FIELD GPS VS. REMOTE SENSING WORKFLOWS FOR LANDFORM REVIEW: SELECTING THE RIGHT TECHNOLOGY FOR THE JOB[1]

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Abstract: The Office of Surface Mining Reclamation and Enforcement (OSM) and the West Virginia Department of Environmental Protection (WVDEP) have reviewed the costs and benefits of two very different types of data gathering to accomplish a specific mission. The agencies generated cross sections of large land disturbances using Trimble Geo Explorer series GPS receiver units ranging from the submeter GeoXT with EVEREST™ multipath rejection technology to the GeoXH with Trimble H-Star™ and optional Zephyr™ external antenna capable of approximately 25 cm. vertical accuracy post processed. Next, they tested the suitability of Lidar data for the same purposes and generated projected cost using that method on the same sites. The potential use of photogrammetry was also considered. By maintaining an accounting of all the time associated with both methods, the agencies gained a better perspective on the costs and benefits of these technologies for future decisions.

In this project, the mission involved comparing pre, proposed and final graded slopes on eight large surface mines in steep slopes in West Virginia as part of the review of "Approximate Original Contour " requirements under the coal mining regulatory program. The agencies found that use of remote sensing technologies, such as aerial based Lidar, can be a cost savings over obtaining digital information using GPS field devices on the ground.

Additional Key Words: Cross Sections, Remote Sensing, Coal Mining.

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Introduction

Background

Since the beginning of recorded history, mankind's activities have changed the earth's topography. Until the past few hundred years, these changes were insignificant when compared to impacts of natural forces such as rainfall-induced erosion, volcanic deposition and glaciation. In the latter half of the twentieth century the significance of civilization's impacts became magnified by our technological advances and the rate at which we can alter our environment increased rapidly. In the coal fields of the Appalachian Mountains in the eastern United States, surface mining began as augering a short distance into a coal outcrop but rapidly evolved to modern practices that arguably alter topography at one of the fastest rates on the planet.

In 1977 the Surface Mining Control and Reclamation Act (SMCRA) was passed by the United States Congress to regulate the manner in which coal mining was conducted to minimize impacts on the environment. Both OSM and WVDEP are charged with its implementation using best practices which inherently requires adapting workflows as new technologies become cost effective.

WVDEP is a partner with OSM on a national level to review various remote sensing techniques to determine where practical applications exist. This effort is aimed not only at proving that certain remote sensing applications will accomplish the agency mission but also at helping the agencies determine if there is an appropriate return on any necessary investment in new equipment, training or contracts.

Purpose

With the goal of evaluating the potential return on investment for various techniques, OSM and WVEP evaluated the costs and potential benefits of different technologies to determine regulatory compliance with landform requirements associated with surface coal mining permitting in West Virginia. Eight permitted facilities and post mining compliance with their respective permit proposals were evaluated. Of three possible methods identified, field data collection using GPS receivers for the creation of elevation data was the method actually used. The selection of GPS, however, was not based on cost or on the quality of data investigators expected this method to produce. Its use was the only choice available because of administrative constraints resulting from the project having not been anticipated during the previous year's budgeting process. This investigation, therefore, documents ramifications of using GPS as the only data collection option, provides insights into costs of other alternative technologies and flags unanswered questions that would have been answered if a more desirable solution could have been employed.

On this particular agency's mission, the precision of the minimal data needed had to be weighed against the timeliness and out-of-budget cost where funding could actually be found.

Setting

The WVDEP requires applicants for coal mining permits to show what the land will look like when they are finished mining. Applicants do this by submitting proposed typical cross sections along various lines within the operation. The cross sections show the proposed elevation for the specific linear distance and assist the WVDEP in determining if the operation is proposing to return the land to its approximate original contour (AOC) or if a variance from AOC should be granted for a specific land use (see Fig. 1 - 2).

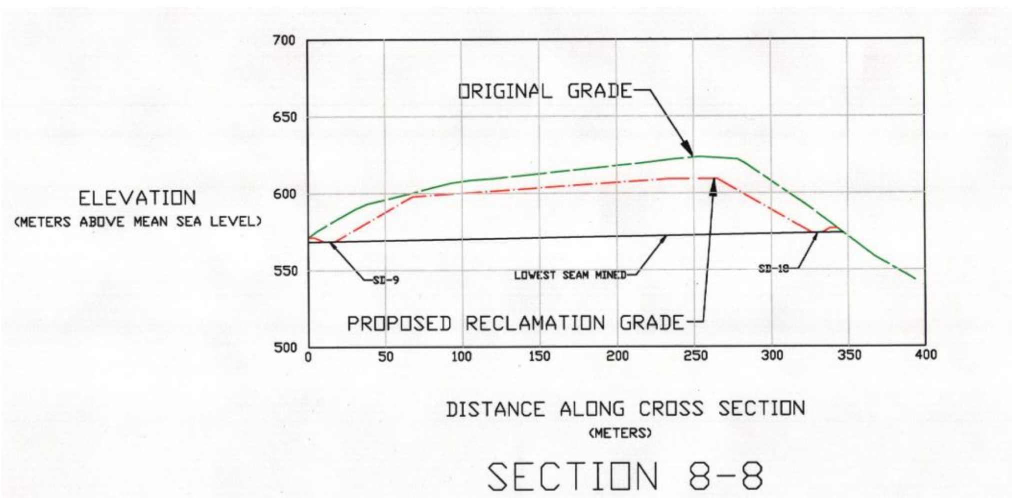

Figure 1. Typical cross section as provided in a permit application.

The federal OSM is charged with oversight of the WVDEP's administration of its regulatory program. In this particular project, OSM's mission was to determine how well the WVDEP was administering the AOC requirements. The mission was to be completed primarily in FY 08. (October 1, 2007 - September 30, 2008). WVDEP agreed to partner with OSM on the oversight project.

The oversight project required a verification of the post mining configuration of the cross sections proposed by the applicant. Because the cross sections are only to be "representative," the field measurements comparing actual to proposed could be several feet off and still show the configuration well enough to be in compliance with the permit. This allowed for several types of data gathering to be considered with timeliness and costs as primary factors.

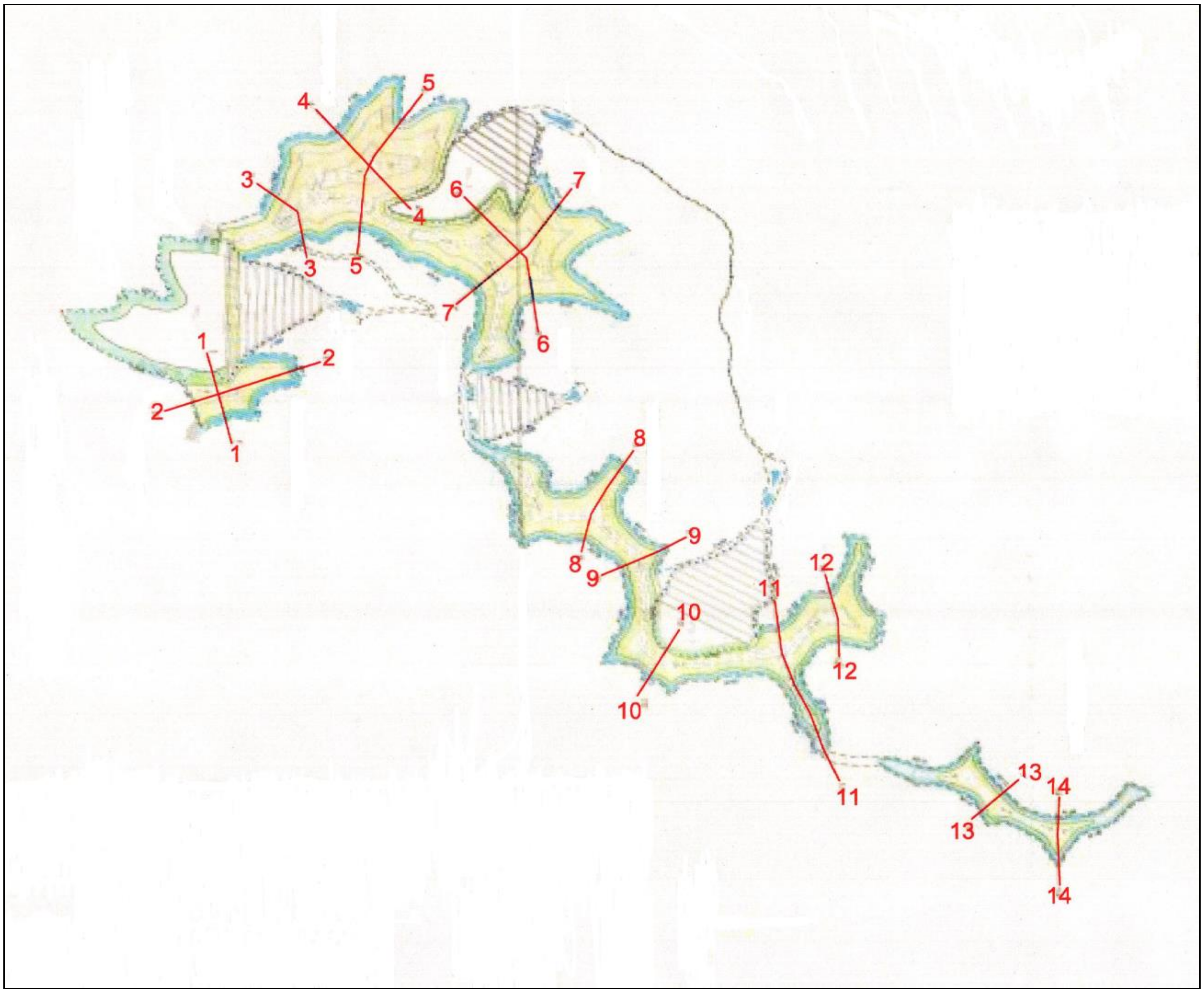

Figure 2. Typical Mine Grading Plan with Cross Section Locations.

Although the short timeline for completion limited the agencies to accomplishing the mission with staff on the ground using GPS receivers, the agencies decided to keep accurate records. The intent was to find monies later to purchase remotely sensed data for comparison with both company-submitted cross sections and GPS cross sections. Unfortunately, additional funding was not found, but costs for production were determined from a commercial source of both photogrammetric-derived and Lidar-based elevation data. This at least allows investigators to evaluate costs of appropriate approaches. Some inferences are also made based on past experience with both photogrammetric- and Lidar-derived elevation datasets from other projects.

Three different data collection methods are available to generate the topographic data needed to evaluate post-mining cross sections:

1. Field GPS equipment to produce elevation data.
2. Remotely sensed elevation data based on photogrammetry and stereo compilation.
3. Remotely sensed elevation data based on airborne Lidar technology.

Site Description

The sites reviewed were large operations by eastern United States standards, removing the entire top of a mountain where reclamation had been completed over a minimum of 0.6 square kilometers. They were scattered northeast to southwest over approximately 120 kilometers which resulted in considerable travel time on the ground and more costly proposals for collection of remotely sensed datasets (see Fig. 3) because sites were widely distributed on the ground. This dispersed pattern was dictated by the programmatic questions being answered by the project but would be typical for issues that might be raised to regulatory authorities in the future. Issues concerning landform will not occur in uniform fashion in central locations.

Four of the mined out areas were to return to AOC and four were to be left in a more level condition to provide for a specified post-mining land use. The applicants covered the areas in the study with three to twelve typical cross sections. The agencies decided to try to verify whether these completed operations resembled the proposed cross sections by making elevation measurements of the actual completed operation along the same line as proposed in the cross section for each approved permit (see Fig. 4).

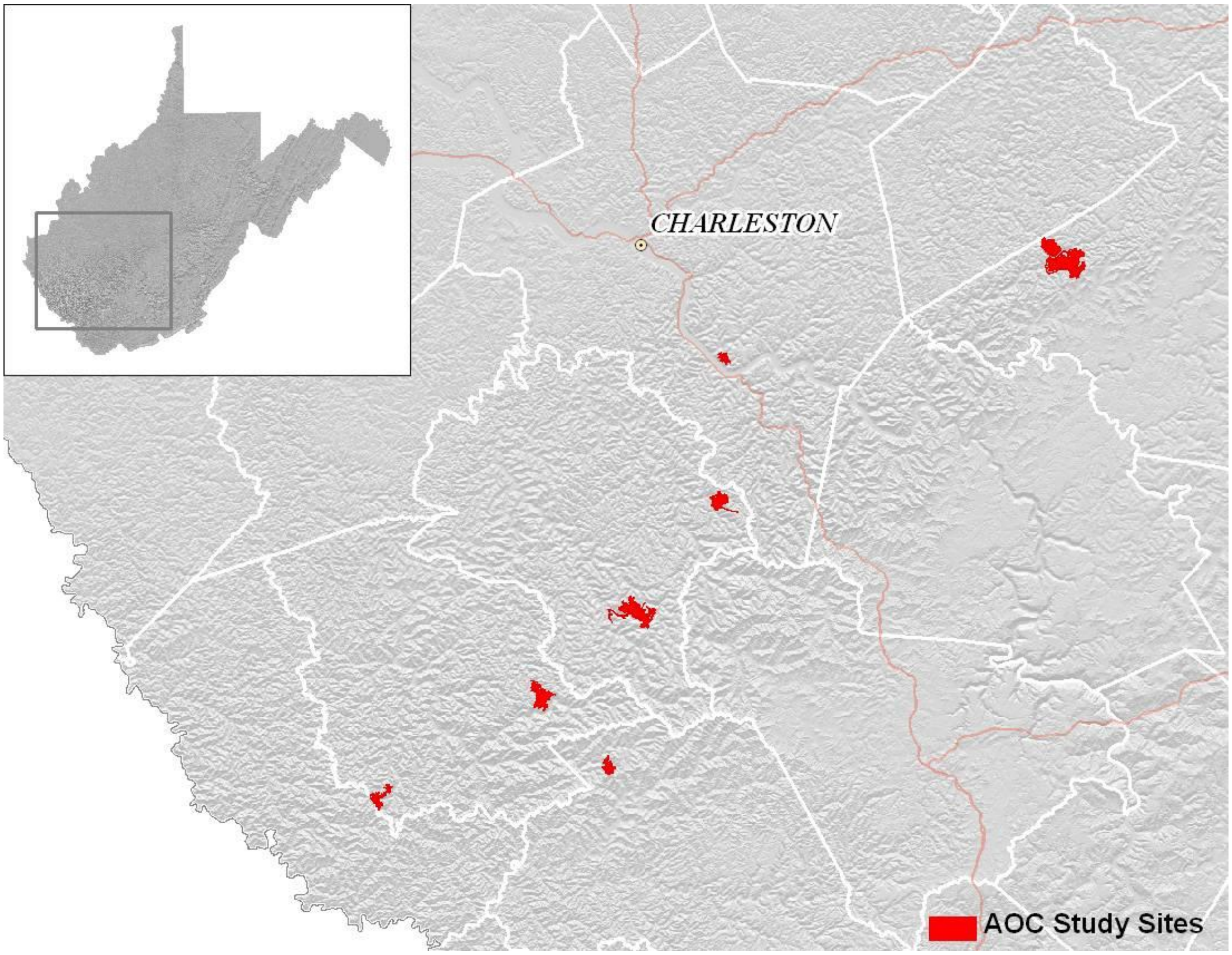

Figure 3. Distribution of sites investigated in southern West Virginia.

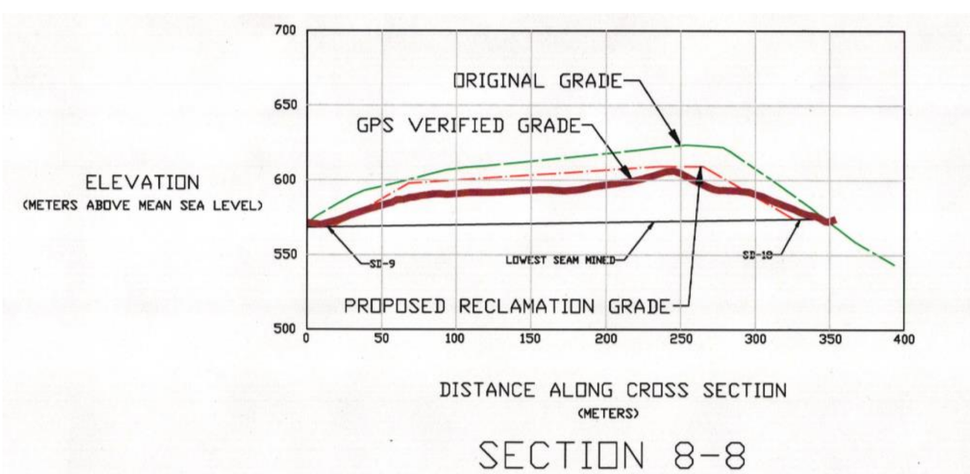

Figure 4: Cross section example.

The Only Method of Data Production Funded: GPS Field Units

Preparation for Field Work

The collection of elevation data on large reclaimed mines using GPS units in the field was an intensive task. The many steps used to build this elevation data required preparation first in the office, collection in the field, and then processing the data before comparison of company-submitted and GPSed transects could begin.

Once a permit was selected, the reclamation profiles in the approved permit application were used to build a line shape file. Coordinates for reclamation profiles were found by georeferencing the approved plans. The vertices in these profiles were then projected in ArcGIS to create a line shapefile. Using a snapping feature between vertices allowed the user to build a real world projection of the approved reclamation profiles. For each permit studied, there were up to 14 approved profiles that were created using from two to nine georeferenced vertices for each profile.

Field Collection of Elevation Data along Cross Sections

The shapefile created in the office was used to collect data in the field by showing the real-world location of the approved reclamation profiles. As many as three individuals collected elevations using handheld Trimble GeoXT and GeoXH GPS receivers. Once at the terminus of the selected profile, the individual attempted to walk the exact profile using the shapefile in ArcPad for field orientation and direction. Data collection was conducted using two methods – collecting a stream of vertices while walking that formed a continuous line using the GeoXH and external antenna, or collecting a series of point features, requiring the user to stop and initiate data collection while using the GeoXT with an internal antenna.

Collecting the data in the field was a demanding process. Once at the site, the GPS operators were required to locate the terminus of the profiles by foot or vehicle, walk the length of the profile while collecting data, and move to the next profile by foot or vehicle. See Fig. 5 and 6.

The selected permits were scattered across five counties in southern West Virginia that required as much as five hours of drive time roundtrip. Moving between profiles once at the permit site was also a time-consuming event accomplished either by vehicle or on foot at permits that covered up to 900 ha. Additionally, many profiles exceeded 1.6 km. in length and traversed steep and difficult terrain. Nearly all of the permits required longer than normal work days (field work plus travel time) to complete the intensive data collection.

Figure 5. Aerial Photo Showing Cross Section Locations.

Processing Collected Data

Field data was gathered using the handheld Trimble GPS data receivers and then corrected in the office using Trimble Pathfinder Office v4.0. The GPS data were exported from Pathfinder Office as shapefiles. The corrected positions were then brought into ESRI's ArcMap for previewing and additional processing such as deleting anomalies. Elevation data could then be analyzed and compared to the approved reclamation profiles in the application using AutoCAD. Preparing the field data for interpretive use was as taxing, if not more so, than the collection of the data.

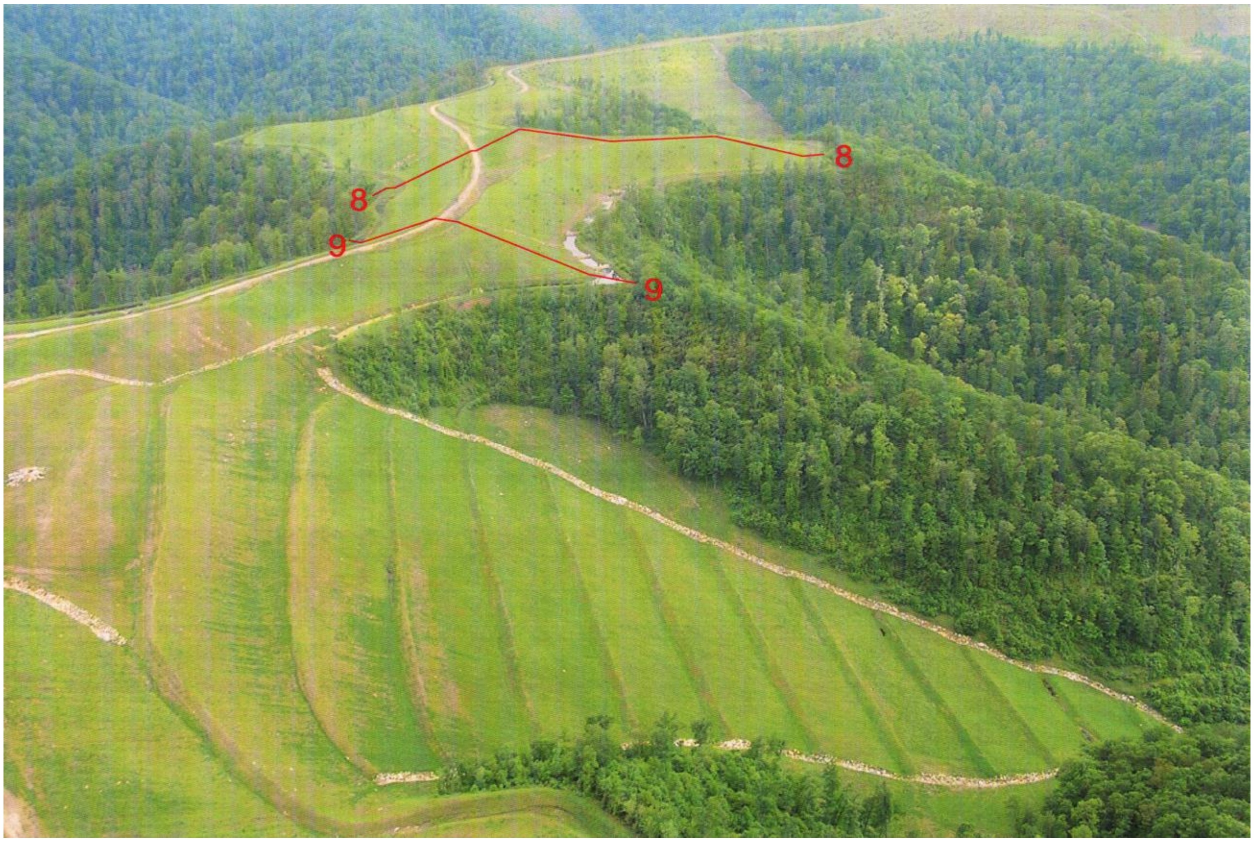

Figure 6. Aerial Photo Showing Cross Section Locations.

GPS Field Data Collection Procedure and Accuracy Assessment

Field data collection was conducted using Trimble GeoXH and GeoXT handheld GPS receivers with ESRI ArcPad and Trimble GPS Correct software installed.

The GeoXH used an external zephyr antenna attached to a backpack, while GeoXTs relied on internal antennas. Antenna height for the GeoXH was calculated by measuring the distance from the floor to the base of the antenna while wearing the backpack. This value was entered into the Antenna height field in ArcPad. Antenna heights for the GeoXTs were based on a typical handheld position utilized during data collection. For future investigations, additional precision could be obtained using a range pole to fix the GeoXT, or an external hurricane antenna.

Data collection occurred under open sky conditions, and obtaining a lock on the minimum number of satellites was rarely a problem. The PDOP cutoff value was left at the default setting of 6, which caused temporary interruption in data collection on several occasions due to poor satellite geometry.

Field data was collected by following profile lines displayed on the receivers using the ArcPad software. Profile lines were created as line shapefiles from permit maps and loaded into the GPS units prior to arriving at the site.

During the project, it was found that significantly better results could be obtained by disabling automatic map rotation while collecting data. At walking speeds, the receiver could not reliably orient the map to the direction of travel. In addition, automatic rotation frequently caused changes in the map display scale. Normal procedure called for the scale interval to read ten meters or less while following the profile lines. With automatic rotation disabled, the display scale remained fixed.

The GeoXH was set up to collect data at a distance interval of 1-meter. Profiles were walked continuously, collecting a stream of vertices that formed a continuous line. The GeoXTs were configured to collect a series of point features, requiring the data collector to stop and initiate data collection at appropriate intervals along the profile. Initially, point features were set up to average ten positions. However, further testing on fixed benchmarks and survey stations with the GeoXT indicated that this was not necessary.

Field data was processed using Trimble Pathfinder Office v4.0. The zephyr antenna used with the GeoXH allowed dual-frequency data collection and carrier processing from multiple base stations, while the GeoXT data was code-corrected using WVDEP's base station located in Kanawha City. Shapefiles representing corrected positions were output from Pathfinder Office and brought into ESRI ArcMap for additional processing.

Accuracy of the receivers was evaluated several times during the project using NGS first-order benchmarks, survey stations, and a locally surveyed marker. Table 1 indicates the results of these tests. The Kanawha City location was used for both horizontal and vertical tests. This marker is an aluminum disk set in cement outside the WVDEP headquarters building, and is often used to test the operation of GPS receivers. The position was surveyed using a Trimble 5700, with data processed using the OPUS service. HX2018 is a first-order vertical benchmark located in a railroad bridge abutment in downtown Charleston, West Virginia. AJ2515 is a GPS survey marker located in front of the state capitol building.

Table 1. Accuracy results for GeoXT and GeoXH receivers on several known locations.

	Location	Receiver	Antenna	Features	Positions per Feature	RMSE Error (meters)	95% Percentile (meters)	Date
	Horizontal Tests							
1	Kanwaha City	GeoXH	zephyr	40	10	0.1354	0.2344	2/17/2008
2	AJ2515	GeoXH	zephyr	2646	1	0.1806	0.3539	3/16/2008
3	Kanwaha City	GeoXT	internal	39	10	1.3566	2.3480	2/17/2008
4	Kanwaha City	GeoXT	internal	390	1	1.3581	2.3507	2/17/2008
5	AJ2515	GeoXT	internal	1222	1	0.9419	1.8461	4/6/2008
	Vertical Tests							
6	HX2018	GeoXH	zephyr	40	10	0.0948	0.1857	2/18/2008
7	HX2018	GeoXH	zephyr	99	1	0.2064	0.4046	2/18/2008
8	Kanawha City	GeoXH	zephyr	40	10	0.1568	0.3074	2/17/2008
9	AJ2515	GeoXH	zephyr	2646	1	0.1751	0.3432	3/16/2008
10	HX2018	GeoXT	internal	40	10	1.2538	2.4575	2/18/2008
11	HX2018	GeoXT	internal	400	1	1.2734	2.4959	2/18/2008
12	Kanawha City	GeoXT	internal	39	10	1.1427	2.2396	2/17/2008
13	Kanawha City	GeoXT	internal	390	1	1.1443	2.2428	2/17/2008
14	AJ2515	GeoXT	internal	1222	1	2.0009	3.9219	4/6/2008

Though these results are not part of a systematic, comprehensive evaluation of receiver accuracy, they represent typical results, similar to what would be obtained in the field. Test pairs 3-4, 10-11, and 12-13 show that averaging a small number of points for each feature is not warranted when using the GeoXT, which led to the practice being dropped part way through the study.

Published specifications indicate horizontal error for the GeoXH should be 20cm RMSE, which was surpassed in these tests (13.5cm and 18.1cm). The GeoXT is expected to produce sub-meter horizontal error, which was achieved in test 5 (0.94m), but not in test 4 (1.36m). Vertical accuracies generally are not given in manufacturer data sheets, making it more important to confirm receiver capability on actual survey markers. The vertical tests on the GeoXH show an RMSE error of less than 21cm for four separate tests conducted on three different locations, while the GeoXT produced errors of 2m or less using the same locations.

Based on the tests presented in Table 1, some profiles may exhibit vertical RMSE errors approaching 2m, though in general it should be less. A secondary error source is associated with GPS readings that fall some distance from the profile line. The amount of error contributed by this factor is arguably minimal for profiles that run parallel to the slope, or flat areas, but could be important for profiles that cross slopes at increasingly larger angles approaching perpendicular.

One of the parameters calculated for all GPS positions was the distance from the GPS point to the profile line. Figure 7 shows the distribution of these errors for one of the project sites. Average distance from the profile lines for all 2,433 GPS readings averaged 1.6m. This figure is actually quite good, considering real-time horizontal GPS errors without differential correction are typically in the range of 3-5m. In terms of the amount of vertical error contributed by these offsets, consider that an average (1.6m) offset from a profile running perpendicular to a 30 degree slope would introduce an additional 0.92m vertical component to the field solution.

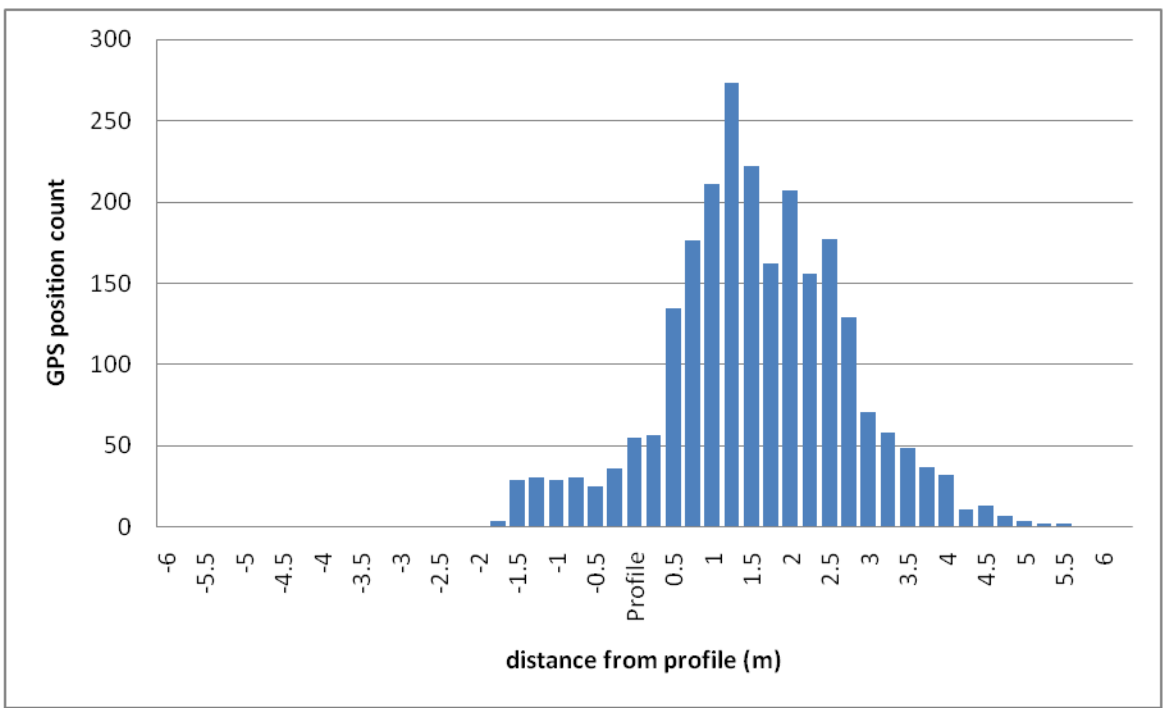

Figure 7. Deviation from profile line for 2,433 GPS positions collected for one permit. Negative numbers represent offsets to the left of the profile, positive numbers to the right.

Costs of GPS Data Collection

The agencies used personnel available for the project without regard to salary so both senior personnel at a relatively high salary and more junior personnel were involved in the data gathering and analysis. This would likely be typical for this type government mission.

Seven individuals (five Federal and two State) worked part time on the project and spent anywhere from 4 hours to 449 hours on the data gathering and analysis. This time was kept in categories as shown in Table 2.

Table 2. AOC Project Costs.

Cost description	**Personnel (hrs)**	**Personnel Cost**	**Vehicle**	**Travel**
Travel time from office to sites	169		4088 GOV miles	7 overnight trips
Time on site with GPS	166			
Data interpretation and analysis	520			
Total hours	855			
Total salaries and benefits for 855 project hours		$36,766		
Overhead allowance (30%)		$11,029		
Mileage allowance ($.50)			$ 2,044	
Per Diem				$ 976
Total cost		$ 47,795	$2,044	$ 976
Grand total				$50,815

This total is developed for comparison to other methodologies only. The cost to the agencies for this project would not normally be shown as separate from their annual budget. The mission was completed with existing personnel and equipment and within normal travel projections. Within OSM, evaluations of a state process are a routine part of the mission; project personnel, for the most part, are still performing within the scope of their duties. However, the people involved were engineers and inspectors and their skills and expertise would normally be better used in areas other than repetitive raw data collection on elevations.

The total cost for this methodology for eight project sites was $50,815 or roughly $6,350 per site. It is quite likely these costs would significantly decrease if the agencies routinely did this type work.

Remote Sensed Data Using Photogrammetry or Airborne Lidar Technology

OSM requested quotations for outsourcing collection of aerial photography and Lidar to produce appropriate elevation datasets. Specifications for both remote sensing technologies required production of 1'=100' two foot contour interval digital topographic mapping. Orthophotography produced was to be 1"=100' with a 6-inch pixel resolution. A recent trend in statewide mapping programs is production of two foot contours. Examples in close proximity to West Virginia include Pennsylvania (see http://www.pamap.info/faq/lidar.htm) and Ohio (http://www.gis-t.org/files/PzgC7.pdf). The same specifications are currently used by WVDEP's Office of Abandoned Mine Lands & Reclamation to solicit mapping services for the abatement of problems arising from abandoned mine lands.

Unfortunately, the agencies were not able to adjust their previously planned budgets in time to acquire aerial data and still meet the timing for the mission objectives. Based on other projects involving Lidar, the reviewers believe digital elevation models could have been obtained and delivered faster than the field work was completed with GPS had the budget process allowed for it. The decision was made to review landforms after the federal fiscal year began and the budget process could not be adjusted in time to meet the mission deadlines.

Precisely walking profiles provided in the permitting process with GPS receivers proved a difficult proposition in the field. Comparison of the planned versus actual track taken varies directly with terrain slope, recent rain and other factors. Likewise, use of either photogrammetry-derived or Lidar-derived elevation data could not be expected to align perfectly with the company-provided profiles. Michael C. Shank, WVDEP's GIS Database Administrator, in an unpublished but downloadable paper used geodetic quality survey data as a control to evaluate Lidar data quality (http://gis.wvdep.org/tagis/projects/lidar_accuracy_assessment.pdf). Shank's comparison is based on coincident points meeting a maximum horizontal separation criterion. His initial comparison is further refined to minimize effects of steep slopes. Shank made an argument for interpolating regular grids from Lidar point data through the use of TINs, and the resulting grid was then compared to the ground survey data. His comparison between Lidar spot elevations and survey transects was conducted by selecting Lidar points falling less than 1 meter from a coincident survey point.

Had funding been available for purchase of photogrammetric or Lidar-derived elevation data, a metric could have been developed using the same logic. The variability of GPSed profile data from transects provided via the permitting process could have been used to establish an average distance away from the targeted course. A point collected by either remote sensing technique falling in such a "buffer" zone could then be used in evaluating AOC.

Left unanswered by GPSing is the question of where all materials finally rest on each of the sites. Either remote sensing technique would have produced a dataset that could have been used to answer that question. Figure 8 taken from Shank's unpublished paper shows GPSed data and Lidar both collected in Scrabble Creek, West Virginia. GPSed data could be used to produce transects across the stream but Lidar data could have produced highly accurate contours of the entire watershed.

Proposed Costs for Remotely Sensed Data Compared to GPS Costs

From prior work using Lidar datasets created from an overflight of abandoned mine sites in 2008 by WVDEP, only a few seconds are required to generate a profile in ArcGIS. Therefore, an estimated 1.5 to 2 person hours would be adequate to create all Lidar based profiles for this AOC study, adding very little in cost compared to other tasks in any of the three proposed workflows.

Table 3 compares costs of all three methods that could have been employed to produce elevation data. While GPSing the sites by walking proposed mining transects met the timeliness condition in that it could be funded, it was not the most cost effective solution. Technical specifications of the more expensive of the two Trimble GPS receivers utilized met the project's very loose elevation accuracy requirements while the less expensive model did not. Neither receiver's specifications could meet the National Map Accuracy standard, the American Society for Photogrammetry and Remote Sensing standard or the National Standard for Spatial Data Accuracy guidelines for 1"=100' mapping that either remotely sensed method could have met.

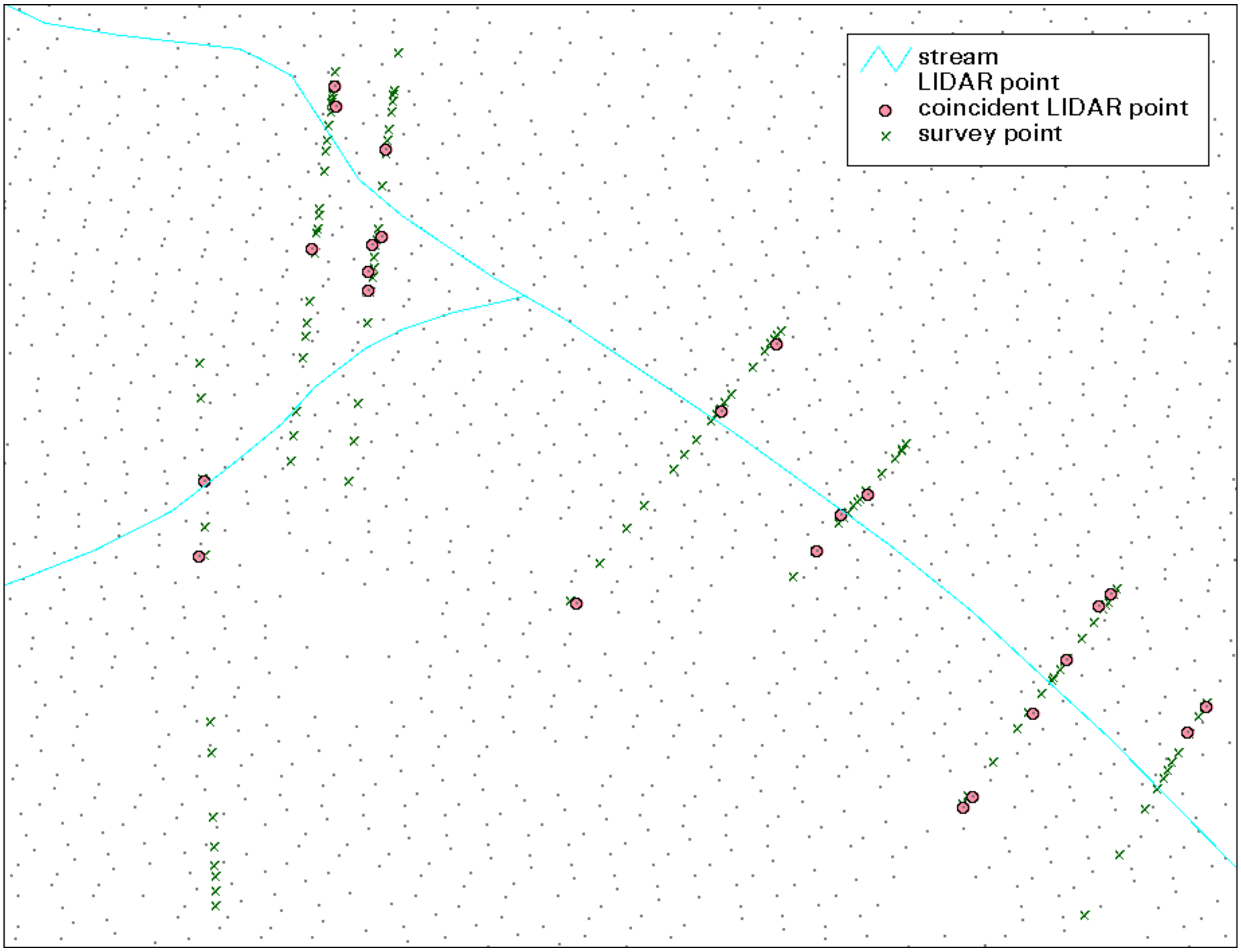

Figure 8. Data density comparison of stream transects prduced using geodetic quality GPS equipment to a remotely sensed Lidar dataset in the Scrabble Creek watershed in southern West Virginia.

Table 3: Cost Comparison of Methods for AOC Elevation Data Production

Method of Data Collection	Dataset Density Across Selected Sites	Cost		
GPSed field elevations post-processed	Low	$50,815	**Cost Comparisons**	**Difference in Cost**
Classic photogrammetry derived elevation data	High	$72,267	GPS vs. Photogrammetry	$21,452
Lidar derived elevation data	Highest	$26,763	Photogrammetry vs. Lidar	-$45,504
			GPS vs. Lidar	-$24,052

Likewise, circa 1950's film photography with stereo coverage as a source for stereo compilation to produce elevations proved to be the most costly method considered. Because of recent technical advances in Lidar sensors being integrated with geodetic quality GPS receivers and precision inertial measurement systems thereby reducing the need for extensive ground control, the quoted cost for Lidar acquisition was the most cost effective method of the three. Lidar would also have created the best point set density had it been employed. Advantages of using Lidar compared to elevation production via photogrammetry include:

- Significant reduction in the number of ground control points required.
- Denser point grid (10' to 15').
- More accurate control in wooded and hillside shadow areas (e.g., north facing slopes).
- Production of a digital surface model of building roofs, tree canopy, etc., as a supplemental end product.
- Considerably less expensive data production costs.

Photogrammetry and Lidar workflows would both meet all three standards/guidelines for accuracy of production of geospatial products.

Comparison Conclusions

- The use of remotely sensed data can actually save significant dollars and resources on an actual mission that would otherwise involve developing elevation data from GPS units in the field.
- In a typical government setting, the field use of GPS units remains a viable choice when timeliness is critical to the mission and the required staff and equipment can be readily deployed. The agencies should consider other methods when several sites are involved.
- The GPS data acquired in the field is limited to the initial paths and more information would require a renewed effort. In other words, when the field conditions did not match the proposed cross sections, the initial field information gathered by following a few lines on site may not tell you where the material went that is not where it was planned to be. Cut and fill volumes cannot be obtained without more field work. Cut and fill information for the entire area would have been readily available had Lidar been acquired. Production of equivalent data density using GPS equipment would have been impractical.
- In relatively small agencies, the costs for gathering significant amounts of GPS data is likely to be high because it is not a normal daily duty. Also, in this exercise, the people available for the project were experienced professional engineers and mine inspectors. They were overqualified for the large-scale field data gathering of GPS elevation data and their valuable time could have been spent on more challenging projects. The use of Lidar would have minimized the amount of time experts spent gathering data.
- Agencies need to begin to plan for the use of remotely gathered data as part of the normal budget cycle to gain government efficiency and reduce costs. Likewise, use of newer, better technologies should become part of routine workflows. The technology is available and can be proven to save costs.