MINE INSPECTION ASSISTANCE USING REMOTE SENSING IMAGERY[1]

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Abstract. With advances in mining technology, surface mines are becoming larger and more complex. The use of satellite imagery and remote sensing technology may provide a way to reduce the cost associated with field inspection of larger mine sites.

As part of its West Virginia oversight process, the OSM Charleston Field Office normally procures a helicopter service to fly an OSM reviewer over a sample of active and bond released mine sites. Drainage controls, downslope spoil placement, fly rock, fill construction, etc. are observed on active operations. Bond released mine sites are reviewed for seeps, vegetation, highwall elimination, and overall reclamation success for postmining land use.

The purpose of this project is to determine if satellite imagery is economically and technologically feasible to reduce the cost associated with helicopter overflights. In addition, this project will attempt to identify any mining features only available using satellite imagery and remote sensing technology.

Four study areas were selected in West Virginia. Helicopter overflights have been completed and satellite imagery received. The multi-spectral and panchromatic imagery was reviewed and analyzed for mining features. A preliminary cost analysis was performed and indicated a cost savings by viewing the satellite imagery for current mining activities as opposed to a field inspection. Development of a tool to aide in identifying relevant features is being considered.

Additional Key Words: Mine, Aerial, Inspection, Remote Sensing

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Introduction

On August 3, 1977, Congress enacted the Federal Surface Mining Control and Reclamation Act Public law 95-87 (SMCRA). SMCRA provides authority to the Office of Surface Mining Reclamation and Enforcement (OSM) to oversee the implementations of State Regulatory programs approved by OSM as meeting the minimum standards specified by SMCRA. The OSM Charleston Field Office (CHFO) is responsible for the oversight of the West Virginia coal regulatory and abandoned mine land programs to ensure that surface coal mining operations are conducted in accordance with SMCRA. Contour, area, auger, mountaintop, and highwall mining operations are the most common methods of surface mining in the State. With advances in mining technology, surface mines are becoming large and more complex.

As part of the Office of Surface Mining oversight process, aerial reviews of active and bond released mine sites are conducted annually to ensure permit compliance and reclamation success. The use of satellite imagery and remote sensing technology may provide a way to reduce the cost associated with aerial oversight of large surface mine sites. Currently, helicopter service is procured annually and an OSM reviewer is flown over a random sample of active mining (Fig. 1) and bond released mine sites (Fig. 2). Some of the features observed are drainage control, downslope spoil placement, highwall reclamation, and fill construction. Bond released mine sites are reviewed for seeps, vegetation, highwall elimination, and overall reclamation success for postmining land use. Helicopter overflights were conducted on each site and the findings were documented. On-the-ground inspection was conducted at one of the aerial sites viewed to validate observations found within the satellite imagery.

Remote sensing technologies can be used in many ways to support inspection and enforcement activities. Applications include surface land-use-change analysis, direct valley fill activity assessment, regional watershed studies, quality and quantity modeling, and many others. These technical elements are important components of the mining programs developed to meet a host of both regulatory and nonregulatory drivers such as land-use changes associated with surface mining activities. High-quality datasets are essential to improving inspection and enforcement management programs.

Site Selection and Background

During 2005, coal was produced in 29 counties in West Virginia. The top six coal producing counties in 2005 were: Boone, Kanawha, Marshall, Mingo, Logan, and Monongalia. These counties were evaluated to determine the number of large active and bond released permits identified on the list for annual review. Four study areas were selected based on the largest concentration of qualifying surface mine permits. These study areas are in Boone and Logan Counties.

Figure 1. An aerial view for a State of WV, Office of Surface Mining oversight inspection of an active mine site.

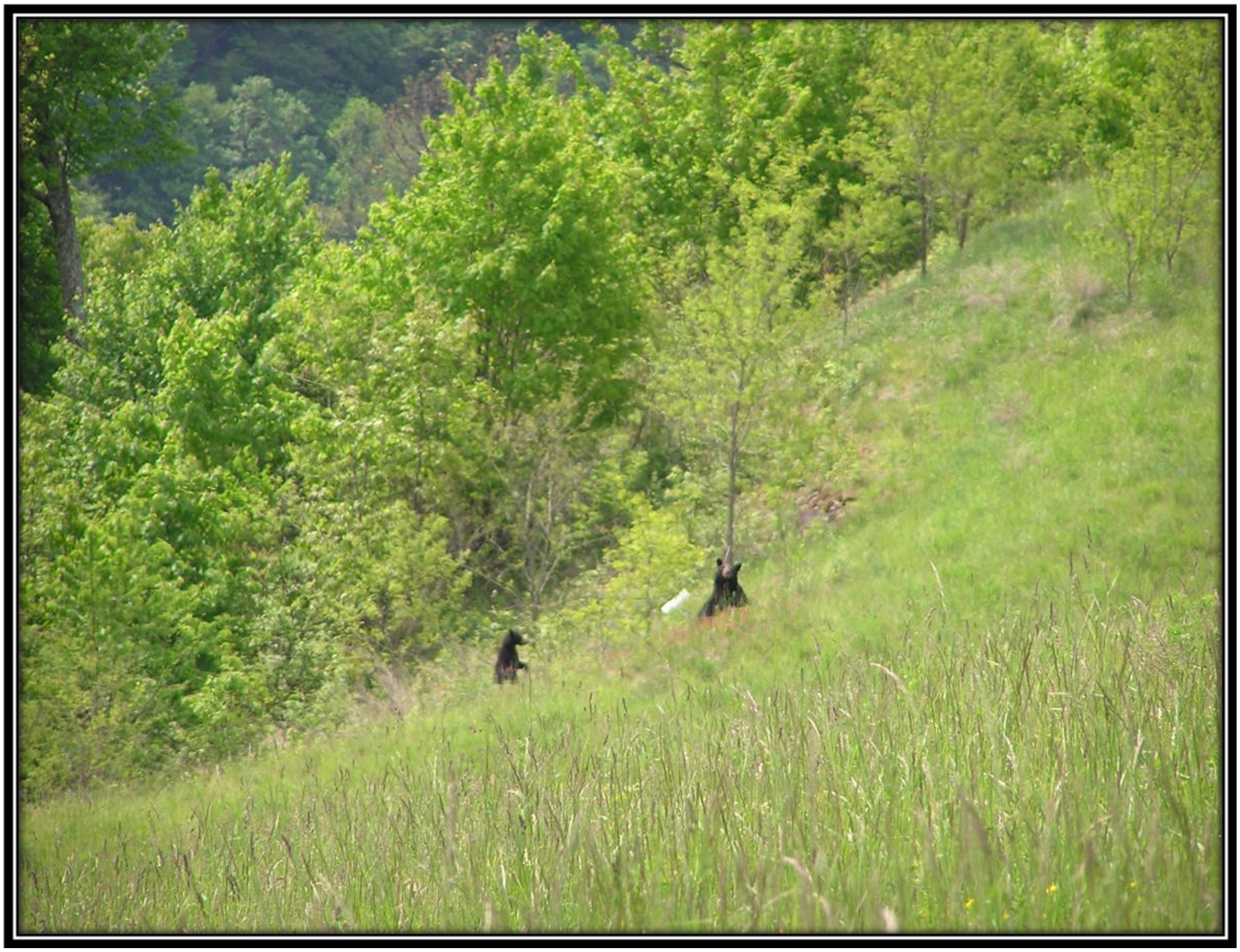

Figure 2. A bond released area for a successful reclaimed surface mine site.

The study areas are located primarily on the Williams Mountain, Wharton, Logan, and Amherstdale USGS 7.5 Minute Quadrangles with areas extending into parts of the Madison, Henlawson, Clothier, and Lorado quadrangles as shown in Fig. 3 and 4.

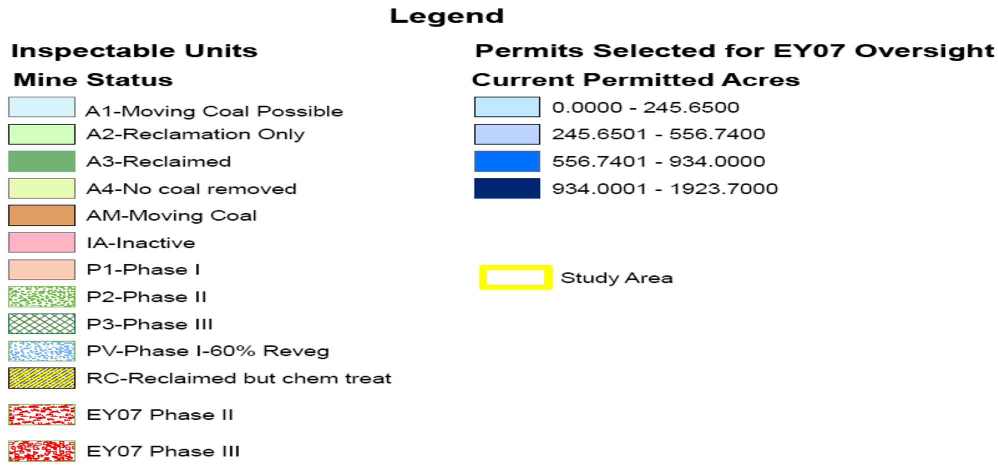

Figure 3. Legend for study areas.

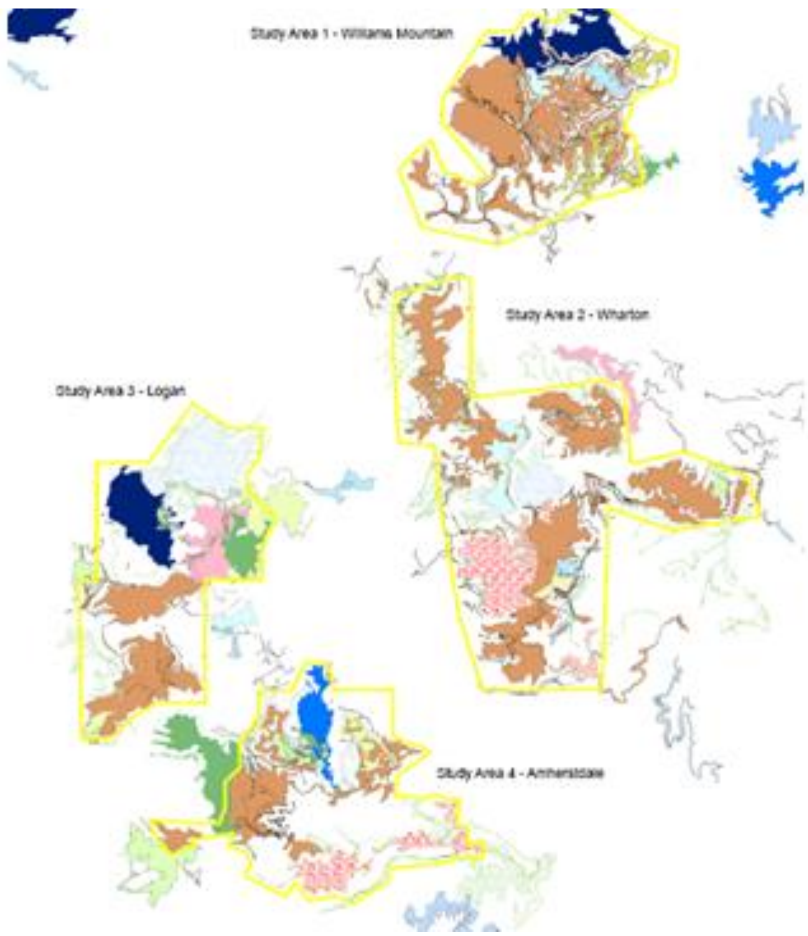

Figure 4. Large active operations & bond released areas from WVDEP data base (not to scale).

Purpose

The purpose of this project is to determine if satellite imagery is economically and technologically feasible to reduce the cost associated with helicopter overflights associated with the State oversight inspection process. The second objective of the project is to identify surface mining features that are viewable using satellite imagery to identify permit compliance.

Methodology and Data Acquisition

The approach chosen to meet the project objectives was an innovative application of remote sensing from high-resolution satellite imagery combined with GIS analysis. Not only can remote sensing be used to view what is currently on the ground but also what will likely be present in the future.

The methodological approach adopted for the identification of these mining features is mainly based on the data obtained from permitted mine applications for the four study areas, regular photos obtained from mine inspectors at the time of aerial overflights, and multispectral and panchromatic (pan-sharpened) images. The data from the QuickBird images enabled the integration of high spatial resolution with the spectral capability of multispectral images, thus allowing us to observe mine site conditions that are not possible using the individual photos from the aerial and field inspections. The analysis focused on the identification of approved permit boundaries, drainage control that included sediment ponds, downslope spoil placement, and valley fill construction with a high level of detail in most of the data viewed.

QuickBird is owned and operated by Digital Globe, Inc. and offers three types of imagery products of basic, standard, and orthorectified. The basic imagery is the least processed of the three types. It is corrected for sensor and platform-induced distortions but not georeferenced or mapped to a cartographic projection. Basic imagery is not pan-sharpened. The standard imagery is georeferenced and mapped to a cartographic projection. It is corrected for sensor and platform-induced distortions and radiometrically corrected. The orthorectified imagery has the highest level of processing. It includes all of the processing applied to standard imagery plus terrain elevation correction. The basic imagery for both multi-spectral and panchromatic products was purchased for $7,000.00 with orthorectification and pan-sharpening processing to be completed by OSM-TIPS (Technical Innovation and Professional Services) in-house staff. The orthorectification and pansharpening of the collected imagery required several months of processing before the finished product was GIS-ready for interpretation.

Visual interpretation instead of digital classification for generating land-cover/land-use mining activity information from the imagery was used. Visual interpretation was performed by examining digital high-resolution imagery displayed on a computer screen. Manual interpretation is a subjective process because results vary with different interpreters. The novice photo interpreter encountered difficulties when presented with their first aerial photograph. Aerial photographs are different from “regular” photos in at least two important ways. Objects are portrayed from an overhead (an unfamiliar) position and very often infrared wavelengths are recorded and photos are taken at scales most people are unaccustomed to seeing. Human interpretations are highly subjective and not perfectly repeatable. This proved to be an added time and cost factor due to training needed for reviewers.

Partial cloud cover within the imagery of some mining areas obscured ground cover that created shadows, making interpretation of mining activities and processing more difficult.

The inability to gather large-scale imagery data quickly and inexpensively hampered the detection of current surface mining activities from the imagery. Surface mining is continuously changing and without real time imagery it is difficult to track on site mining activity changes.

The changing active mining environmental conditions require the development of flexible remote sensing systems that can readily provide real time information that could be detrimental to an inspection and enforcement activity that is extremely time sensitive.

The accuracy of the remote sensing approach makes this process a viable alternative to manual regular photo interpretation (Fig. 5). In the evaluation conducted, large scale mining areas identified with the remote sensing technique were compared with regular photos using the same images. Figure 6 is the panchromatic (pan-sharpened) image of the same mine site with detailed discernible mining features such as, valley fills, parking areas, and highwalls that are viewable without an initial field visit.

Figure 5. Regular photo taken at the time of aerial inspection of the mine site.

Figure 6. Panchromatic view of same image as Figure 5 from a different angle.

Commercial satellite imagery from Digital Globe is composed of two parts: a high-resolution, black-and-white scene panchromatic (pan-sharpened) as scene in Fig. 6, and a multispectral color (plus near-infrared) scene (Fig. 7).

Figure 7. High-resolution multispectral scene.

The primary use of color infrared photography is vegetation studies. This is because green vegetation is a very strong reflector of infrared radiation and appears bright red on color infrared images as seen in Fig. 7. Not only was the remote sensing method determined to be sufficiently accurate, but it also required only a small fraction of the labor effort needed for analyzing the data.

This study involved manual interpretation of a variety of images. Regular photographic data was supplemented by additional digital data provided by the West Virginia Department of Environmental Protection (WVDEP) GIS server that included a multi-layer data set of approved mining permits that were overlaid on USGS topographic 7.5 minute quadrangle maps. Mining related features such as, approved permit boundaries, sediment ponds and drainage structures, and valley fill construction were overlaid on a semi-transparent topographic map of a permitted area. The approach chosen to meet the project objectives was an innovative application of remote sensing from high-resolution satellite imagery combined with GIS analysis. Not only can remote sensing be used to view what is currently on the ground but also what will likely be present in the future.

The benefits of this method included the ability to perform accurate mining activity assessments for large areas in a relatively short time frame, and at a much lower cost than previously possible. It is intend to use the remote sensing data, coupled with other themes from the State's GIS database, to model active mining areas at the sub-watershed level in our development and implementation of effective oversight assessments.

Case Study 1

An accepted standard was developed to verify mining features related to surface mining. Only verified sites were used in succeeding analysis. Mining areas are identified as; areas that fall within a permit boundary. The permit boundary had to match a significant feature of the disturbed area polygon, such that there is no reasonable doubt that the two are related, and that the disturbed area and the permitted area inhabit the same space, areas that contain clearly identifiable valley fills, drainage features, highwalls, haulroads, and/or reclaimed areas (Fig. 8).

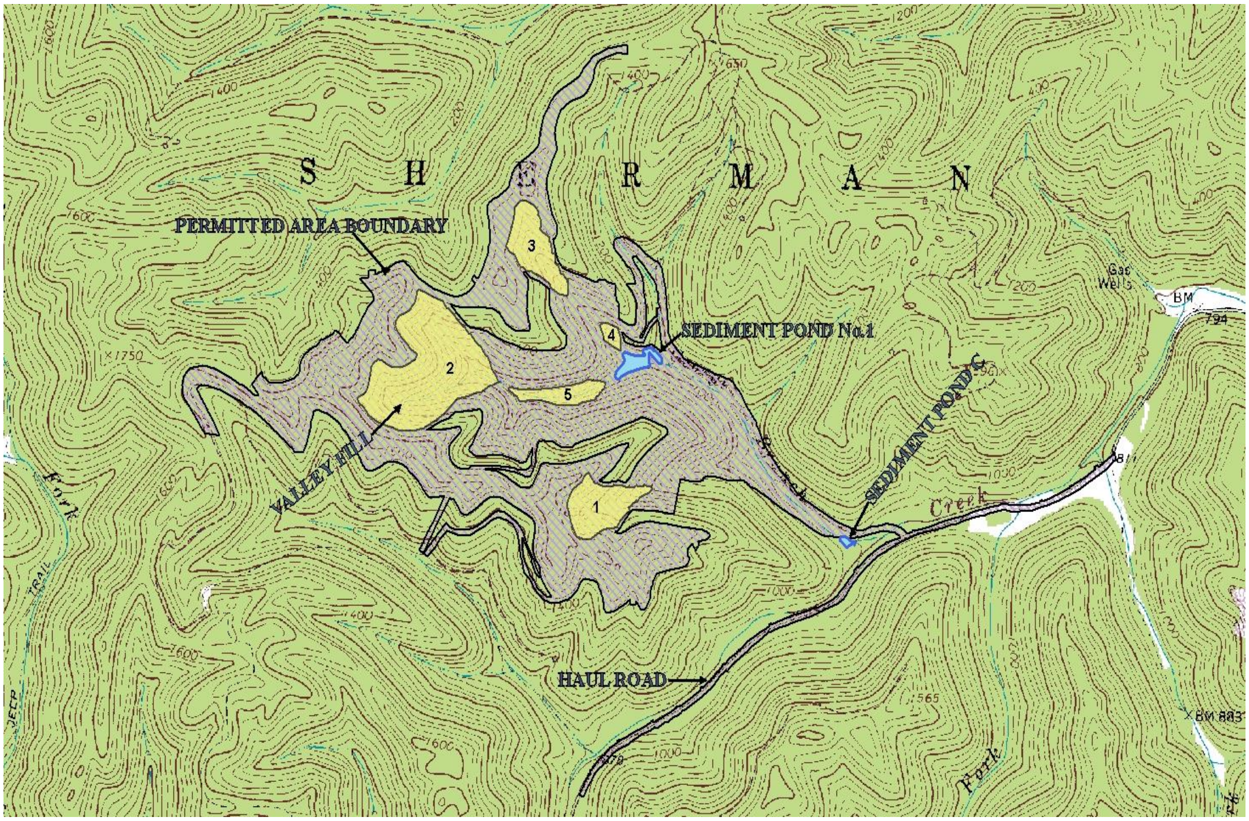

Figure 8. The information found in mining permits for valley fills, permit boundary limits, ponds, and haulroads are overlaid onto the USGS topographic 7.5 minute quadrangle map provided by West Virginia Department of Environmental Protection's GIS database.

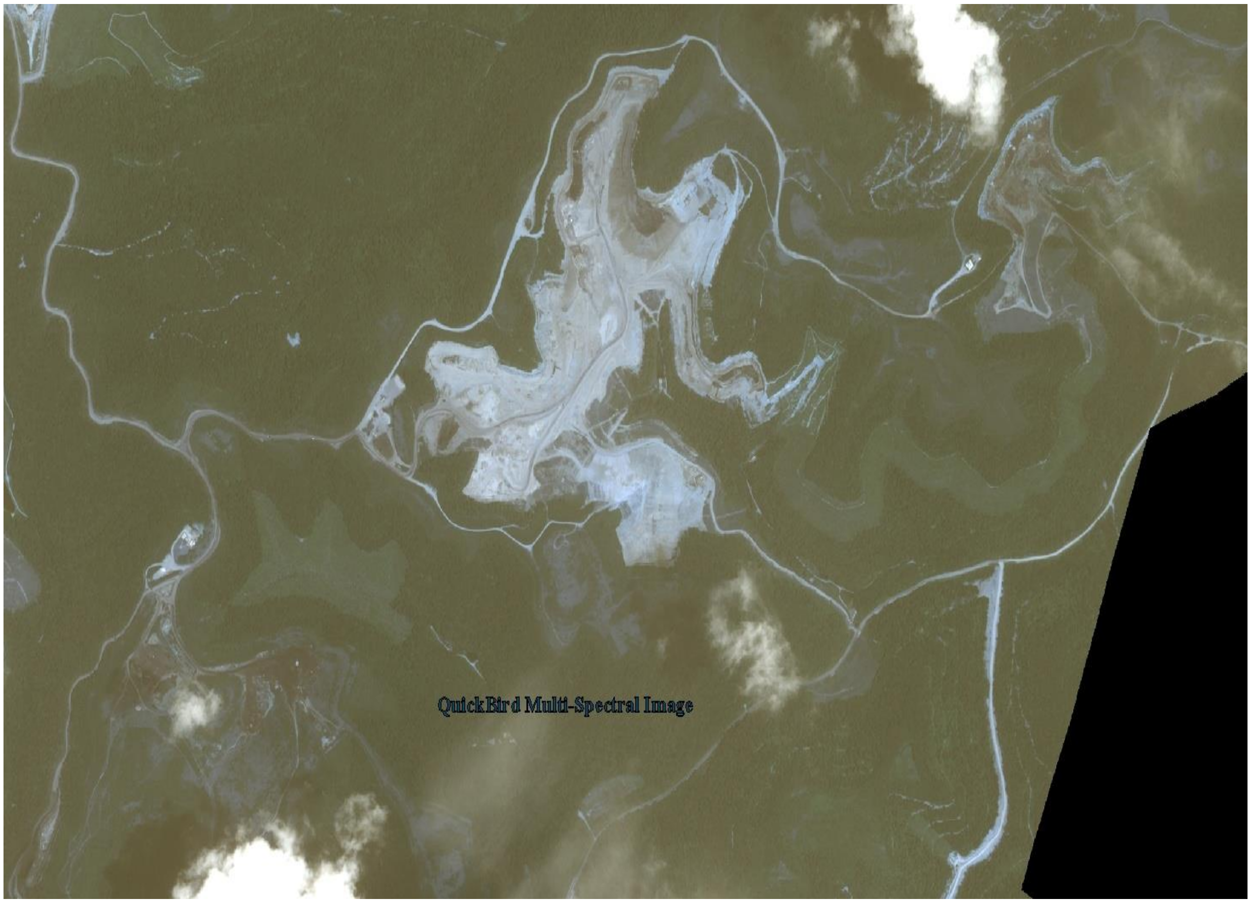

Figure 9. The same drainage areas (including ponds), valley fills, reclaimed areas, and haulroads are visible in the high-resolution imagery. The imagery data can be compared to the permitted data for consistency.

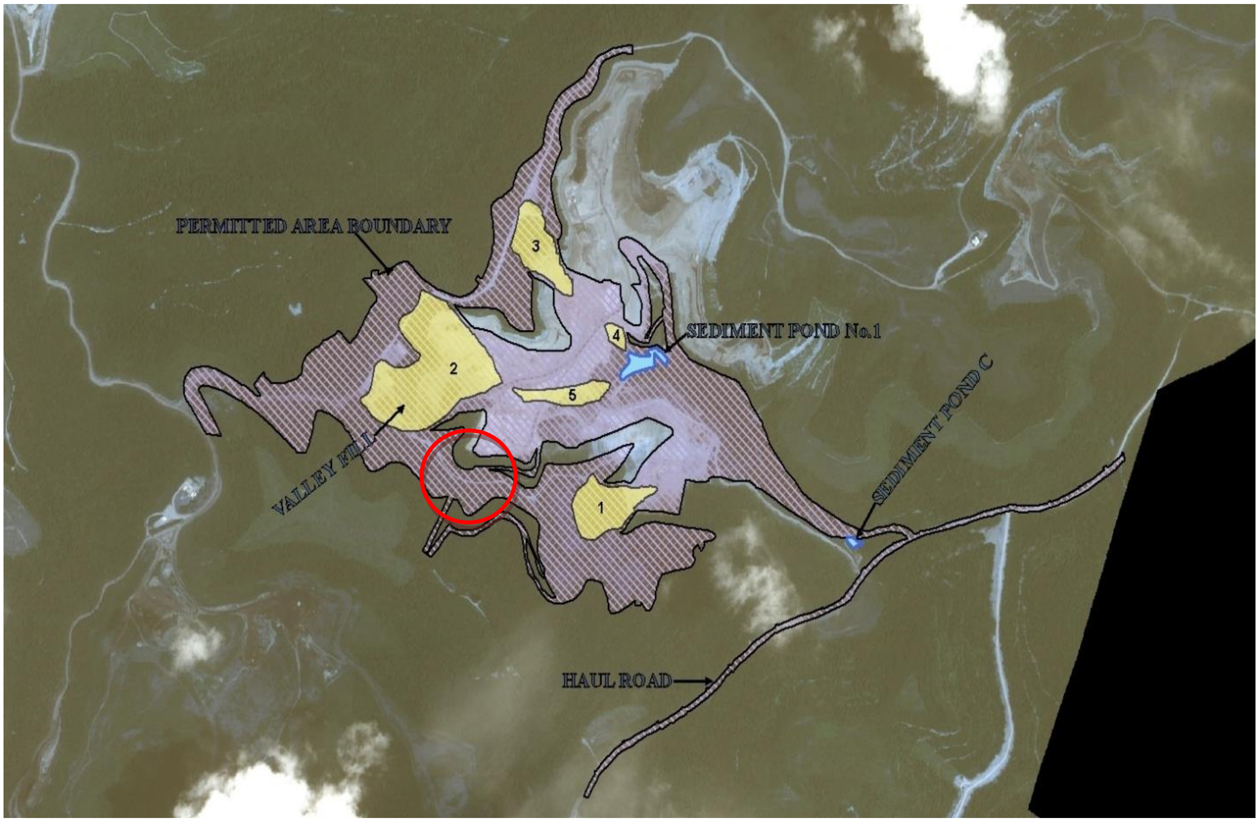

Figure **10.** The overlaid boundaries from the permit data (Fig. 8) onto the satellite imagery (Fig. 9) appear to exhibit an inconsistency in the allowed permit boundary as shown by the red circle. This indicates mining appears beyond the allowed permitted boundaries.

In Fig. 10, permit boundaries were overlaid on the satellite imagery. Based on the results of the remote sensing imagery a determination can be made that delineations of the permitted boundaries appear to be outside the approved permitted area. By viewing only the regular photo, this would be difficult to detect. With real time data acquisition this kind of detailed assessment can aide in making oversight determinations.

<u>Case Study 2</u>

In Fig. 11, a known pond from the permit application appeared to be discolored in the zoomed satellite imagery. After review of the satellite imagery a ground inspection was conducted to determine if the discoloration of the pond was sediment in transport or depositional. The inspection team determined that, in fact the pond had been discolored due to alkaline treatment at the time of imagery acquisition and had since been flushed with fresh water inflow.

Figure 11. A pond identified from the permit application appeared to be discolored in the zoomed satellite imagery. Clouds covered several mining sites making them non-viewable.

Figures 12 and 13 shows the pond from the aerial view and the ground verification view. In fact, the sediment in the pond was depositional and transported sediment.

Figure 12. Photo from inspection of discolored treatment pond shown in satellite imagery.

Figure 13. Photo from field inspection verification of pond after treatment.

Case Study 3

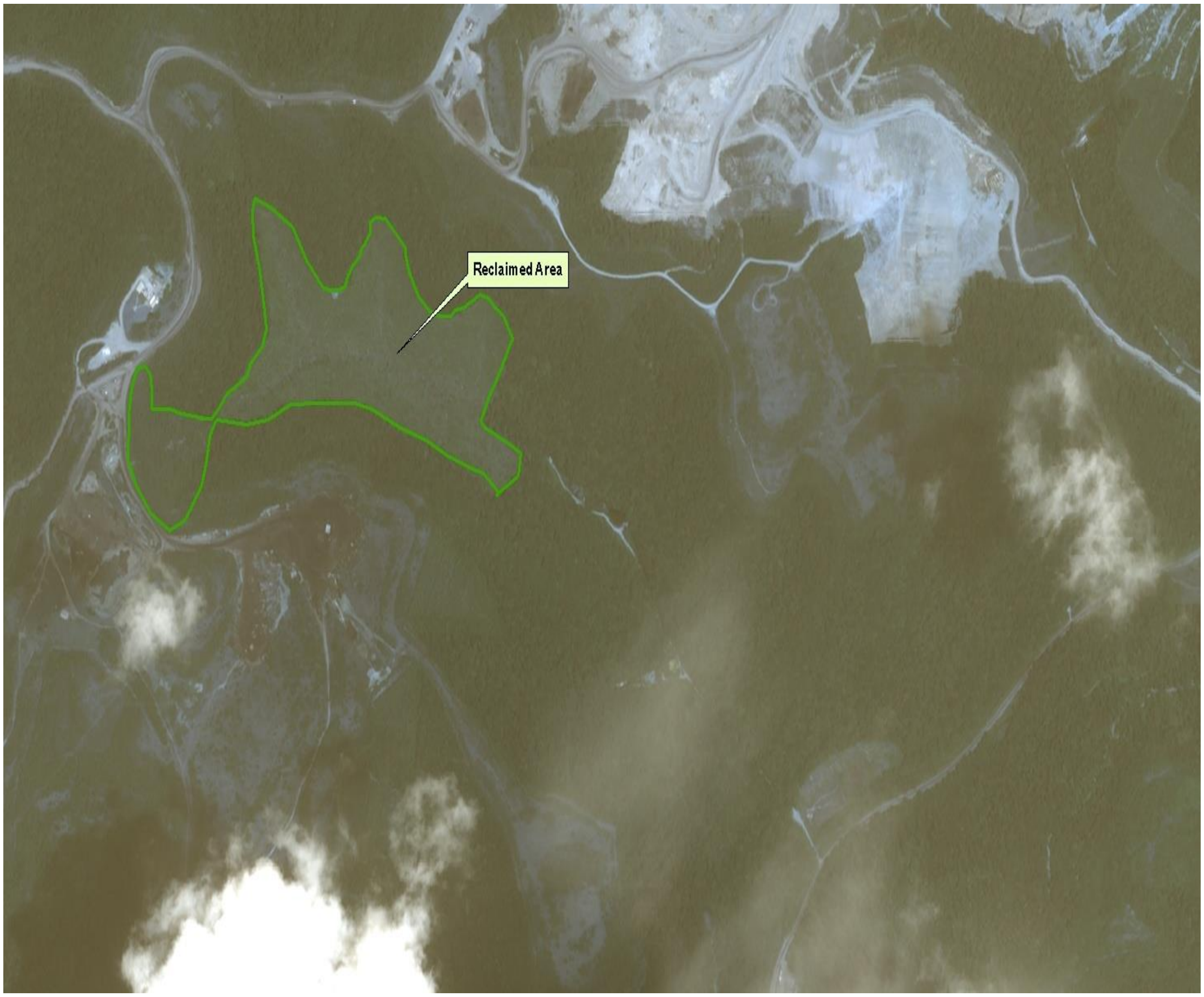

Figure 14. The previously reclaimed areas are visible in the multi-spectral imagery and are identified with a green boundary. Inspectors are able to view large completed areas of successful reclamation prior to any field inspections.

In Fig. 15, the color infrared imagery allows us to see a better representation of revegetation extent on previously reclaimed mined areas. The color infrared photography is primarily used for vegetation studies.

This kind of detailed assessment can offer another tool for oversight management. Without this type of analysis, results such as those shown in the case studies would not be possible. By using available multi-layer GIS datasets developed by the West Virginia Department of Environmental Protection and future acquired high-resolution imagery, multiple surface mining assessment projects can be accomplished. Ground-level photos illustrating the detail captured in the satellite imagery can help verify captured features of interest. Only a field assessment or manual or automated feature extraction from remote sensing can provide verified site-specific data that can be compared to permitted requirements.

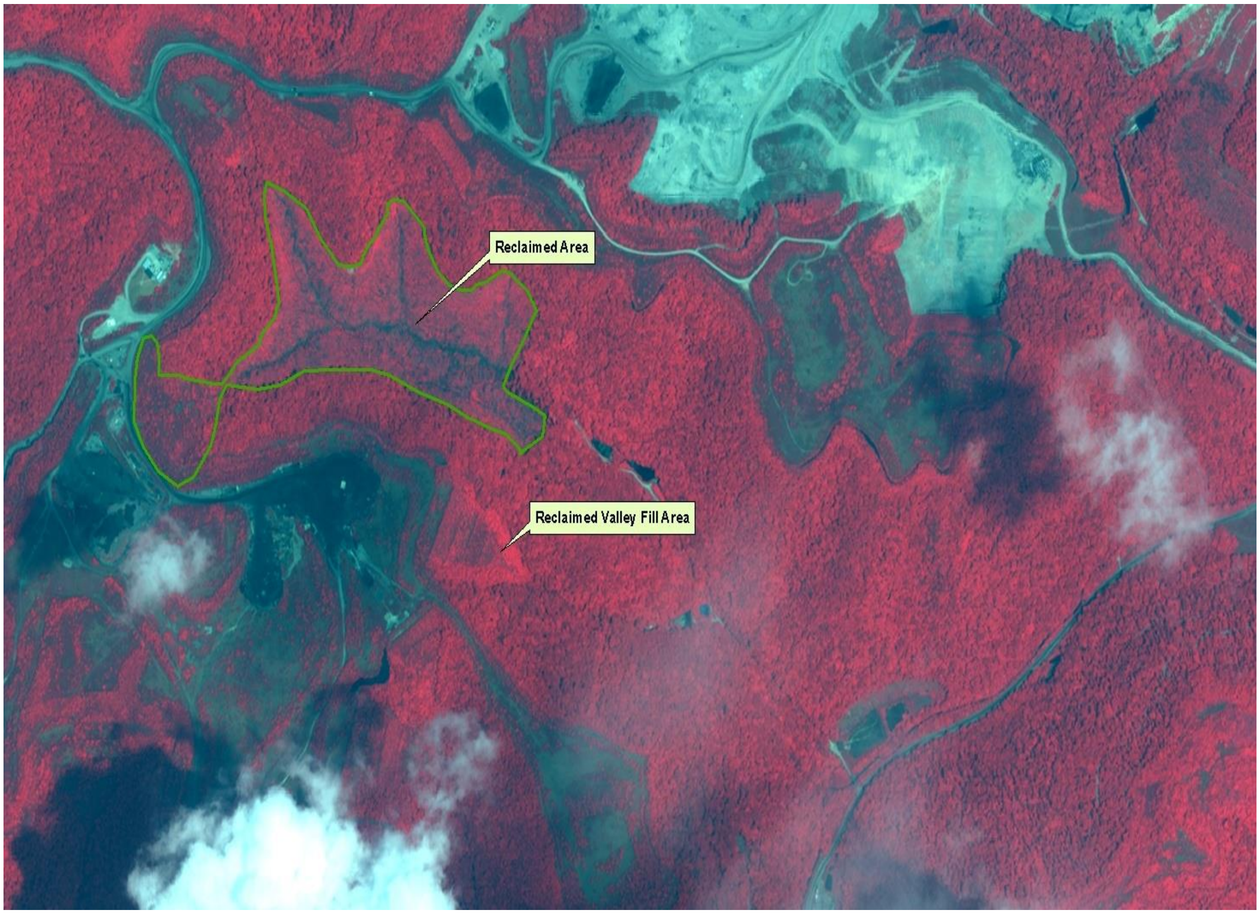

Figure 15. Colored infrared imagery clearly shows vegetation of successfully reclaimed mining areas in red.

Although not ideal, it is a good first step toward a state and federal database of mining activities. The satellite data purchased for this project may have other applications. Already, the Office of Surface Mining Reclamation and Enforcement in Charleston, West Virginia is looking at using the data for analysis of the mountaintop removal program in regard to approximate original contours for large mining complexes. This analysis will not only assist the OSM in coordinating oversight projects but also help fulfill the SMCRA requirements of several programs by guiding the development, the location, and the types of mining activities.

Project Cost Summary

The purpose of this project was to determine if satellite imagery is economically and technologically feasible to reduce the cost associated with helicopter overflights. A project cost summary was assembled (Table 1) and satellite imagery was proven to be a cost effective method of assessing large-scale surface mining activities with a cost difference of $3,885.51 that is a substantial savings.

Table 1. Project Cost Summary

Helicopter

	Rate	Hours	Staff	Total Hours	Cost
Flight Plan Development					
Staff 1	$26.71	15	1	15	$400.65
Staff 2	$65.89	2	1	2	$131.78
Map Preparation					
Staff 3	$50.93	8	1	8	$407.44
Flight					**$12,278.00**
Flight Time					
Staff 4	$31.82	5.3	1	5.3	$168.65
Staff 2	$65.89	5.3	1	5.3	$349.22
Staff 1	$26.71	8	1	8	$213.68
Travel Pilot					
Staff 4	$31.82	1	1	1	$31.82
Staff 2	$65.89	3	3	3	$197.65
			TOTAL	**47.60**	**$14,178.90**

Satellite Imagery

	Rate	Hours	Staff	Total Hours	Cost
<u>Area Preparation</u>					
Staff 3	$50.93	6	1	8	$407.44
<u>Orthorectification</u>					
Staff 3	$50.93	12	3	36	$1,833.48
<u>Image Acquisition</u>					$7000.00
<u>Imagery Review</u>					
Staff 5	$49.50	0.73	17	12.41	$614.30
Staff 6	$27.25	0.73	17	12.41	$338.17
			TOTAL	**68.82**	**$10,293.39**
			AVERAGE HOURLY RATE		**$21.22**
			HELICOPTER COST		**$14,178.90**
			SATELLITE IMAGERY COST		**$10,293.39**
					<u>$ 3,885.51</u>

<u>Note:</u> Savings of approximately $4,000.00 by using the satellite imagery approach.
All staff including technical and inspection was utilized

<u>Conclusions Drawn</u>

The Office of Surface Mining Reclamation and Enforcement in Charleston, West Virginia is considering the high resolution data as a tool for the environmental inspection and enforcement process. An increasing effort to address the fiscal burden of meeting regulatory and environmental protection requirements is an ongoing effort for the agency. Quantification of the location and extent of mining development activities is an important component in managing inspection and enforcement obligations.

For cash-strapped departments, the use of remote sensing and satellite imagery to accurately determine the active and abandoned mining activities can provide significant cost savings as compared to more traditional and manual inspection methods of large scale mining areas. At regional scales, these cost savings can be quite significant. Savings result from the lower cost of satellite imagery as opposed to aerial surveys, as well as reduced staff field time when using satellite imagery to determine the level of activities. Aerial surveys are only conducted annually. Surface mining activities change on a daily basis and impossible for field inspectors to monitor these changes in detail.

Remote sensing analysis can provide a cost-effective tool to evaluate mining activity issues when current real time data is available. Analysis of site condition changes can be conducted to quickly determine where the problem areas are located within a large watershed. This can assist in oversight projects to better control regulatory activities and make improvements. The users will need to become knowledgeable in the benefits derived from the use of remote sensing data

The detailed data acquired from remote sensing studies are becoming the bases for dramatically improved land-use-change, small-scale management studies, improved flood analysis, vegetation assessment, water balance studies, and a host of other innovative approaches that were previously not achievable because of the high cost of site-specific data. However, remote sensing is not seen as a replacement for field surveys. In fact, both methods should work in a complementary way. Field data are always required to calibrate and validate remote sensing analyses. Likewise, remote sensing can help to add value to field surveys. The synergies of both methods should lead to a more efficient system for data capturing to render abundant and reliable information.