Estimating Changes in Drainage Patterns on Areas Affected by Surface Mining

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The increasing availability of elevation data products and data collection technologies suggests the possibility of characterizing landform change over time. Such a capability is particularly applicable to areas affected by surface mining, where the landscape can be radically altered over a short time interval. The availability of multi-date elevation models acquired during pre-mining and post-mining conditions immediately suggests two categories for analysis—the first involving locations and volumes of cut and fill areas, and the second relating to surface drainage patterns. Two preliminary investigations relating to the latter category were conducted for this report, with the objective of providing an initial insight into the problems and possibilities for characterizing drainage changes resulting from surface mining. The first investigation examined streams and drainage catchments produced by two high-resolution elevation models for areas where no significant mining had occurred. The study was designed to establish a basic understanding of the character and magnitude of discrepancies that might arise due to data error, rather than real change. One of the elevation models used for this investigation is a 3-meter LIDAR dataset acquired for a previous project, while the second model was created from high-resolution stereo photography captured in the spring of 2003. The second elevation model is part of a state-wide data set that can be used as a baseline for evaluating landscape change in West Virginia subsequent to its acquisition date. This elevation model also was used for the second investigation, where it was compared with a pre-mining elevation model created from U.S. Geological Survey (USGS) Digital Line Graph (DLG) hypsography. The goal of the second investigation was to identify actual drainage changes due to mining activity.

Investigation 1. Comparison of High-Resolution Elevation Models in Areas of No Topographical Change.

This investigation examined two independently constructed, high-resolution, elevation models for two watersheds in Southern West Virginia—Scrabble Creek, and Sycamore Creek (Figure 1). The first DEM is a 3-meter lattice, linearly interpolated from a Triangular Irregular Network (TIN) whose nodes corresponded to a set of bare-earth LIDAR observations acquired in December, 2001. A previous study indicated a median error of 0.32m and 0.14m for Scrabble Creek and Sycamore Creek, respectively. The second DEM was derived from stereo color aerial photography acquired in April, 2003 by the West Virginia Statewide Addressing and Mapping Board (SAMB). The photography was acquired as part of a larger project to create a comprehensive database to support E-911 operations. The SAMB DEM also was interpolated from a TIN data structure, with enhancements designed to facilitate hydrological modeling. The stated error for the SAMB data is 10 feet (3.04 meters). A comparison of elevations and imagery for the two watersheds indicated no substantive topographic changes between acquisition dates of the two DEMs. Sycamore Creek shows no recent mining activity, and Scrabble Creek's mining operations were reclaimed or inactive during this time.

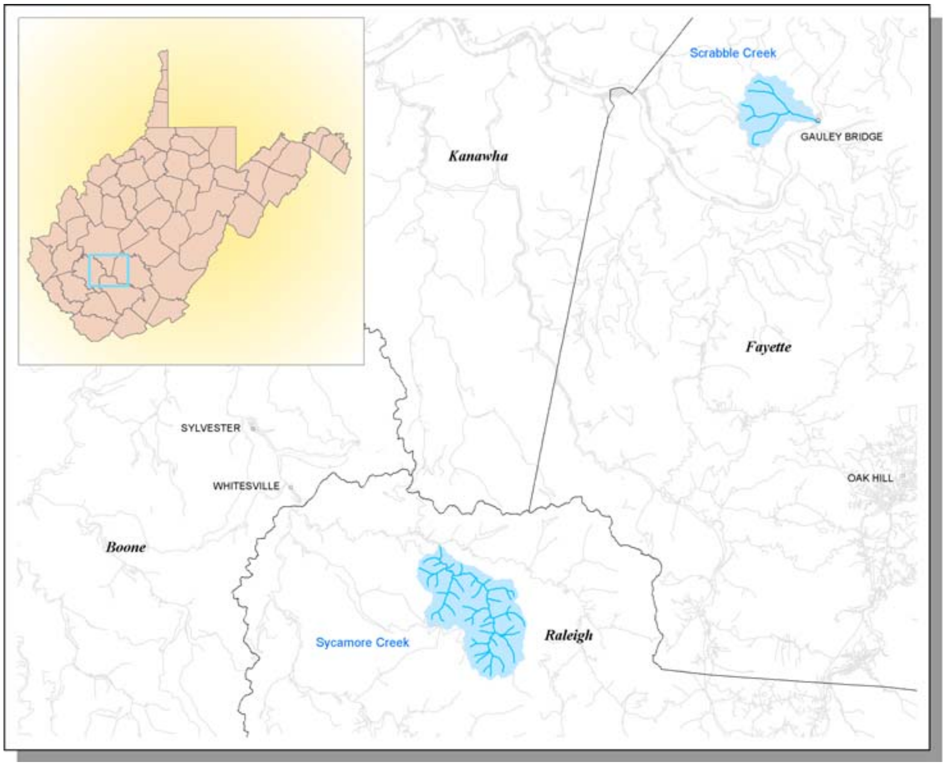

Figure 1. watershed locations used in the first investigation.

Analysis was conducted using the ModelBuilder capability of ESRI's ArcMap software. Figure 2 shows a screen capture of the model used for the Scrabble Creek LIDAR DEM. The approach is fairly common, and uses standard tools (shown in yellow) available with ESRI's spatial analysis extension. The *fill* tool removes depressions, or sinks, in the elevation grid. The *flow direction* tool determines local directional flow for each cell, and the *flow accumulation* tool calculates the total number of grid cells that flow into a particular cell. The *reclassify* tool is used to set a threshold on the flow accumulation grid, where cells with flow accumulations greater than the threshold value are classified as a stream, and all other cells are assigned a NULL value. This produces a grid representation of a stream network with a standard minimum drainage area, which is equal to the threshold value multiplied by the cell size. For example, to create a stream network with a uniform minimum drainage area of 30 acres from a flow accumulation grid with a 3-meter cell size, the threshold would be set to:

$$t = (30 * 4046.856)m^2 / 9m^2$$
$$= 13489.5$$

Where 4046.856 converts acres to square meters, and $9m^2$ is the area of a single cell.

The *stream link* tool assigns a unique id to each segment in the stream network, and the *watershed* tool calculates a drainage area for each resulting stream segment. The primary outputs of the model are two vector products—a stream layer and a corresponding watershed layer, both of which are converted from corresponding grids using the *raster to polygon* or *raster to polyline* tools.

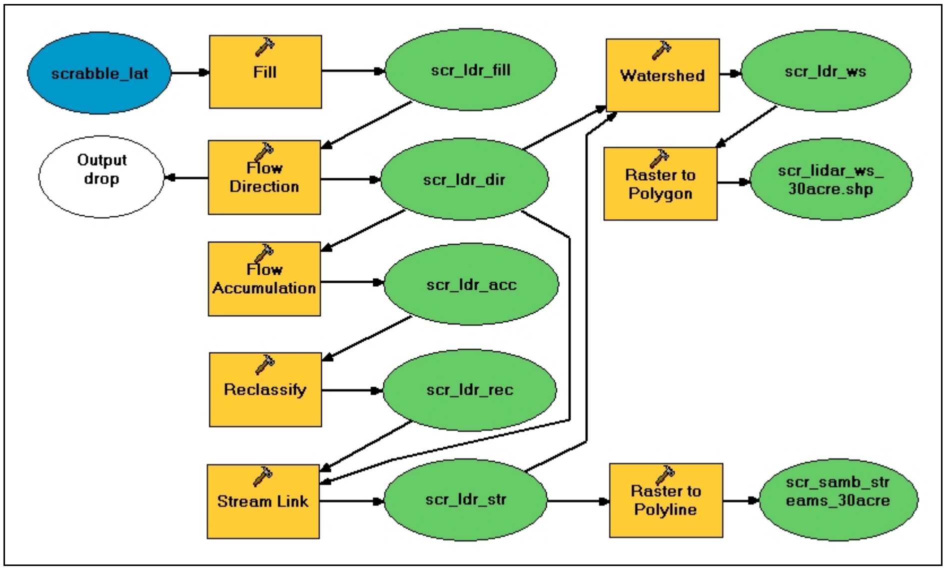

Figure 2. Screen capture of model used to extract stream network and catchments for Scrabble Creek DEM.

The central assumption of this investigation is that two high detail, high accuracy elevation models should produce comparable results when processed using the model in Figure 2. However, there were numerous occasions where this was not the case. Figure 3a shows drainage from an old contour mining bench exiting at point *A* in the LIDAR DEM, while the drainage from the SAMB DEM continues to an adjacent drainage at *B*. Figure 3b, from the Scrabble Creek dataset, shows another bench where the LIDAR DEM routed drainage to the North at *A*, while the SAMB DEM routed drainage into the gully at *B*. This discrepancy produced an apparent shift in drainage of over 50 acres. Figure 3c shows another case in which the LIDAR DEM has routed drainage along a bench to point *A*, while the SAMB dataset drains directly down the hillside at *B*. Note that streams in figure 3 are depicted with a 10-acre threshold. However, these cases will produce apparent changes in drainage even when using significantly larger thresholds. These discrepancies were not the result of large, obvious blunders in either dataset, but appear to arise out of relatively small variations.

It is common practice to embed stream channels into an elevation grid prior to calculating flow direction and flow accumulation, in order to enforce drainage to an pre-existing set of stream channels. In the past, this was done because existing elevation models did not have enough resolution to model stream channels accurately. However, it appears that high-resolution DEMs are subject to similar errors, though probably at some lower rate that has yet to be quantified.

The problem of stream extraction is compounded by the fact that small features can significantly impact stream channel representation. Embankments, roads, trestles, drainage ponds, and bridges can interfere with flow calculations. During the fill operation, the cells behind barriers are filled in, creating a flat plane, often resembling a lake. These flat sections produce erratic stream segments. Avoiding these difficulties requires pre-processing, in which appropriate outlet paths are cut through the barrier features, prior to submittal to the model. Other micro-scale features, particularly roads, and the benches depicted in figure 3, tend to divert flow at least partially along their length. In figure 4, accumulated drainage follows haul roads before jumping downhill at points *A, B and C*, while probable culverts at points *D* and *E* further contribute to misrepresentation of surface drainage in this area. The model expresses an exact point where accumulated drainage jumps from a road and continues following the dominant topographical structure downhill. However, this is most likely a product of small variations in the dataset, rather than a reflection of reality.

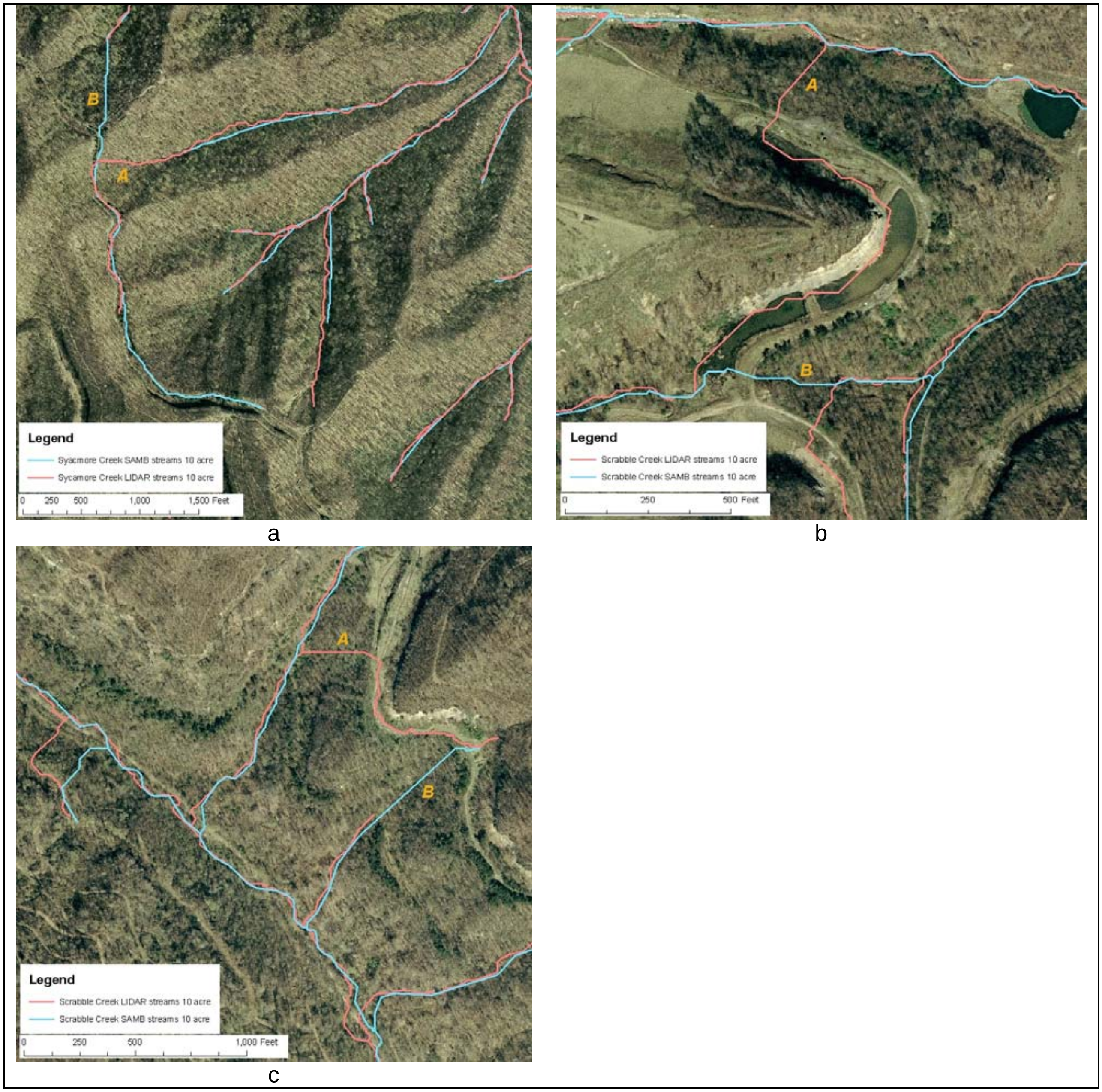

Figure 3. Differences in 10-acre minimum drainage networks extracted from LIDAR and SAMB elevation models.

The observed difficulties in producing reliable stream channels indicates that some cases of apparent change may be the result of data error. However, a second type of drainage change observed during this study, involving shifts in drainage divides, was generally easier to verify. This is because the locations of drainage divides are easier to confirm visually using elevation contours and flow accumulation grids. In addition, agreement between the two high-resolution DEMs generally was good along ridgelines, with a few exceptions. Figure 5 shows polygons that represent apparent shifts in drainage between two divides. The polygons were created by performing an overlay operation on the vector watershed products produced by the model and isolating the intersecting areas. The noted discrepancies for Sycamore Creek included 4 areas larger than 1 acre in size, with a maximum of 1.86 acres. This probably represents a near optimum case, as the ridgelines in this watershed are sharply defined. Scrabble Creek produced similar results, with the exception of polygons that were 2.1, 3.8, 5.6 and 16.6 acres in size. The

16.6 acre discrepancy was produced by the drainage problem outlined in figure 3*C*. An example of real drainage changes due to mining activity is presented in the second investigation.

Figure 4. Accumulated drainage jumps mining haul roads at arbitrary points A, B and C, while un-modeled culverts at D and E further misrepresent actual drainage patterns. The general flow pattern is from Southeast to North.

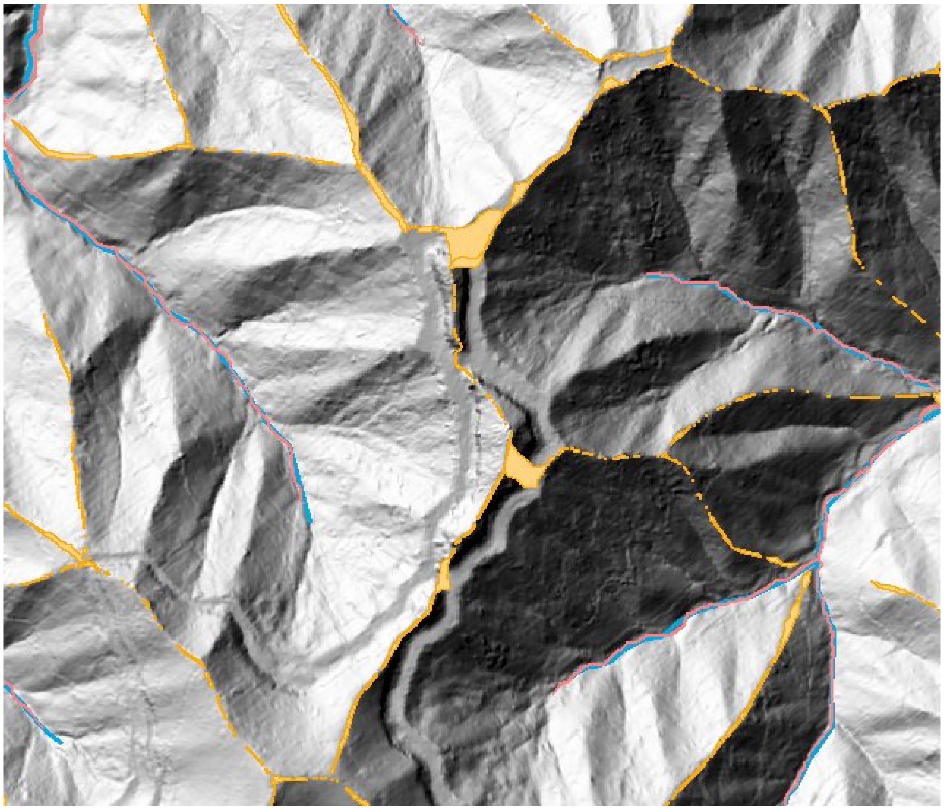

Figure 5. Ridgeline deviations between DEMs (yellow) where no mining has occurred were relatively small. LIDAR and SAMB derived streams shown in red and blue, respectively.

Investigation 2. Delineating Drainage Changes on Large Surface Mines

In order to examine potential drainage changes in areas where mining has occurred, a 10-meter elevation grid was compiled using elevation contours (hypsography) from USGS topographic maps. Source dates for individual quadrangles, from which the hypsography layers were digitized, ranged from 1955 to 1969. This pre-mining DEM was compared to the SAMB DEM utilized in the first investigation, which represented a post-mining condition. Both DEMs were processed using the model shown in figure 2, with the exception that a 1:24,000-scale vector stream network was embedded into the 10-meter DEM prior to executing the model.

Several large scale mining operations were examined, along with areas with little mining activity, which served as a control. Figure 6 shows a control watershed where little change has occurred, except for some activity in the headwaters to the South. Variation along the ridgelines ranged up to 6 acres, suggesting this value as a threshold for resolving real shifts in drainage divides for mined areas. In addition, two significant variations in drainage patterns were noted. One resulted from a series of drainage ponds and a railroad embankment modeled in the SAMB DEM that were not present the 10-meter grid. The second was caused by disagreement in the precise location of a stream confluence. The latter problem is quite common, even when comparing high-resolution DEMs.

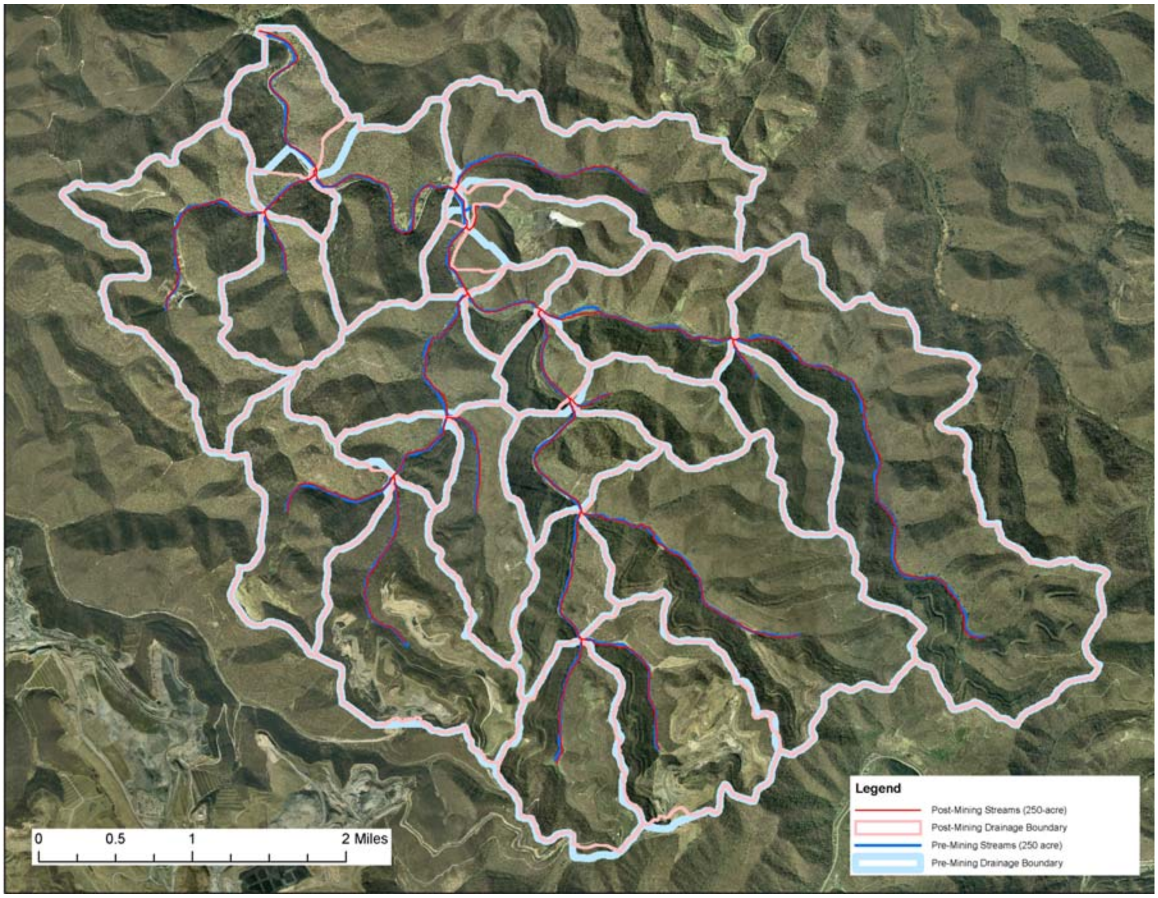

Figure 6. Control watershed, where little mining has occurred, indicates good agreement between the two elevation models, with some exceptions.

Figure 7 shows changes in drainage patterns on a large mining operation in Boone County, West Virginia (Hobet 21). Individual polygons range up to 34.7 acres in size, and the drainage to the West has added nearly 70 acres of cumulative drainage area. This example has a reasonably high confidence level because the changes are associated with shifts in drainage divides; the analysis does not depend on how the DEM models a particular stream channel.

The case shown in figure 8, however, is more difficult to interpret. Pre-mining conditions indicate the drainage is to the Northwest at A. Post-mining analysis indicates a parallel stream has now captured over 50 acres of this drainage, which is routed over the edge of the mining operation and into the valley at B. However, there is little evidence of an established channel at this location when examining the aerial photography from which the post-mining DEM was derived. In fact, close examination of the flow accumulation grid produced by the model, and the aerial photography, suggest an alternate route of drainage parallel to the haul road and into the original drainage system.

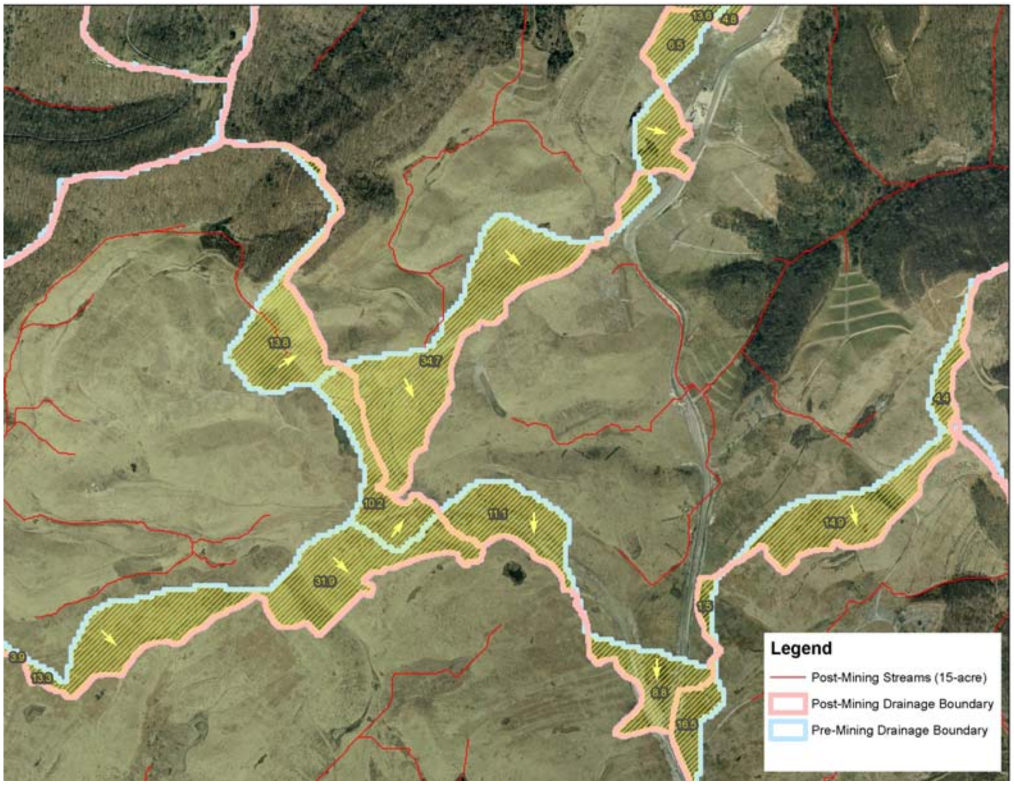

Figure 7. Shifts in drainage divides due to mining. Arrows indicate the direction of shift, labels indicate polygon areas, in acres.

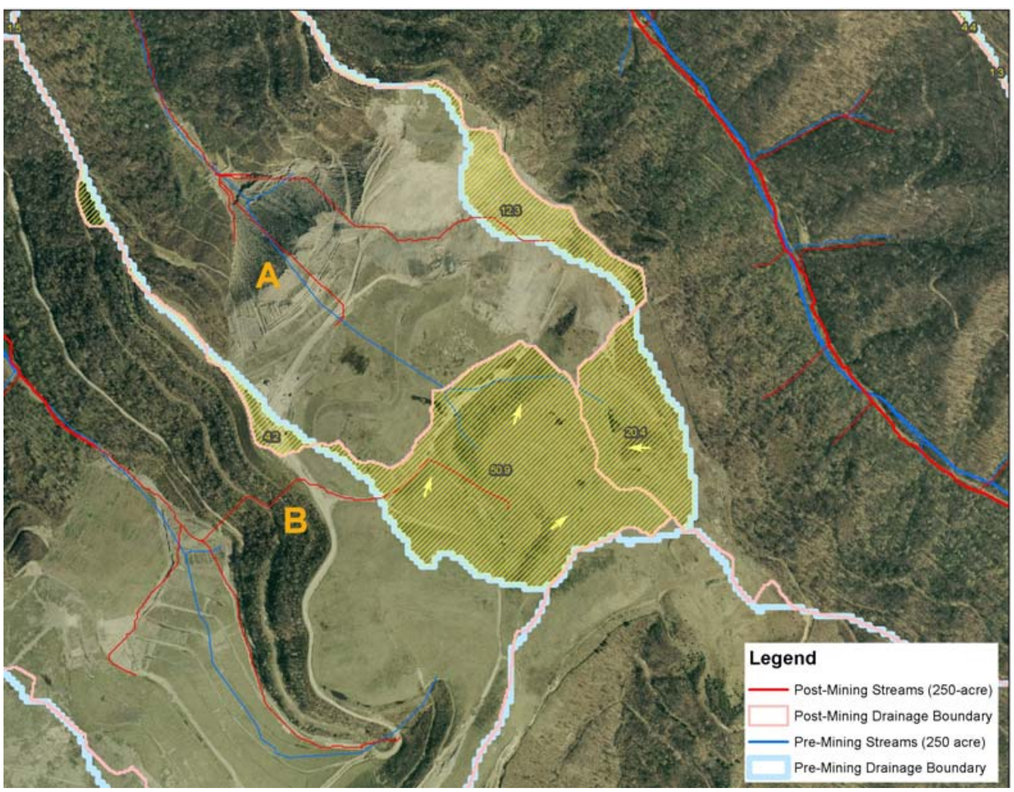

Figure 8. Pre-mining drainage to the stream at point A, apparently has been redirected to B, causing a 50 acre change in drainage area. However, the photography does not support the existence of a stream channel at this location. Arrows indicate the direction of shift, labels indicate polygon areas, in acres.

Preliminary Conclusions

The comparison of two high-resolution DEMs for Scrabble Creek and Sycammore Creek watersheds in Southern West Virginia indicated several discrepancies in how the datasets delineated surface drainage routes. These discrepancies produced some apparent changes in drainage, even though no mining activity had occurred. Differences between the two stream networks did not appear to arise out of significant blunders in the source data.

Significant differences occurred when accumulated drainage was interrupted by a bench cut into the hillside, or by a ditch. It can be speculated that benches are relatively flat, making it difficult to model drainage direction. Ditches and roads are relatively shallow features that may be modeled well enough to catch and redirect drainage. However, in both cases, relatively small variation in the source data may be sufficient to redirect drainage out of the feature at an arbitrary point.

Difficulties in automatically extracting consistent drainage networks can make it difficult to determine whether drainage changes actually have occurred when comparing pre-mining and post-mining elevation models. In several cases, high-resolution aerial photography was able to cast doubt on a particular result because no visible channel was present. Therefore, it would be recommended that high resolution photography be captured along with elevation data to assist in interpreting the results of a drainage analysis.

While it can be difficult to interpret apparent changes resulting from rerouted streams, cases arising from shifts in drainage divides often are easier to verify . Particularly in areas of high relief, divides are easy to confirm and are less reliant on the subtle differences that can cause significant divergences in stream channels. The comparison of high resolution DEMs indicates relatively close agreement on the locations of divides at the 30-acre drainage level. A similar result was noted when using a 10-meter DEM, which produced relatively few error artifacts on the order of 5 acres.

These investigations indicate that changes in drainage catchments can be estimated under certain circumstances, but not in all circumstances. The process resists automation, and often requires interpretation of multiple data products, including elevation contours, hillshade images, flow accumulation grids, and optimally, high resolution photography.