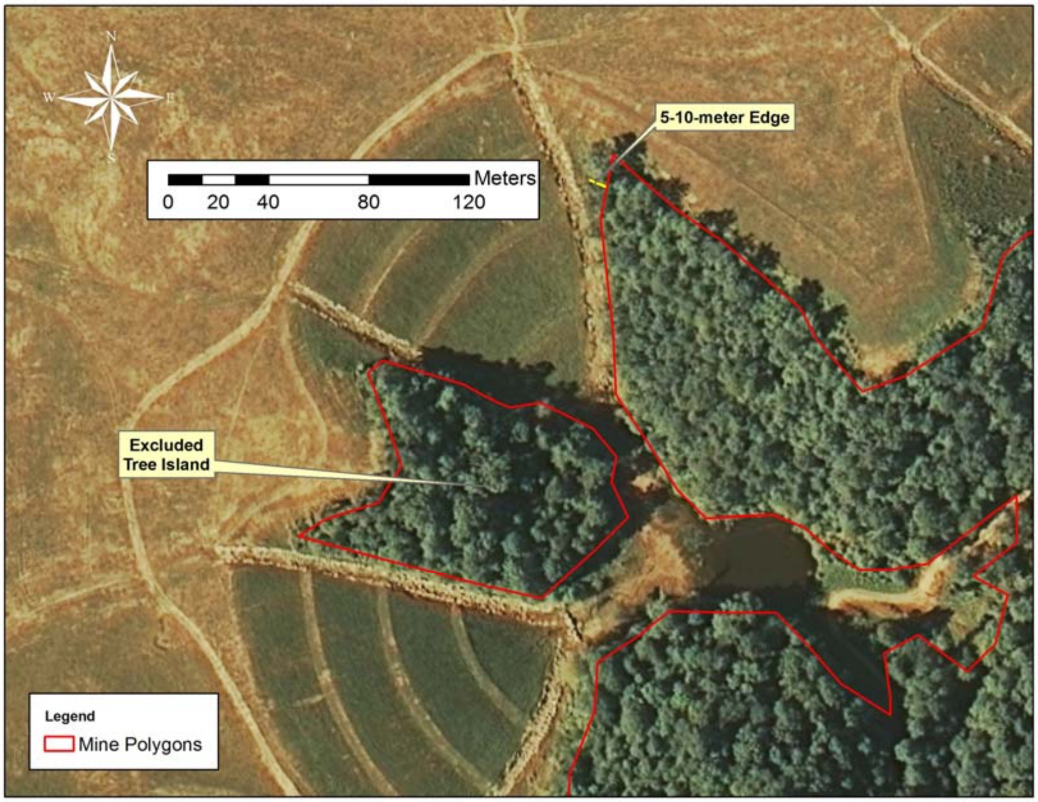


Figure 2. Map of a surface mine in Martin County, KY illustrating digitizing rules for edge tolerance and tree "island" separation distance.

Once digitized, a set of attributes was assigned to each polygon, including county, state, feature type/description, reclaimed use if relevant, and a classification code. Mine features were identified as accurately as possible as to the type of surface mine that they represented. True MTR polygons were identified as such if they contained a pre-identified mountain summit or ridgeline where mining had removed 100 feet or more of overburden. Other surface mine types included highwall, generic strip mine, contour mine, and various types of reclaimed surface mines. Slurry impoundments and processing facilities were also uniquely identified whenever they stood apart from other polygonal features but were often incorporated into larger MTR and strip mine "complexes" that encompassed features of multiple types over vast areas. Valley fills were also not uniquely identified and were included within larger mine complexes. However, these features can and should be extracted at a later date for future analyses.

Once all mine features were completely digitized inside all 60 sample plots, features were then clipped to the sample plot boundary edges and areas were calculated for all clipped polygons. This clipped layer provided the final baseline sample to which all others were compared. Next mine polygons from each of three pre-existing datasets were similarly clipped to compare samples of equal area: 1) the 2006 Appalachian Voices study polygons (hereinafter "2006 Mines"); 2) a similar 2007 dataset from Appalachian Voices (hereinafter "2007 Mines"), which included additional areas digitized in West Virginia by a GIS technician; and 3) the derived polygons from the Skytruth remote sensing time series (hereinafter “Skytruth Mine Sample”). The latter time series data, which consisted of four separate polygon datasets (one each from 1976, 1985, 1995, and 2005) were merged and dissolved prior to clipping in order to eliminate overlapping, polygons. This is because a large number of overlapping polygons, or vectorized “pixels”, were shared across the time series, as some areas continued to experience surface mining for periods greater than 10 years. Merging these datasets also reduced processing demands due to the very large size of the datasets (over 100,000 polygons each).

For each of the four samples, polygonal areas were summed to derive a total area of mine polygons within the sample plots. These steps were then repeated for a subset of mine polygons from each dataset that were classified as true MTR mines. Basic proportionality was then used to extrapolate the differences between the 2009 sample area and the areas of the other three samples to arrive at estimated total surface mining acreage for the entire region. These three estimates were given +/- 10% range values, a margin of “error” that was deemed reasonable after extrapolating the sample proportions to the entire region given the high level of digitizing accuracy. It is important here to differentiate between this value range and a true confidence interval (C.I.), which is more appropriate for statistical analysis across a large number of samples.

Total area, however, is only one measure of accuracy and does not give a complete picture. For example, two polygons can be very close in total acreage but can cover totally different locations on the ground. For this reason, errors of “omission” and “commission” were analyzed. To calculate these errors, it was assumed that the 2009 sample has an accuracy of 95% or better. This is not an unreasonable assumption for the following reasons: 1) every effort was made to digitize mine polygons to within 5-10 meters of the native vegetation edge; 2) the average size of mine polygons is over 200 acres and several hundred meters in length on at least one axis, with the largest polygons being over 5,000 acres in area; 3) the difference in area to most polygons that 5-10 meters of error makes is less than 5%. For example, a 200-acre circular polygon whose radius is increased by 10 meters experiences only a 1.2% increase in total area, a difference of about 2.4 acres; and finally, 4) it is also assumed that digitizing errors will average out over large areas where in some instances boundaries were digitized on the forested side of the line while in other instances boundaries may have drifted a few meters onto the mining side of the line. **Figure 3** shows a visual comparison of the difference in precision between the new 2009 Sample and the 2006 Mines dataset.

Errors of commission and omission were calculated by performing a series of clip operations to identify areas of intersection and areas that were not shared among the different datasets. First, the 2009 sample was used to clip each of the other samples to calculate the areas of intersection. The areas of intersection were then subtracted from the total area of each respective sample. This difference was assumed to be equal to the area of total “error of commission”, or areas that were erroneously digitized in the previous samples.

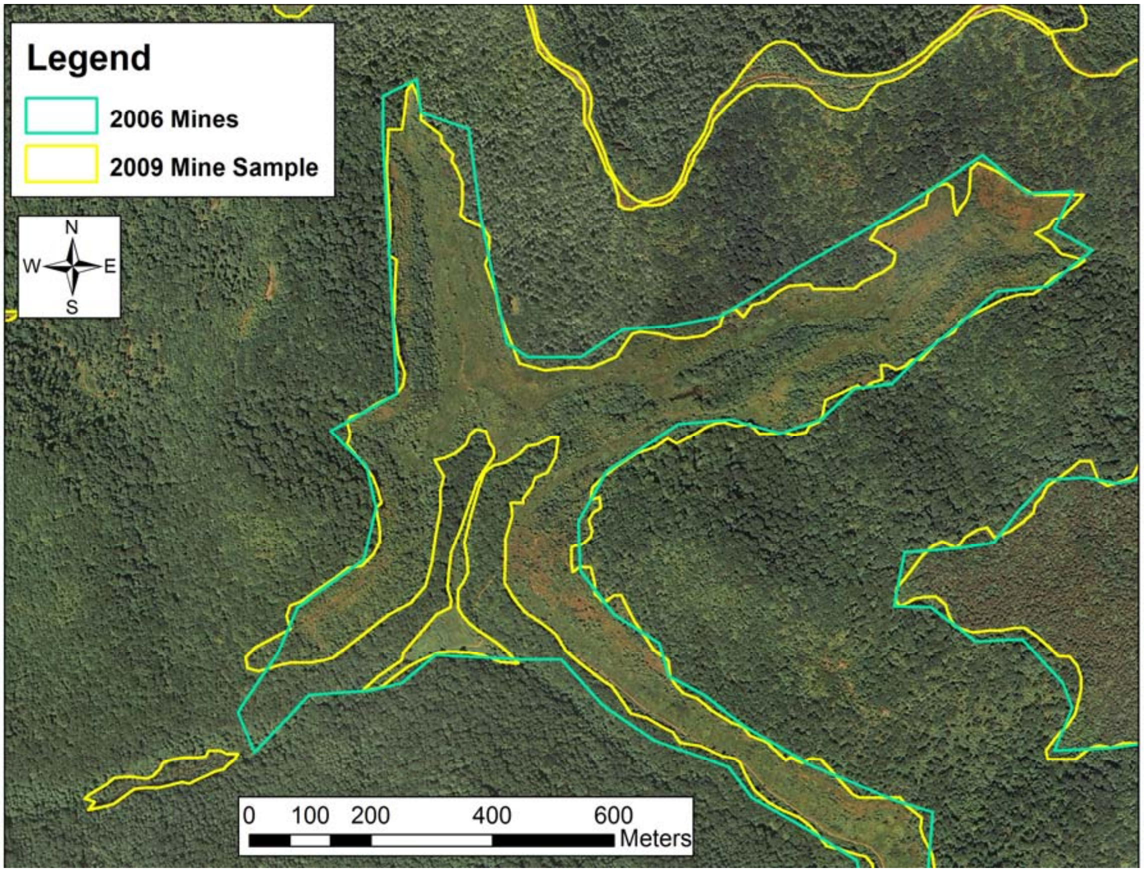


Figure 3. Map showing the difference in precision levels between the 2009 and 2006 digitized mine samples. Note the wide berth the 2006 data (aqua) gives to the sediment pond above the scale bar, whereas the 2009 sample excludes forested areas.

Errors of omission were defined as areas that were not digitized in previous samples that upon closer inspection should have been digitized. Errors of omission are somewhat more problematic to deal with because the average age of imagery used for the 2009 sample was at least 2-3 years more recent than the imagery used in the previous studies. Hence some of the mining that was “omitted” had simply not occurred at the time of the older studies. Without accurate measures of actual surface mining rates, it is not possible to determine what proportion of mining missed was due to the time lapse between imagery. For the sake of this study, mining that took place during the interval between the different imagery datasets was not quantified, but it is understood that a significant portion of recent mining may contribute to these results.

To calculate the total area of omission, the previous study samples were used to clip the new 2009 sample. The difference in area between these clipped 2009 polygons and the total 2009 polygonal area was assumed to be the area omitted in each of the previous study samples. Proportionality analysis was then used to calculate % error for both Type I and Type II errors.

RESULTS

Total Surface Mining Area

Total area results were very precise between the 2006 Mines from Appalachian Voices and the Skytruth Mine Sample. Both fell short of total 2009 Sample area by approximately one-third: the 2009 Mine Sample contained 33.89% more mining area than the Skytruth Sample and 32.62% more than the 2006 Sample. The 2007 Mines dataset was by far the closest in total area, falling only 16.36% short of the total 2009 Sample area. See **Appendix A** for a summary of the sample area results for all datasets.

Extrapolated surface mining area for the entire MTR region varied from a low of 1,135,494.41 acres using the 2006 Mines data to a high of 1,199,695.71 acres using the Skytruth Data. The mean surface mining area for the entire region was 1,163,929.66 acres, with a +/- 10% value range of 1,047,275.11 - 1,280,002.91 acres. **Table 1** below lists a summary of the extrapolated area results:

Sample	Total Measured Area	Extrapolated Area	90% Value	110% Value
2006 Mines	765,086.60	1,135,494.41	1,021,156.36	1,248,079.99
2007 Mines	967,423.60	1,156,598.86	1,040,938.97	1,272,258.74
Skytruth	793,161.44	1,199,695.71	1,079,729.99	1,319,669.99
AVERAGE	**841,890.55**	1,163,929.66	**1,047,275.11**	**1,280,002.91**

Table 1. Summary of extrapolated area results with 90-110% Value ranges for each sample. All figures are in acres.

State by State Breakdowns

Figures for each state were also derived. Because the 2007 Mines layer only included additional data for West Virginia, only the 2006 Mines and Skytruth Data layers were used for this analysis. Sample subsets from each state were used to extrapolate the area of each state individually. The assumption behind this method was that these sample subsets would accurately reflect the variation among the states and should be taken into account when extrapolating. For example, both Tennessee and West Virginia's data from 20006 and Skytruth measured much lower in area (< 50%) within the sample plots compared to data from Virginia and Kentucky (approximately 75% or better for each sample). This is most likely due to the different nuances in imagery used, mine age, and prevalent mine types. A range +/- 10% range value was then calculated for each state. Results are in **Table 2** below.

State	2006 Mines	Skytruth	Mean	90% Value	110% Value
Kentucky	552,979.87	595,434.29	574,207.08	516,786.37	631,627.79
Virginia	158,100.86	153,835.13	155,967.99	140,371.19	171,564.79
West Virginia	346,540.29	357,469.25	352,004.77	316,804.29	387,205.25
Tennessee	69,214.94	87,152.87	78,183.91	70,365.51	86,002.30
TOTAL	**1,135,494.41**	**1,199,695.71**	**1,167,595.06**	1,044,327.38	1,276,400.13

Table 2. Statewide calculated surface mining areas. All areas are in acres. Prop. = proportion.

MTR Area

Total MTR mining acreage of the 2006 Mines and Skytruth Samples was also compared to the 2009 sample*. Here the Skytruth data compared very well to the 2009 Sample data, with only 9.76% less total acreage in the sample area classified as MTR. The 2006 Mines layer had 39.9% less MTR acreage in the sample area than the 2009 Sample. These results extrapolated to a range of 494,281.9 – 586,825.5 acres of actual mountaintop removal. See **Appendix A** for all results related to MTR mine classification.

Assessing Total Accuracy (Type I and Type II Error Calculation)

The 2007 Mines layer had the greatest area of intersection with the 2009 sample with 21,884.8 out of 33,659 acres, or 65.02%. Interestingly, this dataset also had the highest incidence of Type I errors or errors of "commission" at 18.62%. These errors represent areas that were erroneously digitized or classified as mining, i.e. mine polygons that really do not contain mining activity. The dataset with the least amount of Type I error was the 2006 Mines layer, with 11.89%. Skytruth had slightly more Type I error with 12.39%.

All of the datasets compared relatively poorly when it came to Type II errors. These errors represent areas that were not classified as mining but should have been. Skytruth had the highest Type II error with 46.28%. The 2006 Mines layer was only slightly better with 44.52% while the 2007 Mines had the lowest Type II Error at 34.98%. Rounding out the total accuracy results, both the Skytruth and 2006 Mines layers had comparatively low total accuracy (intersection) with 55.48% and 53.72% respectively. **Figure 4** above shows a good visual example of how Type I and Type II errors were determined. A summary of the accuracy analysis results is presented in **Table 3** below.

* The 2007 Sample was not compared for MTR mining because this sample did not include classification attribute data.

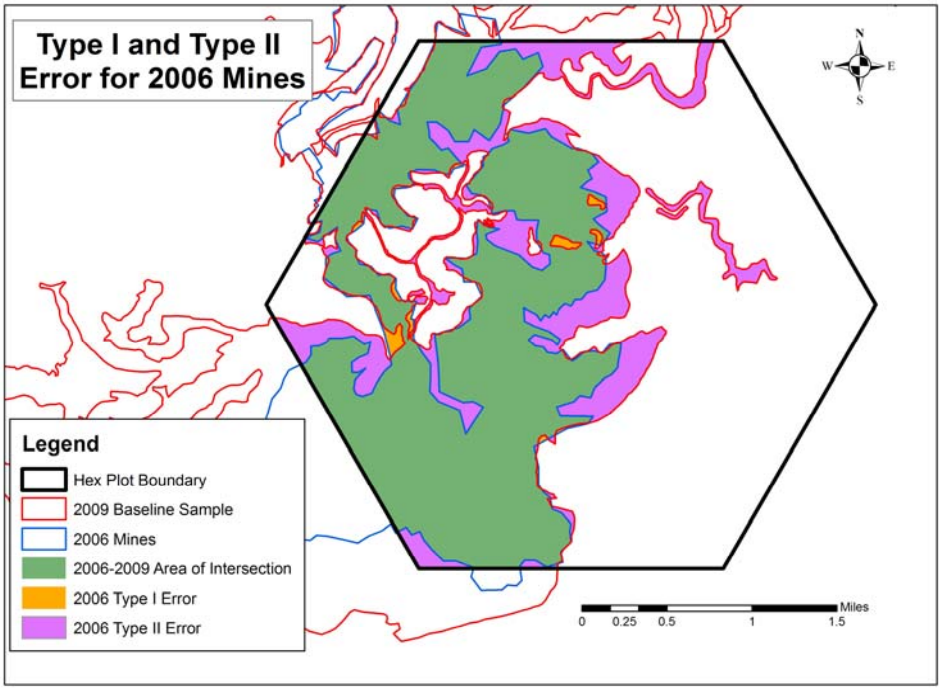


Figure 4. This map of a sample plot in Fayette County, WV graphically illustrates Type I and Type II errors for the 2006 Mines layer. Areas in green represent 2006 areas that are spatially correct. Orange and lavender represent Type I and Type II errors respectively.

Sample	Sample Area	Intersection	Type I Error	Type II Error	% Accuracy
2006 Mines	22,679.06	18,675.41	4,003.65 (11.89%)	14,983.48 (44.52%)	55.48%
2007 Mines	28,153.58	21,884.82	6,268.76 (18.62%)	11,774.06 (34.98%)	65.02%
Skytruth	22,253.11	18,081.00	4,172.11 (12.40%)	15,577.88 (46.28%)	53.72%
2009 Sample	33,658.88	N/A	N/A	N/A	N/A

Table 3. Summary of accuracy analysis results. All measurements are in acres and represent total area for each sample within the 60 Sample plots.

DISCUSSION AND CONCLUSIONS

High-resolution digitizing of surface mines at large scales can be a very effective method of accurately documenting surface mining activity. The amount of mining activity detected in the new 2009 sample using a 1:5000 or higher scale, was significantly greater than all of the other previous samples. This would indicate that this method is much more sensitive to subtle differences in land cover than both small scale digitizing and remote sensing.

The two primary studies in this analysis, the Skytruth Mines dataset and the 2006 Digitized mines, had very comparable rates of accuracy for both total surface mining area and total accuracy of mined areas. The 2007 Mines sample showed some marked differences from these two datasets, which can largely be explained by the way in which it was developed; this dataset is really a second iteration of the 2006 Mines dataset. In 2007, QA/QC of the 2006 Mines dataset indicated that many mined areas in West Virginia had not been digitized. Appalachian Voices hired a GIS technician to digitize these additional areas, many of which were reclaimed. Over 100% more area was digitized in the West Virginia portion of the MTR region during 2007 to supplement the original data. However, as this analysis shows, much of this area was erroneous in that not all of it included actual mining (Type I Error). Much of this error was due to the over-digitizing of mine roads and old, reclaimed highwall mine scars by including large buffers of in-tact forest within the mine features. If digitizing had continued with this level of Type I error throughout Kentucky, Virginia, and Tennessee, the 2007 Mines dataset potentially would have greatly over-estimated the actual amount of surface mining for the region.

It is important to note here that all digitized mine datasets detected much more reclaimed areas than Skytruth's remote sensing method. But for an overall estimate of mining, the remote sensing method is comparable to digitizing at a scale between 1:8,000 and 1:12,000, which is the approximate scale range at which most of the 2006 Mines dataset was created. These two different methods capture different areas on the ground, however. The actual area of intersection between the two datasets themselves for the entire MTR region is 582,941.66 acres, or approximately 75% of each dataset. This difference in shared areas on the earth is accounted for primarily by the methods' differential ability to detect reclaimed mine areas.

As mentioned earlier, it was believed prior to this analysis that the 2006 Mines layer omitted many areas, particularly in West Virginia. This suspicion was confirmed by the high rates of Type II error of this dataset at over 44%. Whereas Skytruth's Type II error was largely due to the failure of remote sensing to detect reclaimed mine areas, human error and lack of thoroughness in the beginning of the 2006 project was the primary factor leading to such high rates of error in 2006. This is further reinforced if just the West Virginia subset of the 2006 Mines Sample is compared to the 2009 Mines Sample; the WV data subset fell more than 53% short of the current version, a rate some 18% worse than for the entire region. Since digitizing in 2006 commenced in the West Virginia portion of the region, it is apparent that skill level probably plays a major role in digitizing accuracy. In addition, the four-year age difference in imagery between the imagery used (2003-2007) in the two samples probably played a significant role as well. A third factor was also the lack of consistent, rules-based digitizing methodology, which was not fully developed until this analysis.

It should also be noted that even though total surface mine area for the Skytruth Sample was lower than that for the 2006 Mines, the extrapolated area using the Skytruth data was greater than that for the 2006 Digitized Mines by about 65,000 acres. This has to do with the extensiveness of the area covered by remote sensing as opposed to levels of detection. On a per-unit area, slightly less mining was detected by Skytruth, but because Skytruth's analysis covered more area, total acreage was still higher. Here it should be noted that original total mine area figures for each dataset were used for the extrapolation. If another baseline standard were used, or if a mean area statistic were instead used for extrapolation, results most likely would have been different. But once again, the large areas in West Virginia that were omitted in 2006 probably account for this discrepancy.

Estimating state surface mining totals proved more challenging than suspected. This is because there are many ways to extrapolate these subsets of data. Another way of estimating these numbers would be to take the average proportion of each state's total mining area across all studies and to apply that same proportion to the total extrapolated area of 1,163,929.66 acres. This method is particularly tempting given that the proportions of each state's area of both the Skytruth and 2006 Mines datasets were remarkably precise. For example, the WV subset of the Skytruth data (actual, measured) was 23.79% of the total area; the same subset measured 21.05% of the total 2006 mines data. All four states were within only a few percentage points of each other, suggesting that relative proportions of mining are very consistent for each state, as long as the same methodology is used throughout the region. These percentages could be averaged, and then applied to the final extrapolated total to arrive at state by state totals. However, in the end, this method did not account for the much lower detection rates in Tennessee and West Virginia. Yuill (2001, in EPA, 2003) estimated that some 244,000 acres in West Virginia had been impacted as of 2001. My estimate of 352,000 acres is significantly greater than the Yuill's figure, yet using statewide proportion method outlined above the figure for West Virginia is more like 280,000 acres. The uncertainty surrounding statewide totals strongly demonstrate the need for more up-to-date, spatially explicit data. Similarly, watershed- and county-scale measures of surface mining will be impossible without a complete, accurate inventory of all surface mining features.

The accuracy assessment portion of this study illustrates how important it is to not only have an accurate figure for total mining area, but also to obtain an accurate spatial representation of mining activity. This becomes extremely important if any scientific geospatial analysis is to be conducted, particularly any that examines "direct hits" to features of interest. The 2007 Digitized Mines layer demonstrates this point dramatically. Even though the sample for this dataset resulted in total area only 16.36% less than that of the 2009 Sample, it's total accuracy was still only 65% (+/- 5%), and it exhibited the highest levels of Type I error of all three tested samples. If such errors of commission were to be included in geospatial analyses, this could undermine the credibility of the data used for such studies. Hence a spatially explicit surface mine dataset that is >/= 95% accurate is necessary in order to perform scientific analysis such as assessing impacts of mining to rare, threatened, and endangered species; determining the number of permanent and intermittent streams buried or otherwise impacted by surface mining; assessing watershed impacts; and determining what community facilities such as schools and residences are within close proximity to mining features. All other datasets can really only yield rough estimates at best of total surface mining activity and its impacts.

Permit data was not analyzed as part of this study, but it would be very interesting and quite straightforward to perform a similar analysis quantifying the spatial differences that exist between permit polygon data and high-precision mine polygon data. This could be especially revealing, since permit data has been so heavily cited for many years to document rates of mining activity and also to focus public and media attention on MTR mining trends.

With regard to determining annual surface mining rates, Skytruth's time series remote sensing analysis attempted to examine rates of mining over several decades. Much area of overlap exists among the four different datasets from each decade spanning 1976-2005. In order to quantify actual rates of change, a dissolve would need to be performed on each data layer prior to area calculation. However, because remote sensing tends to detect active mining much better than reclaimed mines**, this method may be quite effective in assessing average annual rates of change in active surface mining areas, but only for total active mining area. Another method that would be very effective but potentially more time-consuming would be to digitize sample areas using NAIP imagery datasets from different years. For example, in Kentucky, which comprises roughly half of the MTR region, NAIP datasets exist for both 2006 and 2004. As noted above, skill level and rule consistency can play large roles in digitizing accuracy, hence the need for clear, standardized rules for digitizing. If the same rules were applied using multi-year imagery datasets over a large-enough sample area, a highly accurate average annual rate of surface mining could be calculated. A sample area of at least 3-5% is recommended in the future for such time change analysis.

The time required to digitize surface mines to 95% accuracy is by far the greatest investment required by this method. Extrapolating the person-hours spent sampling the areas for this study, as many as 3,000 person-hours may be needed to digitize the entire MTR surface mining region to the same standards of accuracy. However, as mentioned above, this could be time wisely invested. As surface mining continues at unabashed rates throughout the region, there will be a great need for accurate spatial information to analyze its impacts. Future efforts to transition and restore the regional economy may also be highly dependent upon this type of spatial information as reclaimed mine lands are converted for other uses.

** Skytruth's method was designed in particular to detect active MTR as defined by the Office of Surface Mining (OSM) primarily using slope and overburden criteria (Campagna, 2007).

ACKNOWLEDGEMENTS

I would like to thank the staff members at West Virginia University's GIS Technical Center, the Kentucky Division of Geographic Information, Radford University's GIS Center, and the Tennessee Geographic Information Council. In particular, I'd especially like to thank Dan Widner at the Virginia Geographic Information Network for his assistance with image procurement.

REFERENCES

Appalachian Voices. 2006. Unpublished data produced in partnership with Ross Geredien.

Campagna, David. 2007. *Measuring Mountaintop Removal Mining in Appalachia*. Technical Report by Skytruth (http://blog.skytruth.org/2007/12/measuring-mountaintop-removal-mining.html).

Geredien, Ross. 2008. *Falling Through the Cracks: A Geospatial Analysis of Mountaintop Removal Coal Mining Impacts to Rare, Threatened, and Endangered Species in Appalachia.* Technical Report to Appalachian Voices, unpublished.

Kentucky Division of Mine Permits. 2009. Published GIS data for Permit Locations, http://www.minepermits.ky.gov/mapsspatialdata/spatial.htm.

West Virginia Department of Environmental Protection. 2009. *Draft West Virginia Mining Permit Boundary Data*. Geospatial metadata document.

Yuill, C. "*Land Use Assessment: Mountaintop Mining and the Mountaintop Mining Region of West Virginia*". Draft report. West Virginia University, 2001 in Environmental Protection Agency, 2003. *Draft Programmatic Environmental Impact Statement on Mountaintop Mining/Valley Fills in Appalachia*. P. III. F-12.

Appendix A

Complete Data and Results

Sample Areas

Layer	Acreage (S)	Ratio for Total Sample ($R = S/S_{2009}$)
2006 Surface Mines Sample	22,679.00	0.6738
2007 Surface Mines Sample	28,153.58	0.8364
2009 Digitized Mine Sample	33,658.88	1.0000
Skytruth Data	22,253.00	0.6611
Total 60 Hex Plot Area	320,998.02	N/A
Total AV MTR Region Area	10,155,352.16	N/A

Extrapolation Calculations

Sample	Total Actual Polygon Area (A)	Extrapolated Acreage ($A_E = A / R$)	90% Value $A_{0.90} = A_E * 0.90$	110% Value $A_{1.10} = A_E * 1.10$
2006 Mines	764,493.87	1,134,618.18	1,021,156.36	1,248,079.99
2007 Mines	967,423.60	1,156,598.86	1,040,938.97	1,272,258.74
Skytruth Data	793,161.44	1,199,699.99	1,079,729.99	1,319,669.99
MEAN	**841,692.97**	**1,163,639.01**	**1,047,275.11**	**1,280,002.91**

Mountaintop Removal (MTR) Calculations

Sample	Acreage A_{MTR}	MTR Ratio R_{MTR}	Extrapolated MTR Area A_{MTR} / R_{MTR}
Total Skytruth MTR area	446,039.75	N/A	494,281.91
Total 2006 Mines MTR area	352,564.77	N/A	586,825.52
2009 Sample MTR area	14,677.60	1.0000	
Skytruth Sample Only MTR	13,245.37	0.9024	N/A
2006 Sample Only MTR	8,818.35	0.6008	N/A

Type I Error

Sample	Sample Area A_S	2009 Sample Area A_{2009}	Area of Intersection A_{int}	Type I Error $E_I = A_S - A_{int}$	% Type I $(E_I / A_S)*100$
2007 Mines	28,153.58	33,658.88	21,884.82	6,268.76	77.73%
2006 Mines	22,679.06	33,658.88	18,675.41	4,003.65	82.35%
Skytruth Sample	22,253.11	33,658.88	18,081.00	4,172.11	81.25%

Type II Error

Sample	Sample Area	2009 Sample Area	Area of Intersection	Type II Error	% Type II
	A_S	A_{2009}	A_{int}	$E_{II} = A_{2009} - A_{int}$	$(E_{II} / A_{2009})*100$
2007 Mines	28,153.58	33,658.88	21,884.82	11,774.06	34.98
2006 Mines	22,679.06	33,658.88	18,675.41	14,983.47	44.52
Skytruth Sample	22,253.11	33,658.88	18,081.00	15,577.88	46.28

State by State Breakdowns

2006 Mines Summary

State	2009 Sample	2006 Sample	2006 Ratio	2006 Actual	2006 Extrapolated
	A	**B**	**R = B/A**	**T**	**E = T/R**
Kentucky	14,843.31	11,826.50	.7968	440,590.20	552,979.87
Virginia	5,659.80	4,781.85	.8449	133,576.16	158,100.86
West Virginia	11,838.69	5,502.89	.4648	161,079.80	346,540.29
Tennessee	1,317.08	567.83	.4311	29,840.44	69,214.94
TOTAL	**33,658.88**	**22,679.07**	**.6738**	**765,086.60**	**1,135,494.41**

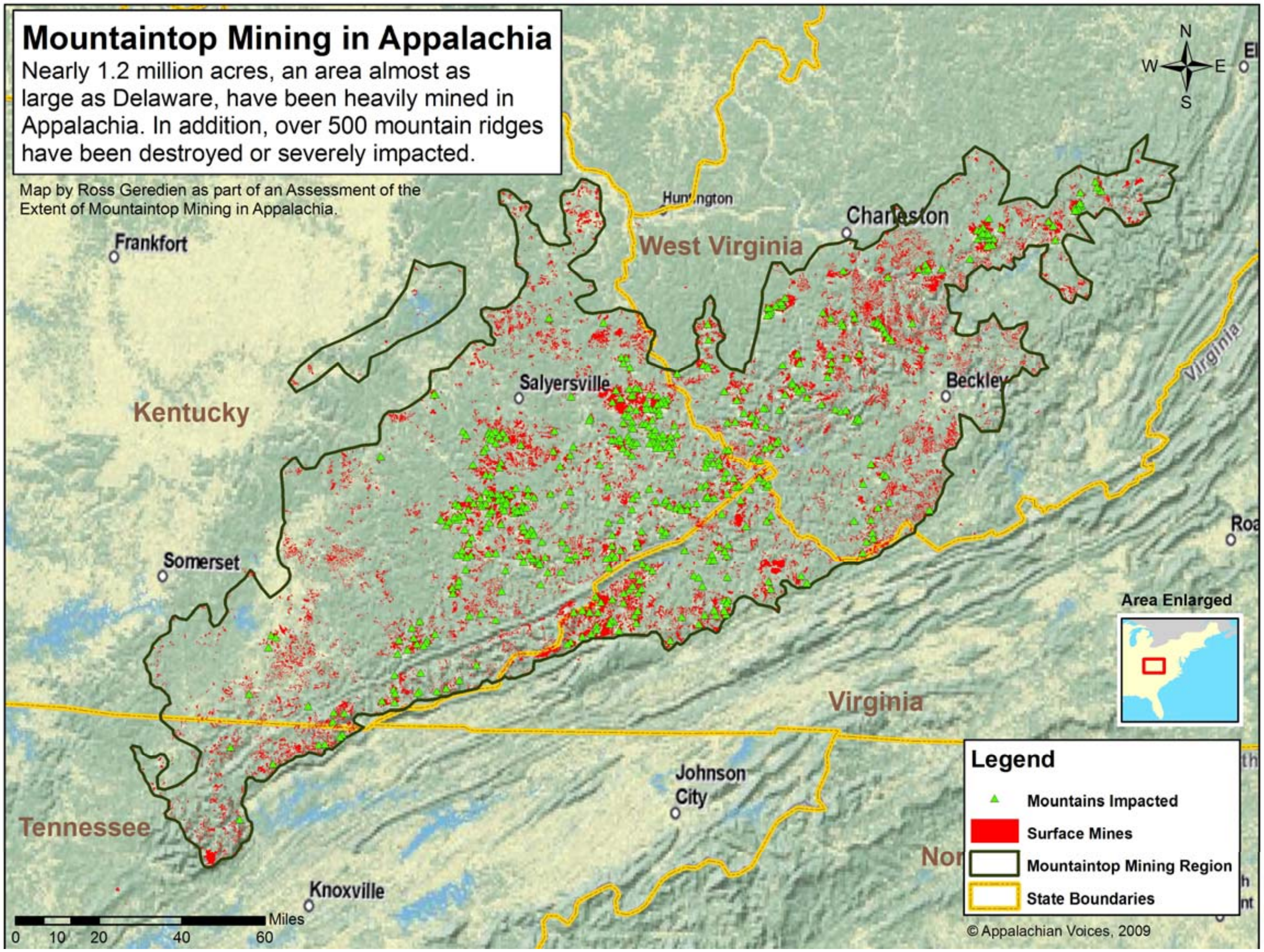
Skytruth Data Summary

State	2009 Sample	Skytruth Sample	Skytruth Ratio	Skytruth Total	Skytruth Extrapolated
	A	**C**	**R = C/A**	**S**	**E = S/R**
Kentucky	14,843.31	11,152.10	75.13	447,362.70	595,434.29
Virginia	5,659.80	4,205.67	74.31	114,311.40	153,835.13
West Virginia	11,838.69	6,249.98	52.79	188,718.31	357,469.25
Tennessee	1,317.08	645.33	49.00	42,702.00	87,152.87
TOTAL	**33,658.88**	22,253.08	66.11	793,161.44	1,199,695.71

Extrapolated Results Summary

State	2006 Mines	Skytruth	Mean	90%	110%	Rounded	Proportion of Total
Kentucky	552,979.87	595,434.29	574,207.08	516,786.37	631,627.79	574,000	49.48%
Virginia	158,100.86	153,835.13	155,967.99	140,371.19	171,564.79	156,000	13.45%
West Virginia	346,540.29	357,469.25	352,004.77	316,804.29	387,205.25	352,000	30.34%
Tennessee	69,214.94	87,152.87	78,183.91	70,365.51	86,002.30	78,000	6.72%
TOTAL	1,135,494.41	1,199,695.71	1,167,595.06	1,044,327.38	1,276,400.13	1,160,000	100.00%

Appendix B



Mountaintop Mining in Appalachia
Nearly 1.2 million acres, an area almost as large as Delaware, have been heavily mined in Appalachia. In addition, over 500 mountain ridges have been destroyed or severely impacted.
Map by Ross Geredien as part of an Assessment of the Extent of Mountaintop Mining in Appalachia.
Frankfort
Huntington
Charleston
West Virginia
Salyersville
Beckley
Kentucky
Somerset
Virginia
Johnson City
Tennessee
Knoxville
Area Enlarged
Legend
Mountains Impacted
Surface Mines
Mountaintop Mining Region
State Boundaries
Miles
0 10 20 40 60
N
W
E
S
© Appalachian Voices, 2009