3-D Modeling of Large Anthracite Open Pit Mining Operations to Assist in Pennsylvania's Conversion to Conventional Bonding[1]

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Abstract. In 2001-2002, the Pennsylvania Department of Environmental Protection (PA DEP) and the U.S. Office of Surface Mining (OSM) cooperated on a project to assist in the implementation of Pennsylvania's Conventional Bonding system for coal mines by volumetrically modeling large open-pit anthracite mines. Pennsylvania announced its decision to overhaul its bonding mechanism in October 1999. The new conventional bonding system would be based on actual cost estimates to reclaim abandoned and forfeited mine sites. As a result of the overhaul, accurate estimates of backfill and spoil volumes were needed to calculate the bond liability of several open pit mines. These particular sites were selected because of difficulties arising from their sheer size. Remote sensing of these operations was critical since the affected areas totaled over 5,600 acres. Considering time and funding constraints, current aerial photography was deemed the best option. Color high-resolution imagery of 75,000 acres in east central Pennsylvania was completed in January 2002 at a cost of under $15,000. Using ERDAS Imagine, EarthVision and ESRI ArcView software provided by OSM's Technical Innovation and Professional Services (TIPS), OSM and PA DEP were able to three-dimensionally model several open pit mines, which led to more accurate volume measurements, and allowed PA DEP to require an additional $5 million in bond over what the operators estimated.

Additional Key Words:

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Introduction

For almost 60 years Pennsylvania's law has regulated surface mining, and has required some degree of land reclamation. For most of the same period it has also required bonds, of various amounts and methods of calculation, to ensure adequate land reclamation.

Since 1981 Pennsylvania has used an alternative bonding system (ABS) for surface coal mine permits. A $3,000 per acre bond for actual mining areas was required along with another $1,000 per acre bond for support activities, such as sediment controls, topsoil storage, and haul roads. Higher rates were imposed when the maximum thickness of rock overlying the coal exceeded certain thicknesses requiring deeper pits. When reclamation activities were completed these bonds were released. In addition, there was a statewide bond pool funded by the collection of a non-refundable, non-releasable reclamation fee of $50 or $100 per acre permitted.

The ABS had many shortcomings. There was a lack of parity between different categories of mining operations. Consequently, in the event of bond forfeiture, the contributions to the bond pool by some operators were not proportionate with contributions from others. For example, the Commonwealth's cost to reclaim a coal refuse reprocessing, originally bonded at $1,000 per acre, averages more than $11,000 per acre. Conversely, a surface mine originally bonded at $3,000 per acre may cost the Commonwealth less than $6,000 per acre to reclaim.

Parity was also lacking within categories of mining. Operations with large open pit areas were much more expensive to reclaim than the average surface or contour mine. However, both paid the same reclamation fee and both used the same per acre bond rates.

Operators who did not intend to stay in business found it cheaper to forfeit bonds than complete the reclamation required by law. Approximately 10% of the surface mining permits issued to Pennsylvania's industry have resulted in forfeiture.

A major change was needed and in 1999 Pennsylvania decided to implement a conventional bonding system (CBS). The conventional bonding system is based on the mine operator's description of the maximum amount of reclamation needed during the term of the permit. The proposed dimensions of the mining activity are combined with bond rate guidelines to calculate the total bond. The PA DEP developed bond rate guidelines using actual bid costs submitted for abandoned mine lands and forfeited mine site reclamation contracts and other appropriate sources.

Although every operator was required to calculate the volume of their active pit and supply supporting documentation, it was the PA DEP permitting staff's responsibility to review the adequacy of each submitted plan. After an OSM demonstration project using IKONOS satellite imagery to model mine sites in 3-D, it appeared to be ideal to use this same technology to model and calculate pit volume of some of the anthracite region's large open pit mine operations. In January 2002, the PA DEP formally requested technical assistance from OSM to complete the conversion from ABS to CBS for several large open pit mine operations in Pennsylvania's anthracite coal region. Specifically requested was the acquisition of aerial photographic imagery

to generate digital photogrammetric data with the goal of three-dimensionally modeling mine sites for volumetric calculations.

Major Anthracite Open-Pit Mining Operations

An anthracite open pit mine involves multiple coal seams mined concurrently within a single mining phase or multiple mining phases, or a basin removal where the open pit encompasses the entire cross section of a synclinal basin portion. This differs from the more common method of anthracite mining, which is the modified block-cut mining or contour mining, where mining takes place along the outcrop or strike of the coal seam by extracting successive blocks of overburden and coal. Table 1 is a list of anthracite open pit mine sites that required evaluation for conventional bonding and Figure 1 is a map showing the location and permitted area of each site.

Table 1. Summary of specific anthracite open pit operations.

Company	Operation Name	Bond Acreage	Max. Depth, ft
Reading Anthracite	Wadesville P-33	218	500
Reading Anthracite	Wadesville	396.5	650
Reading Anthracite	Buck Run & Pine Knot	770	450
Reading Anthracite	Pott Bannon P-50	243	200
Jeddo Highland	Jeddo Basin West	115.2	350
Pagnotti Enterprises	Jeddo Basin East	230.8	350
Pacton Corp.	Jeddo Refuse Area 1	170.6	250
Pacton Corp.	Jeddo Refuse Area 2	131	150
Mallard Contracting Co.	Sayre Stripping	107	250
Schuylkill Recl. Corp.	Peach Mountain	136.4	300
Anthraco	Primrose Mine	45.3	150
Blaschak Coal Corp.	Logan Surface Mine	86.5	115
City of Phila., Girard Estate	Continental Mine	207.7	300
Coal Contractors 1991	Gowen Mine	392	250
Coal Contractors 1991	Stockton Mine	468	300
Mammoth Anthracite	Lattimer Basin	136	350
B-D Mining Company	Overall	542	n/a*
Lehigh Coal & Navigation	LCN	1259	400
White Pine Coal Co.	Baby Boy Jarvis	67.9	200

* not an open pit mine

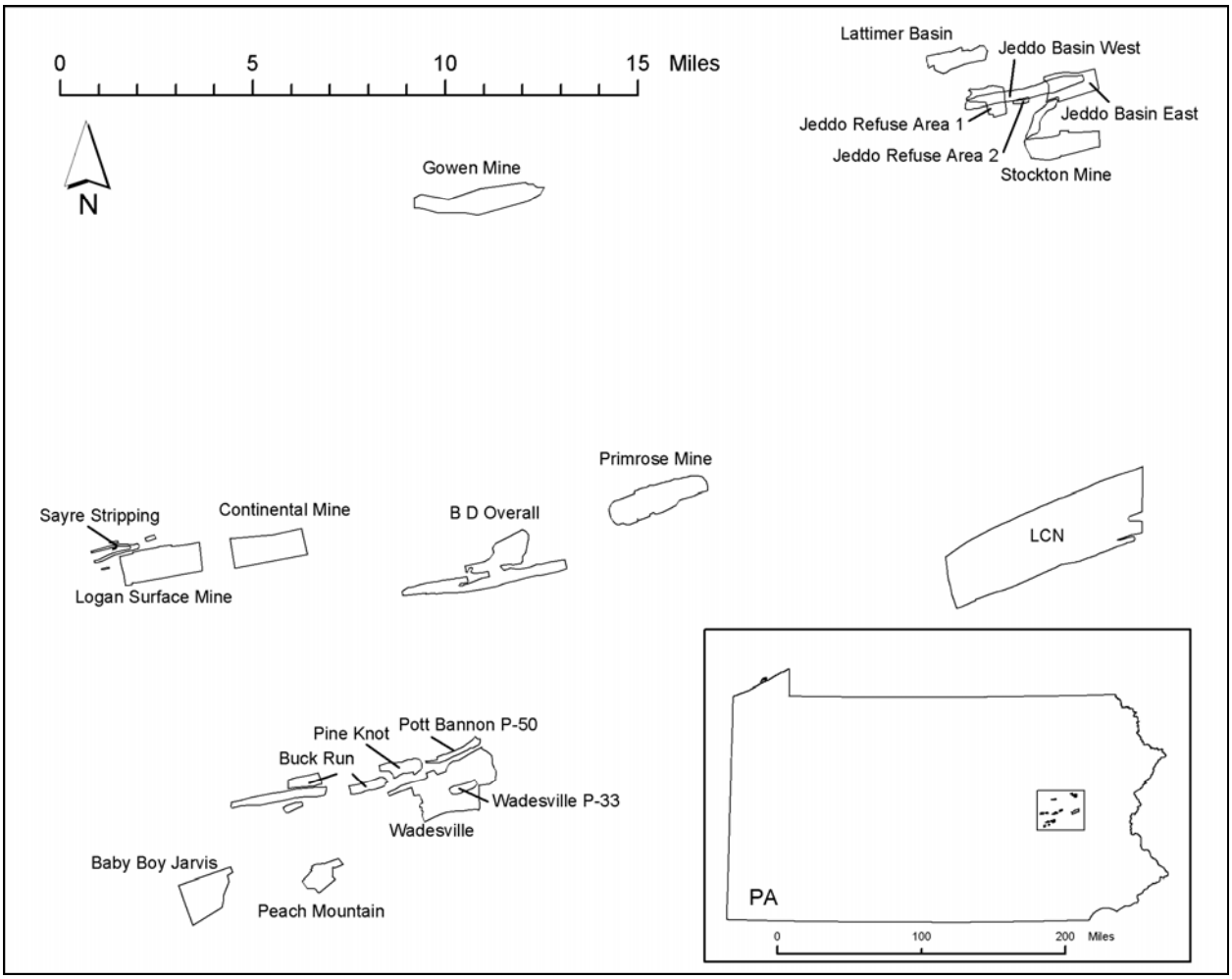

Figure 1. Map of open pit mines in Pennsylvania's anthracite region.

The modeling project developed into three phases; 1) remote sensing and ground control points, 2) orthorectification and digital photogrammetry, and 3) 3-D computer modeling and volumetric calculation. OSM completed the first two phases and PA DEP the third. Outside of the image acquistion, the rest of the project was done "in-house." The following information highlights each of the project's phases.

Aerial Imagery and Ground Control Points

The first phase was acquiring high-resolution imagery of all the sites shown in Figure 1. In order to achieve the best possible results, this phase was critical and would build the foundation for the rest of the project. Large areas had to be covered, that were located throughout a 500 square mile region. Satellite images of all the areas in Figure 1 were already available but were either too outdated or lacked high enough resolution, or in case of IKONOS, cost prohibitive. Since funding was a major factor, aerial photography was deemed our best option.

Since the start of the project was in the winter, leaf coverage was not a concern, but snow coverage was a factor. The vendor was able track weather and cloud cover conditions, but frequent communication was necessary with the vendor to report current snow conditions on the

ground since the vendor was located in Philadelphia. It was necessary to conduct the aerial survey within a few weeks of the start of the project in order to finish before the bonding conversion period ended. Fortuitously, a warming trend occurred late in January, 2002 and melted enough of the snow to proceed.

The aerial photography was acquired on January 26, 2002. The overall aerial imagery consisted of 9 flight lines covering approximately 75,000 acres at a photo scale of 1:15000 and contained 86 color exposures with forward and side overlap to produce stereo pairs. The vendor delivered photogrammetric quality scans of the exposures at 16 microns on CD-ROM in TIFF format by the second week of February 2002.

Ground control points, or GCPs, are known surface features used to establish the relationship between the camera/sensor, the images produced, and the ground itself. Full GCPs have measured x and y ground coordinates along with a z-coordinate that represents the elevation at that point. For this project, establishing GPCs took approximately 4 days of fieldwork. Since the aerial survey used airborne GPS it was only necessary to collect GPCs at the ends of the flight lines for a total of 4 per flight line. Using two GPS units (a Trimble ProXRS and Ashtech Z-Surveyor) one was set as a stationary receiver on a local control point and the other as a rover. This enabled us to differentially correct from the one unit and cut our occupation time down to several minutes per control point.

Setting up panel markers ahead of the aerial survey was not feasible considering the size of the coverage area, so cultural features were used instead. GIS software on a laptop and the TIFF images on CDs made it easier to find the cultural features in the field. Ends of painted lines in parking lots were a common GCP. Figure 2 shows the ProXRS set up at a road sign post.

Figure 2. GCP at a road sign.

Digital Photogrammetry

With the GCPs obtained, the digital "softcopy" photogrammetry process was ready to begin. Digital photogrammetric techniques use aerial and satellite images to obtain x,y, z coordinates of objects ranging from buildings to landforms. A critical step in the process is orthorectification. Orthorectification removes the geometric distortion inherent in imagery caused by camera/sensor orientation, topographic relief displacement, and systematic errors associated with imagery to produce digital orthophotos that are planimetrically correct, and can be joined together into a single image, or mosaic.

With the vast size of the project area this process took about 2 months to complete. OSM preformed this process using ERDAS IMAGINE OrthoBASE software. OSM delivered mosaics of each flight line georeferenced in UTM 18N, WGS84 Datum. Each mosaic contained several images or tiles, each covering an area of 2500 meters by 2500 meters at 1-meter pixel resolution. The tiles were formatted in both MrSID (.sid) and Imagine (.img) file format. Each file was named according to the UTM coordinate at the upper left corner of the tile. Creating index sheets for each mosaic was very helpful in retrieving files and staying organized. Figure 3 shows the index file overlain on the imagery of the Gowen Mine.

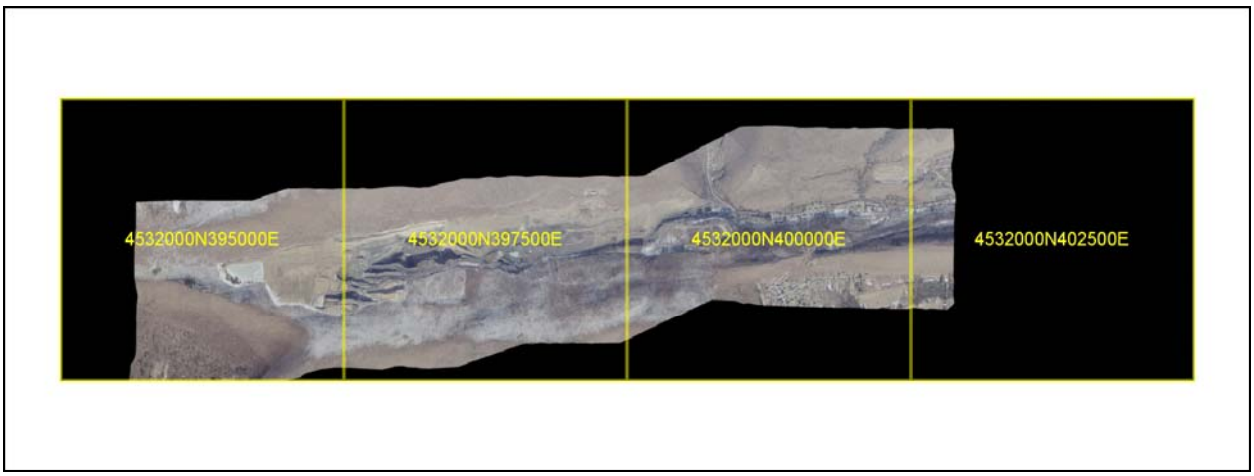

Figure 3. Mosaic of aerial imagery of the Gowen Mine with index file overlay.

The other major deliverables from OSM were files containing millions of individual x,y,z data points. These x,y,z data points or spot elevation points were formatted as ArcView shapefiles for GIS use and contained various attributes such as x,y,z coordinates and elevations in mean sea level (MSL) and height above ellipsoid (HAE). The IMAGINE OrthoBASE software analyzes the quality of each data point and allows filtering for removal of suspicious data. Only "excellent" and "good" quality data points were kept during this process.

3-D Modeling and Volumetric Calculation

The spot elevation points were raw data points created during the digital photogrammetric process. Points on features such as buildings, mining equipment, and water needed to be removed. Having the data points in an ArcView shapefile made it easy to edit the points. The process involved overlaying the points on the imagery and deleting these points in the shapefile. Focusing just on those areas that were going to be modeled made the point editing process manageable.

Another task well suited for ArcView was creating a polygon for use in clipping the area around that area going to be modeled. The clipped points were exported as an ASCI or text file containing x,y,z coordinate and common elevations.

The text files were imported into EarthVision for the modeling. EarthVision was used primarily because everything (modeling, visualization, and analysis) was integrated. In fact, without the excellent 3-D visualization that EarthVision provided, we would not have been able to discover problems that had arisen in our models.

To model or grid the data files, minimum tension gridding was used. Minimum tension gridding is the primary gridding technique used in EarthVision. This technique represents the values of the data as closely as possible, calculating a natural looking surface for grid nodes that are not close to data points. A grid report was automatically created with each grid calculation. These reports were reviewed to quickly check the fit of the grid, especially the maximum Z-error value, which measures the maximum distance between a data point and the calculated grid. (Using the Graphic Editor to view the grid file to determine the nature of a high maximum Z-error and remove if necessary). Generally, maximum Z-error values were found at abrupt changes in terrain, such as the intersection of a near vertical highwall and flat pit bottom.

Modeling the pits from the data generated from the aerial survey was relatively straightforward and produced accurate 3-D models of the existing surface topography of the mine sites. However, before volumetric calculations could be performed, the approved final reclamation grades for backfill or “lid” had to be modeled as well. Contours were needed to depict the surface of the mine site after the pit has been backfilled and graded.

The maps of operator’s reclamation plans ranged from CAD drawings to hand drawn cross-sections. The industry’s CAD maps were referenced within their local mine system, which meant that the maps would not overlay on our imagery and had to be reprojected. Using features on the reclamation plans, such as bench marks, buildings, and road intersections, as control points made it possible to reproject and in most cases digitize the contours lines using ArcView.

Once the reclamation contours were properly digitized and georeferenced another text file containing x,y,z coordinate and elevation data was created to import into EarthVision. However, all the contours were digitized as polylines, so a utility was used to generate points along each polyline to create the data point files.

EarthVision's layer volumetric was used to perform the volume calculations. Layer volumetrics calculates the volume of layers that are defined using two 2D grids and a polygon file acting as a lateral delimiter. In each model, an "existing" 2D grid and a "final" 2D grid were defined as the sequences or zones. A deposition or unconformity was simulated to represents the backfilling volume. After running the first volumetric calculation, it was apparent that something was wrong after receiving an unexpectedly high fill volume. Even though the calculation was limited to slightly beyond the pit area, fill volumes were calculated in those areas beyond the pit area. The cause was due to an improper fit of the "final" 2D grid to the "existing" 2D grid for various reasons, including the vertical and horizontal accuracy of the reclamation maps and inherit errors in registration, digitizing, and reprojection. To overcome this, we had to better define the affected areas to limit performing calculations on unaffected areas and edit the "final" 2D grids to better tie into existing contours. Building and viewing the model prior to performing the volumetric calculation was useful to identify and correct these problems.

EarthVision's Geologic Structure Builder was used to build the 3-D model of the pits. Figure 4a. shows a display using EarthVision's 3D Viewer of the Sayre Stripping site's existing topography in January 2002. Figure 4.b is the same site with approved reclamation grades (gold color) modeled.

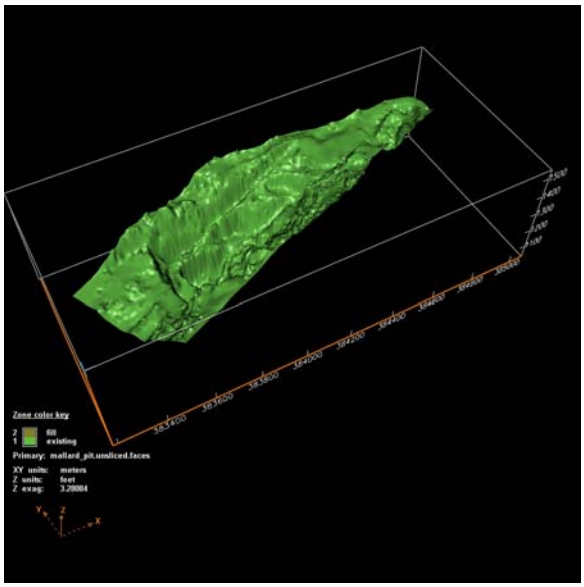

Figure 4a. EarthVision model, Sayre Stripping mine site - active.

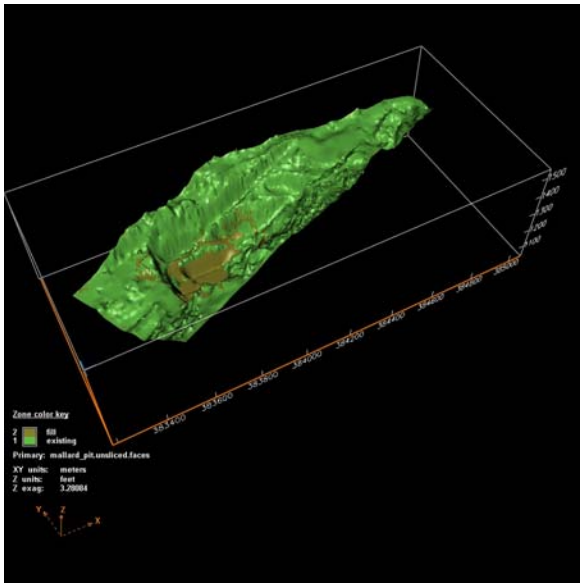

Figure 4.b. EarthVision model, Sayre Stripping mine site - reclaimed.

Figure 5 shows the volumetric report with the volume calculated at slightly over 650,000 cubic yards for the gold colored backfilled area shown in Figure 4b.

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                              2-D Volumetrics Report


                         VOLUMETRICS REPORT

                         Run by: mihill
                        Version: 6.0.1
                           Date: Wed Jun 19, 2002
                    Report file: mallard_fill2.2vrpt

                   Polygon file: mallard_pit.ply
                Zone definition: Operational
         Unconformity operation: mallard_recl.2grd
           Deposition operation: mallard_existing.2grd
            Global yield factor: 1.0
                  Primary field: Polygon ID
                 Sorting method: Polygon order
                    Input units: meters square by feet
 Volumetrics conversion factor: .398663348703
                   Output units: Cubic yards
      Global minimum thickness: 0.0

-------------------- Zone name: fill              --------------------

                     Minimum z: none
                     Maximum z: none
              Minimum thickness: 0.0
                   Yield factor: 1.0


                              2-D Volumetrics Report


                     Zone name: fill
   Polygon ID
        Polygon Class
                                        Area           Volume      Positive Area
-----------------------            --------------  --------------  --------------

                                   136,196.436201  652,571.011426  66,149.532923
```

Figure 5. Volumetric report of the Sayre Stripping generated by EarthVision.

Sites

Although the 19 mine sites listed in Table 1 had aerial coverage and sufficient elevation data to model each one, only six sites were eventually modeled and had volumes calculated during the project. The deadline to complete the conversion to conventional bonding was the main factor in this, but some of the operators conducted their own detailed computer modeling with acceptable results. Sites were prioritized base on reclamation liability and insufficient or inaccurate calculations. Since all the sites are “pre-primacy” sites from the 1960s and 1970s, or earlier, when the sites were repermitted in the 1980’s as primacy permits the new reclamation plans contained backfill contours that were less than the natural approximate original contour.

Of the six (6) sites selected for modeling, three examples can be used to characterize the overall project. The Repplier Pit was the one that resulted in the largest increase of bond directly due to the modeling project. The Continental Mine served as an example of how we identified a discrepancy in the operator’s own computer models. The last example is the LCN Mine, which is the largest mine in the anthracite region. This site validated the project when our volumes were within 10% of the operator’s CAD based volumetric calculations.

The Repplier pit as shown in Figure 6a is part of an approximately 3,500 acre mining operation known as the Buck Run & Pine Knot Operation. The Repplier pit is one of five separate mining areas within the operation. Large-scale mining of the earlier "pre-act" (pre-1977) strippings started in the early 1990s. The blue colored area in Figure 6b represents the deepest portion of the pit as depicted on the January 2002 aerial image, and the configuration of the blue area approximates that of the pit water impoundment shown on Figure 6a. The gold colored area on Figure 6c is the lid or reclamation grade and all areas and areas outside the gold colored area are either at final grade or have material stored above grade. The large active spoil pile at the eastern end of the operation was modeled separately as a large cut section. This is the source of most of the fill. Figure 6d shows the January 2002 configuration of that spoil pile, and the gold colored area on the figure depicts all the areas of cut that must meet the approved reclamation configuration shown in Figure 6e.

ABS bond for the pit was $1,039,000 and the operator had submitted quarterly reports stating that reclamation was on schedule, indicating in 2002 that a pit volume of about 1.5 million cubic yards remained to be backfilled. However, since the conventional bonding calculations were based on truck-count volumes, the accuracy of the calculations were questionable. PA DEP calculated 4.6 million cubic yards remaining to be backfilled. The modeling and volumetric calculation were instrumental in successfully negotiating an additional $2,345,000 bond for this site. The volume of material to be cut from the large spoil pile was calculated at 5.5 million cubic yards, of which a portion is planned to backfill a pit to the east of spoil pile.

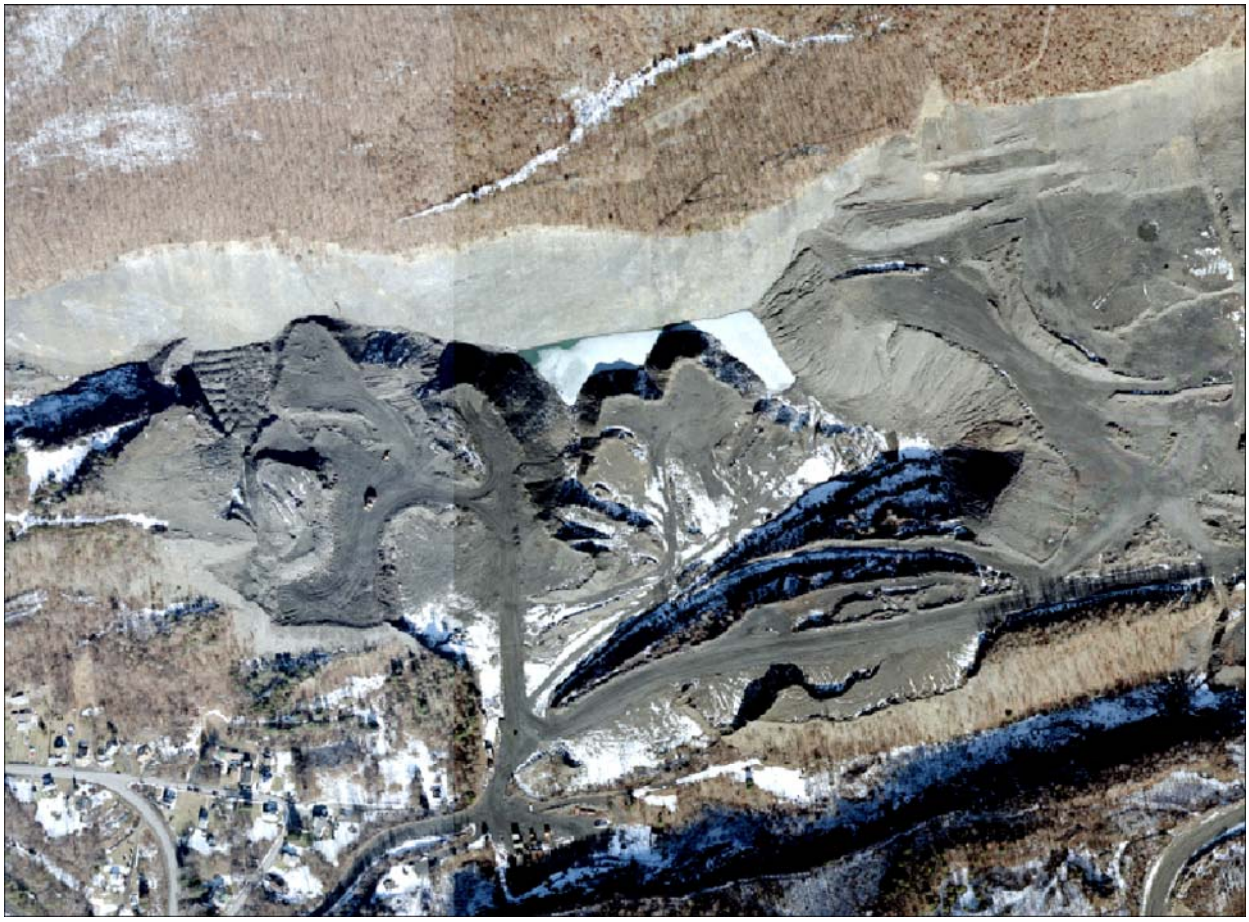

Figure 6a. Aerial image of the Repplier Pit acquired on January 26, 2002.

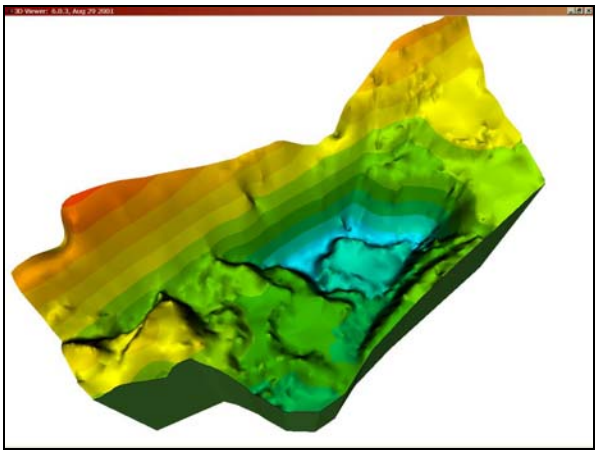

Figure 6b. EarthVision model of the Repplier pit - active.

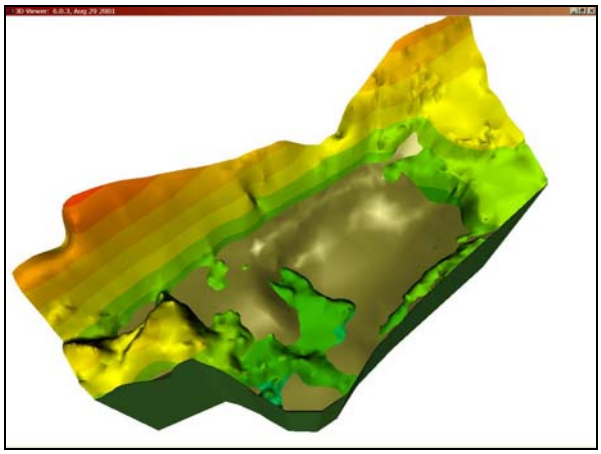

Figure 6c. EarthVision model of the Repplier pit - reclaimed.

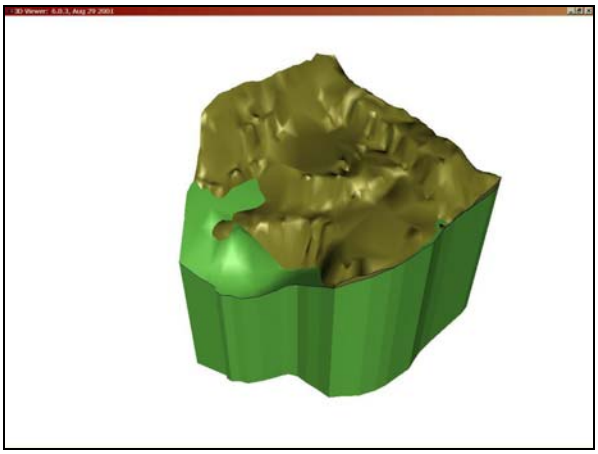

Figure 6d. EarthVision model of Repplier's spoil pile - unreclaimed.

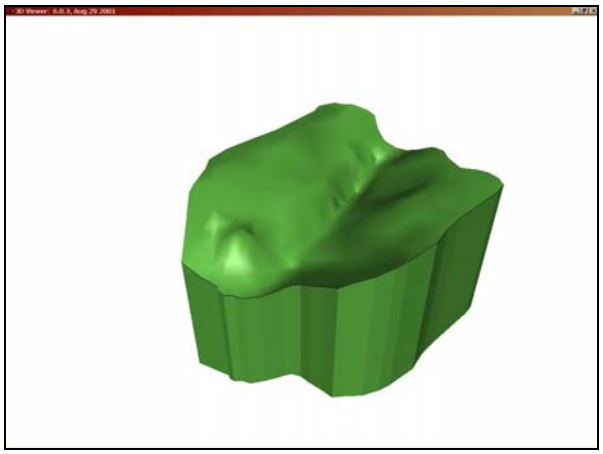

Figure 6e. Earthvision model of Repplier's Spoil pile - reclaimed.

The Continental Mine is a major open pit mining operation which is removing a synclinal basin in phases. The active pit as seen in the dark area in Figure 7a was the feature that was modeled and represents the maximum extent of open area at any one time. The deepest portion is shown in purple in Figure 7b, which is an EarthVision model of the pit based on the January 2002 aerial survey. Figure 7a shows the spoil storage to the east, and the pit is advancing westward. Figure 7c is the final reclamation configuration consisted of two flat areas terraced at 35° with a shallower pit at a higher elevation than the surrounding flooded deep mine complex.

The operator's consulting engineer did a thorough job of calculating the open pit and spoil volumes, but a significant difference existed in backfill volumes as was discovered with the EarthVision models shown in Figures 7b and 7c. This prompted a through review of the consultant's data, which lead to identifying an area that was excluded in their model. Once the consulted include this area the differences in volumes between the models became insignificant. This discrepancy probably would not have been detected without the results of this project, and ultimately lead to calculation of an increase of several hundred thousand dollars over the operator's original conventional bond calculation.

Figure 7a. Aerial image of the Continental Mine acquire on January 26, 2002.

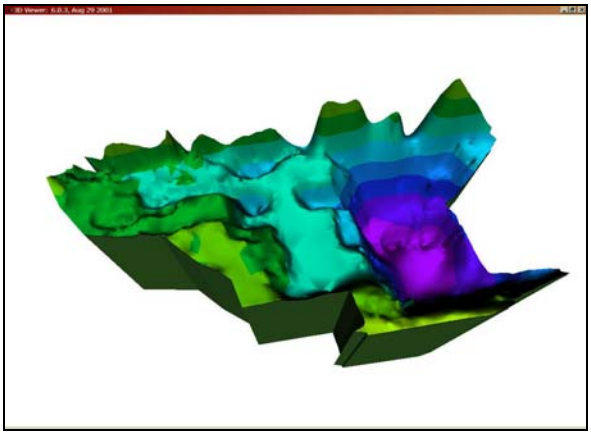

Figure 7a. EarthVision model of the Continental Mine - active.

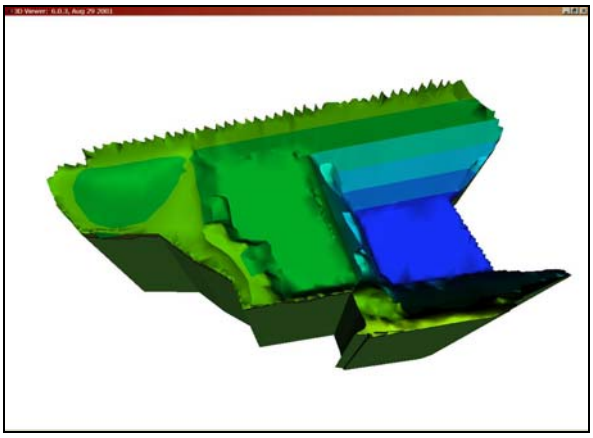

Figure 7b. EarthVision model of the Continental Mine – reclaimed.

The entire LCN Mine site is 7,596 acres and contains two large open pit mines known as Pit 111/Job 99 and Springdale Pit. The deepest portions on the Pit 111/Job 99 site is filled with water as shown on Figure 8a. The reclaimed surface area is shown on Figure 8c, with the gold colored area representing the "lid" developed from the approved reclamation plan. The approved reclamation plan for Pit 111/job 99 is three relatively flat terraces connected by 35° slopes. Note that because of vertical exaggeration, the reclaimed slopes in Figure 8c appear steeper than the modeled 35°. Also, since part of the pit is filled with water, the pit beneath the water level had to be modeled by editing in contour lines into the 2D grid. The final volumetric

calculation was just over 11 million cubic yards of open pit to backfill to the configuration shown on Figure 8c, compared to slightly more than 10 million cubic yards that the operator had calculated.

Figure 8a. Aerial image of the LCN's Pit 111/Job 99 acquired January 26, 2004.

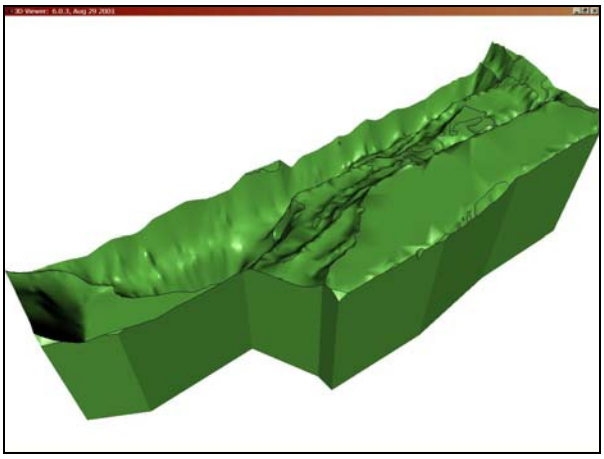

Figure 8b. EarthVision model of Pit 111/Job99 – unreclaimed

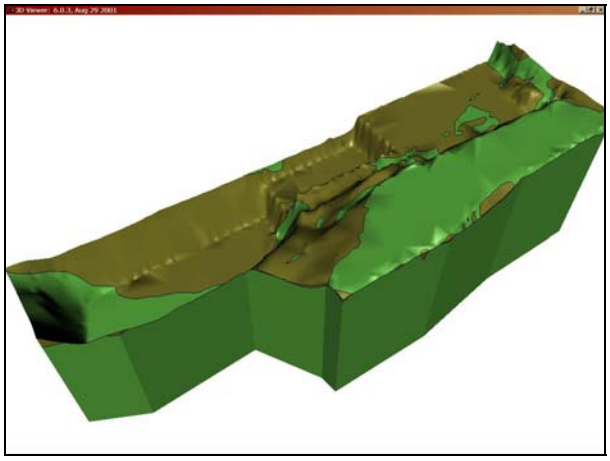

Figure 8c. EarthVision model of Pit 111/Job 99 – reclaimed

Conclusions

With the use of high-resolution aerial imagery and TIPS support, OSM and PA DEP digitally modeled in 3-D several large open pit anthracite mines. The models led to detailed volumetric calculations for reclamation of the mines, which enabled Pennsylvania to secure over $5 million in additional reclamation bonding over the original bond estimates submitted by the operators. The project took several months to complete, but at relativity minor cost to OSM and PA DEP because of "in-house" experts and their use of TIPS.

However, some challenges were encountered during the project. Most notable, was the process of converting the reclamation plans into a 3-D model. Even after the reclamation models were generated it was necessary to edit them, several times, in order to smoothly integrate the approved reclamation plans with the existing terrain models. In some case, simplifying the reclamation contouring made it easier to integrate. Also, we found that if the affected areas were not thoroughly identified and defined, the volumetric estimates in the results contained unwanted additional backfill volumes, due to slight variations between existing topography and projected reclamation grids.

In addition to the original intended use, the aerial imagery has been used in mapping projects for inspection purposes and has been shared with industry, consultants, and the public. The spot elevation data generated from the imagery also has been used for several contour mapping projects.

Acknowledgements

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