A Cause and Effect Relationship between Antiquated Mapping Standards/Techniques and Recent Mining Accidents and Fatalities[1]

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Abstract. Reliance on last millennium's antiquated mapping standards/techniques had a documented role in recent mining accidents and fatalities. Disasters beginning with the Martin County, Kentucky coal slurry impoundment failure and concluding with the Aracoma incident in Logan County, West Virginia, a cause and effect relationship was found between events and inaccurate paper maps and/or limited survey control. These two factors either played a role in causing these events or significantly impeded rescue efforts. The Mine Improvement and New Emergency Response Act of 2006 (MINER Act), was enacted because of the unacceptable number of deaths in 2006. Unfortunately the MINER Act failed to address the role played by poor maps and insufficient awareness of proximity of people to hazards that ultimately lead to deaths in the coal fields. In the last two years, West Virginia Department of Environmental Protection processed over eight hundred mining permit maps in updating the Agency's digital mine boundary geodatabase. Many of these maps appeared to be very accurate when initially inspected. That twenty-four month project, however, showed that error could be produced at every step in the automation process. While it is possible to quantify and control errors associated with the paper to digital conversion process to some degree, it is impossible to evaluate overall map accuracy because the accuracy of the source map itself is unknown. This situation did not change with adoption of CAD software by the mining industry. CAD has resulted in maps that present an appearance of precision, and perhaps an unconscious assumption of high accuracy. Our experience in the past two years shows that a subset of CAD maps received in the permitting process also contain unacceptable inaccuracies.

The solution to this problem is adoption of modern geospatial standards and techniques. The joint OSM/States National Coal Mining Geospatial Committee's effort to create standards for coal mining geospatial data attempts to improve the ability of both industry and regulatory authorities to accurately locate activities on the ground thereby lowering risk and hopefully avoiding future loss of life. A mechanism that succeeds in converting the permitting process to use modern geospatial techniques remains undiscovered.

Additional Key Words: SMCRA, MINER Act, GIS, CAD, map automation, interoperability, mining disaster, Aracoma, error, survey control

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Introduction

Coal mining began in the United States in the 1740s but Congress did not pass the first federal statute governing the mine industry until 1891. That legislation established minimum ventilation requirements at underground coal mines but only applied to mines in U.S. territories. It also made it unlawful for operators to employ children less than 12 years of age. This was the beginning of increasingly comprehensive federal legislation regulating the mining industry.

During the decade from 1900 to 1910 the number of coal mine fatalities exceeded 2,000 annually. This loss of life resulted in Congress establishing the Bureau of Mines as a new agency in the Department of the Interior in 1910. The newly established Bureau was tasked to conduct research and to reduce accidents in the coal mining industry. No inspection authority, however, was given to the Bureau at that time. Federal inspectors were not empowered by Congress to enter mines until 1941. Formulation of the first code of federal regulations for mine safety was authorized by Congress in 1947.

Surface mining did not become widespread until the 1930s. At the end of that decade, states began to enact the first laws regulating the nation's surface coal mining industrial activities. West Virginia was the first state to pass legislation in 1939 followed by Indiana (1941), Illinois (1943) and Pennsylvania (1945). Demand for coal during World War II, however, led to mining being conducted to support the war effort with little regard for environmental consequences. After the war ended, states resumed enactment of legislation and expanded regulatory programs. During this post-war period some began to require mining permits or the posting of bonds to ensure that mined lands would be properly reclaimed after extraction was completed. Since laws varied from state to state, mining operations were perceived by Congress to be expanding more in states where regulations were least restrictive. Additional federal oversight, therefore, was perceived as necessary.

The Federal Coal Mine Safety Act of 1952 provided for annual inspections in certain underground coal mines, and gave the Bureau of Mines limited enforcement authority, including power to issue violation notices and imminent danger withdrawal orders. This Act also authorized assessment of civil penalties against operators for noncompliance with withdrawal orders or for refusing inspectors access to mine property. No empowerment, however, was made

for monetary penalties for noncompliance with safety provisions. In 1966, Congress finally extended coverage of the 1952 Coal Act to all underground coal mines.

The Federal Coal Mine Health and Safety Act of 1969 (often referred to as the Coal Act), was more comprehensive and stringent than any previous Federal legislation governing the mining industry and included both surface and underground coal mines within its scope. For the first time federal legislation mandated annual performance standards (two annual inspections of every surface coal mine and four at every underground coal mine) and dramatically increased federal enforcement powers. In addition to monetary penalties for all violations, this Act established criminal penalties for willful violations. The Coal Act also provided compensation for miners who were totally and permanently disabled by the progressive respiratory disease caused by the inhalation of fine coal dust known as "black lung".

Through administrative action, the Secretary of the Interior created the Mining Enforcement and Safety Administration (MESA) as a new departmental agency separate from the Bureau of Mines in 1973. MESA assumed the safety and health enforcement functions formerly carried out by the Bureau thereby avoiding the possible appearance of a conflict of interest between the enforcement of mine safety and health standards and the Bureau's responsibilities for mineral resource development.

Congress sent additional federal mining regulation bills to President Gerald Ford in 1974 and again in 1975. They were vetoed by President Ford because of concern that they would harm the coal industry, increase inflation, and restrict the nation’s energy supply. Even more stringent than proposed legislation killed by Ford, the Surface Mining Control and Reclamation Act of 1977 (SMCRA) was sent by Congress to newly elected President Jimmy Carter. President Carter signed SMCRA into law August 3, 1977. SMCRA created two programs: one for regulating active coal mines and a second for reclaiming abandoned mine lands. It also created the Office of Surface Mining to promulgate regulations, to fund state regulatory and reclamation efforts, and to ensure consistency among state regulatory programs.

Even with joint Federal and State protections, post-Y2K environmental and safety problems continued. Inspection of published reports regarding cause and effect of twenty-first century

problems discloses a cause and effect relationship between antiquated mapping standards/techniques and recent mining accidents and fatalities.

Role of Inaccurate Paper Maps and Limited Survey Control in Recent Mining Disasters

The information that follows was compiled to demonstrate this irrefutable relationship between inaccurate mapping and limited survey control in recent national mining disasters. In some instances inaccurate mapping was a direct cause of an emergency. On other occasions it was a significant impediment to rescue operations. Survey control was also discovered to have been both a causal factor and a rescue impediment.

Inez, Kentucky Slurry Impoundment Failure

On Oct. 11, 2000 the nation's largest coal slurry spill occurred at the Martin County Coal Company in Inez, Kentucky. At the time it occurred, the United States Environmental Protection Agency called the Inez spill the worst environmental catastrophe in the history of the Eastern United States. It was documented as causing far more extensive damage than the widely known 1989 Exxon Valdez oil spill off the coast of Alaska, dumping an estimated 306 million gallons of toxic sludge down 100 miles of waterways. The MHSA report issued October 17, 2001 pointed to inaccurate mapping as the principal cause of this environmental disaster. *"The investigation of the spill shows that the protective barrier between an underground mine and the Martin County coal-waste impoundment was far thinner than regulators thought. Map information Martin County Coal Co. gave the state in seeking a permit to expand the impoundment showed a barrier of about 70 feet (21 m) between the bottom of the impoundment and the mine. However, … the barrier was apparently less than 10 feet (3 m) thick."*. Additional research indicates that this finding has subsequently been adjusted in later MHSA publications.

The legacy of poorly documented extent of old underground mined out voids presents very real potential for additional future environmental disasters. Recognizing this, federal and state regulating authorities are working together to capture images of old paper maps before they deteriorate to the point they cannot be used or are lost. These resulting scanned images are sometimes subsequently georeferenced for comparison with other geographic information (GI). An even more progressive use of the georeferenced images is conversion of the extent of the

underground mining to polygons for inclusion in today's Geographic Information Systems (GISs).

Quecreek Mining Accident

During this emergency the primary mechanism for working with mining related geospatial data remained paper maps (Figure 1 below). Dependence on paper maps that cannot be easily or quickly compared to other geospatial information to check for inaccuracies impeded rescue in a digital information age with far better potentially workflows available.

Figure 1. The Governor of Pennsylvania et al. study a paper map during the Quecreek rescue

Fortunately for the nine men trapped underground for 4 days, everyone remembers Quecreek because the rescue effort was successful. Paper maps were unfortunately perceived only as having saved the day by allowing rescuers to accurately locate and drill the rescue shaft used to free the trapped men (Figure 2 below). Unfortunately for workers trapped in other mines after Quecreek, people that propose legislation never learned or quickly forgot why the Pennsylvania mine became inundated July 24, 2002.

The United States Mine Safety and Health Administration issued a report on July 24, 2006 that again cited faulty maps as a cause in the Quecreek Mine disaster. According to the MHSA's Quecreek accident report, *"The primary cause of the water inundation was the use of an undated*

and uncertified mine [paper] *map of the Harrison No.2 mine."* See also Faulty Maps to Blame for Quecreek Mine Disaster. The MSHA report states *"The root cause of the accident was the unavailability of a certified final mine map for Harrison No.2 mine in the State of Pennsylvania's mine map repository."* While that is certainly true, the inability of the company to see the Quecreek #1 mine map overlaid on Harrison No.2 mine workings more accurately describes the cause and highlights the limitations of operating with only paper maps in a twenty-first century digital world.

Figure 2. Successful rescue of nine miners at Quecreek mine (Directions Magazine, 2003)

Requirements for survey ground control in Pennsylvania prior to Quecreek were basically similar to what the author believes exists today in most coal mining states. Underground maps are referenced to a cluster of ground control points typically tied together near the face up of the mine. As a result of delays encountered in surveying the location to drill a rescue shaft during the successful Quecreek rescue, Pennsylvania passed reform legislation requiring survey control at one mile intervals along the axis of active underground mining operations.

Sago Disaster

On January 2, 2006 an explosion at the Sago Mine killed 12 miners, leaving one survivor who had to undergoing extensive rehabilitation after spending nearly two days underground surrounded by carbon monoxide fumes.

A geodetic survey expert called in to survey locations to drill holes for the Sago rescue related to the author that he was delayed several hours because he had to establishing survey control before he could be sure of the relationship between the surface and the underground mining operations. The lack of post-Quecreek Pennsylvania ground control regulations impeded the Sago rescue operation by wasting valuable time while men underground were running out of breathable air.

Another facet of the problem of continued reliance on paper mapping in our digital world came to light at Sago. March 14, 2006 International Coal Group's press release proposed lightning as the source of the energy for ignition at Sago. Potential paths for the electricity into the sealed area were listed including … *"through the gas well casing and through the ground, or through the network of gas well lines on the surface and into the ground."* (see Associated Press, 2006). The importance of having all oil and gas well casings and pipelines in the vicinity of underground coal mining operations located with a high degree of accuracy was elevated to national attention. Submittal of highly accurate geospatial data by both coal and natural gas extraction operations must be viewed as having the greatest potential of save lives in the mining industry but is not required via a reasonable standard. Oil and gas exploration and transmission workers need to know when their activities may be impacted by surface or subsurface mining activities, infrastructure or mined out voids. With the increasing national demand for energy, it is a certainty that distances between these two types of mineral extraction operations will diminish over time increasing the potential for future accidents. Companies in both industries commonly conduct high accuracy surveys for their own uses but submit relatively less accurate mapping, still mostly paper-based, in permitting processes.

Black Castle Strip Mine Fatality

On February 1, 2006, a bulldozer operator was killed at the Elk Run Coal Co.'s Black Castle strip mine in Drawdy, WV. The 58-year old bulldozer operator with 15 years experience was fatally injured due to an ignition of natural gas. As the bulldozer operator was developing a drill

bench, the blade of the machine contacted and ruptured a 16-inch low-pressure, high-volume natural gas line which immediately burst into flames. Figure 3 shows the intensity of the fatal blaze.

Figure 3. Ruptured natural gas line at a strip mine causes loss of life.

In the **DESCRIPTION OF THE ACCIDENT** section of MHSA's report about the fatal accident the statement is made that *"Vira told Moss to stay 100 feet away from the gas line. Neither Vira nor Moss knew the exact location of the gas line."* Clearly lack of knowledge of the precise location of the pipe line was the primary cause of the fatality. It is important to note that this fatality was in no way related to underground operations and MSHA federal oversight.

Aracoma

A June 17, 2006 article written by Dennis B. Roddy and Steve Twedt in Pittsburgh's Post-Gazette brought to light mapping issues with attempted rescue activities at Aracoma Coal Co.'s Alma No. 1 Mine after the Jan. 19th accident that claimed the lives of two West Virginia miners. Ellery Hatfield and Donald I. Bragg became lost in the dense smoke and suffocated. In testimony given to an attorney representing the widow of Mr. Hatfield, Timmy Paul Morgan gave a statement that rescue team members complained that the map they were given to search for the missing men was inaccurate, showing doors and stoppings in places they did not exist.

While inaccurate mapping was not a factor in causing this tragedy, the rescue operation was clearly impeded by poor geospatial information and again the use of inaccurate paper maps.

Care must be exercised not to conclude from reviewing findings concerning these recent accidents that simply converting paper-based maps to digital data is a fix for mining related mapping issues. The answer is no. Error, both inherent in the source map itself, and added during the conversion process, combine to create a product that is of limited use in permitting workflows and even less applicable in a mining emergency.

Converting Paper Maps to Digital Data and Movement toward Use of CAD

Current practice for integrating mapping provided by the coal industry via the permitting process has several steps in most coal producing states. They are as follows:

- Scan a paper map into a digital raster image.
- Georeference the scanned paper map. This involves stretching the image so that it matches a specific coordinate system by matching features such as buildings, road intersections, or coordinate grids with corresponding features on existing maps or aerial photographs with known coordinates.
- Trace the outline of a mining feature using a mouse, thereby creating a digital representation of the feature shown on the map.

In the last two years, the West Virginia Department of Environmental Protection has processed over eight hundred mining permit maps in order to update its digital mine boundary database. Many of these maps exhibited high quality and appeared to be very accurate. However, our automation project showed that error could be produced at every step in the paper to digital conversion process. First, scanning a paper map to produce a digital image can add a small amount of error, especially if the map has been folded, or contains creases, or if the map slips while being fed through the scanner. More error is produced when the image is warped to match a coordinate grid (georeferencing). This error can range from a few feet to perhaps tens of feet. Finally, error is added when a technician traces the outline of a feature onscreen with a mouse during heads up digitizing.

While it is possible to quantify and control errors associated with the digital conversion process to some degree, it is impossible to evaluate overall map accuracy because the accuracy of the source map itself is unknown. The really bad news is that this situation did not change with the adoption of Computer Aided Design (CAD) software by the mining industry. On the

contrary, the use of CAD has added new opportunities for inducing error, while adding a surficial appearance of precision that may not hold up under close scrutiny. For example, many CAD maps use digital versions of features found on United States Geological Survey (USGS) maps as a background. However, these features can be misaligned in various ways, making it difficult to georeference the map precisely, and casting doubt on the accuracy of the map altogether. For example, Figure 4 shows features from USGS maps with an inset area containing data from a different source. The two datasets are misaligned, evidenced by the misalignment of the stream and road features. This map could not be adequately georeferenced until the outer area was discarded during the georeferencing process.

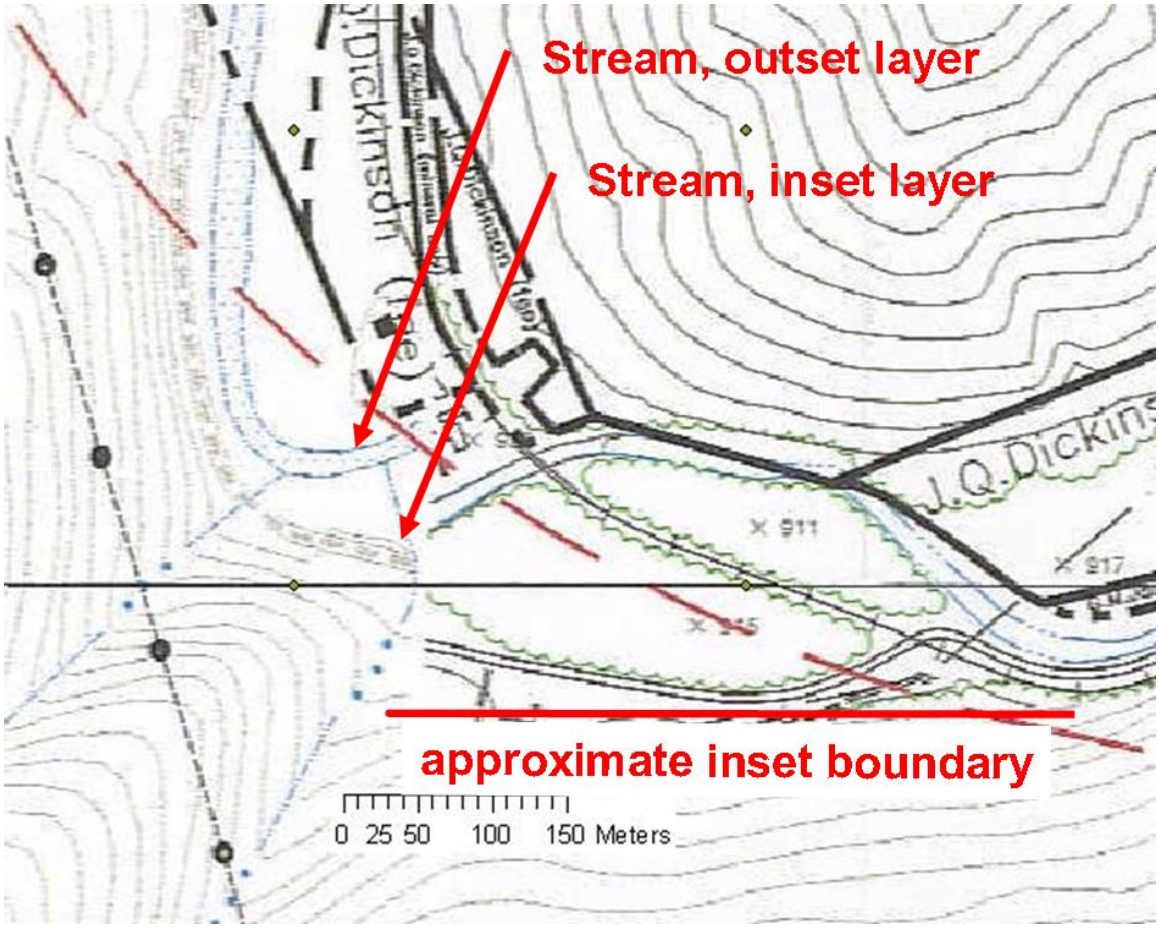

Figure 4. A second data source was used to create an inset in this permit map (the figure shows the lower left corner of the inset area). Misalignment of the two data sources is obvious in the mismatched location of streams and roads

The map shown in Figure 5 depicts a similar misalignment, where a detailed inset was combined with layers derived from USGS quadrangles. The inset area is shifted to the south, illustrated by the misalignment of the stream from each layer.

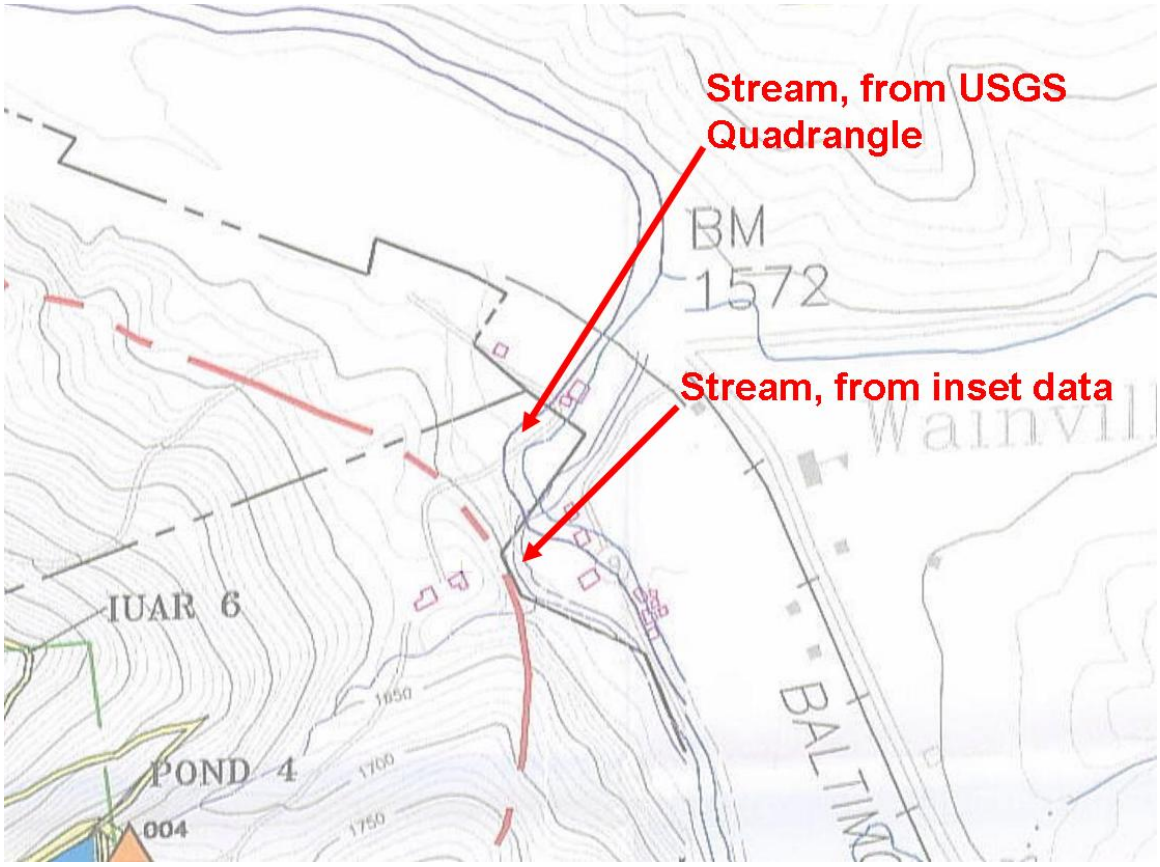

Figure 5: Misalignment of streams from two different data sources on a permit application map.

When a permit extends across a USGS map boundary, features from more than one USGS quadrangle must be used to cover the entire map. Figure 6 shows a mismatched seam between two USGS quadrangles resulting from improper placement of one, or both, of the USGS background data layers. Since most of the mine occurred to the left of this seam, the map was georeferenced by discarding reference features to the right of the seam.

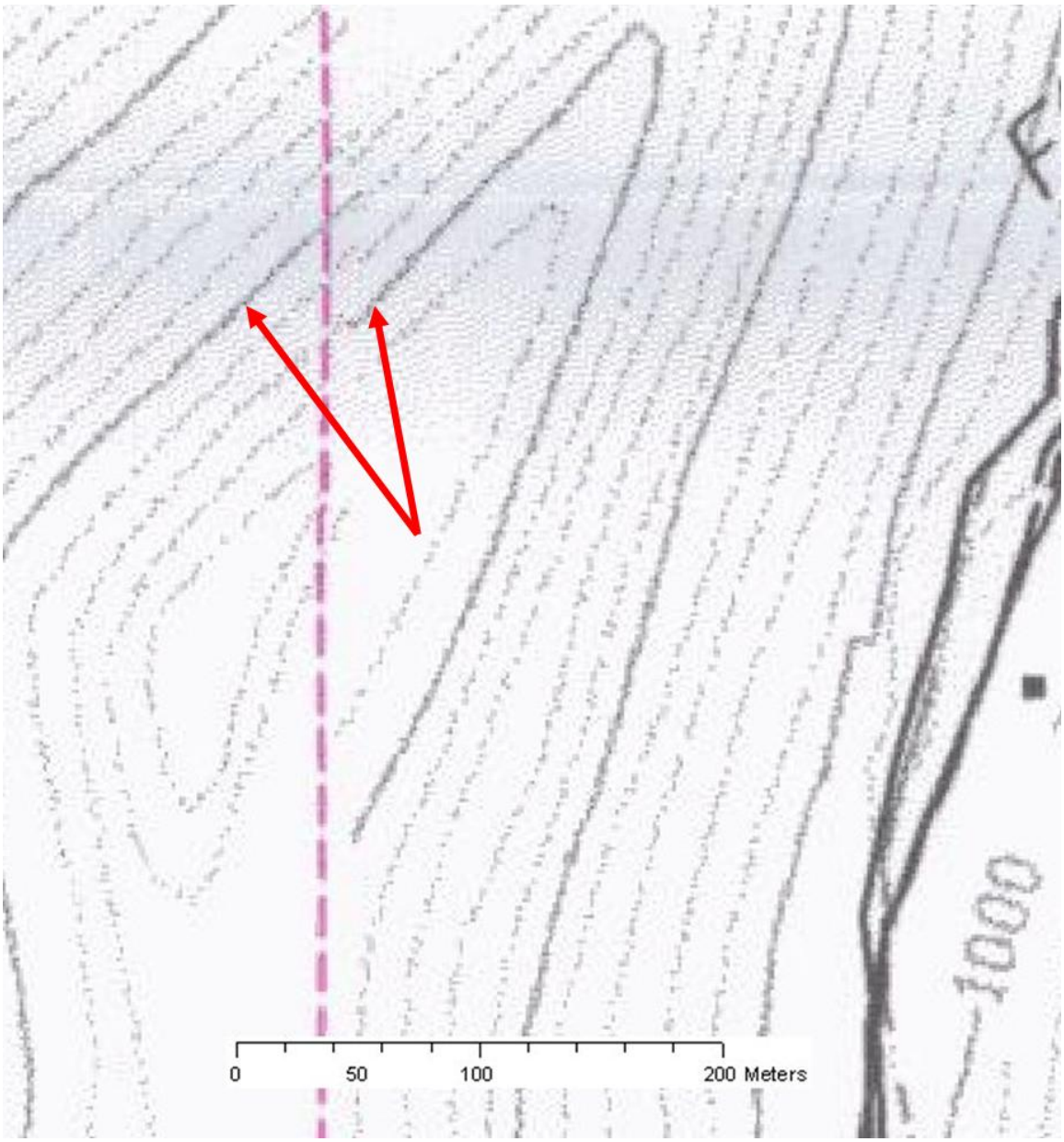

Figure 6: Permit map with misaligned contour lines along the boundary between two USGS quadrangles.

In the last several years, it has become more common for permit maps to include coordinate grids, or tic marks, that correspond to a common coordinate system. These coordinate grids can provide the best possible results during the georeferencing process, because they provide a precise set of well distributed points with known coordinates placed throughout the map. However, there have been occasions when the placement of the coordinate grid itself has been uncertain, such as in Figure 7. In this case, a relatively precise map showing multiple building outlines appeared to be shifted to the east when the coordinate grid was used to georeference the

map. After careful examination, it was decided to use the buildings, roads, and other features to align the map rather then the coordinate grid.

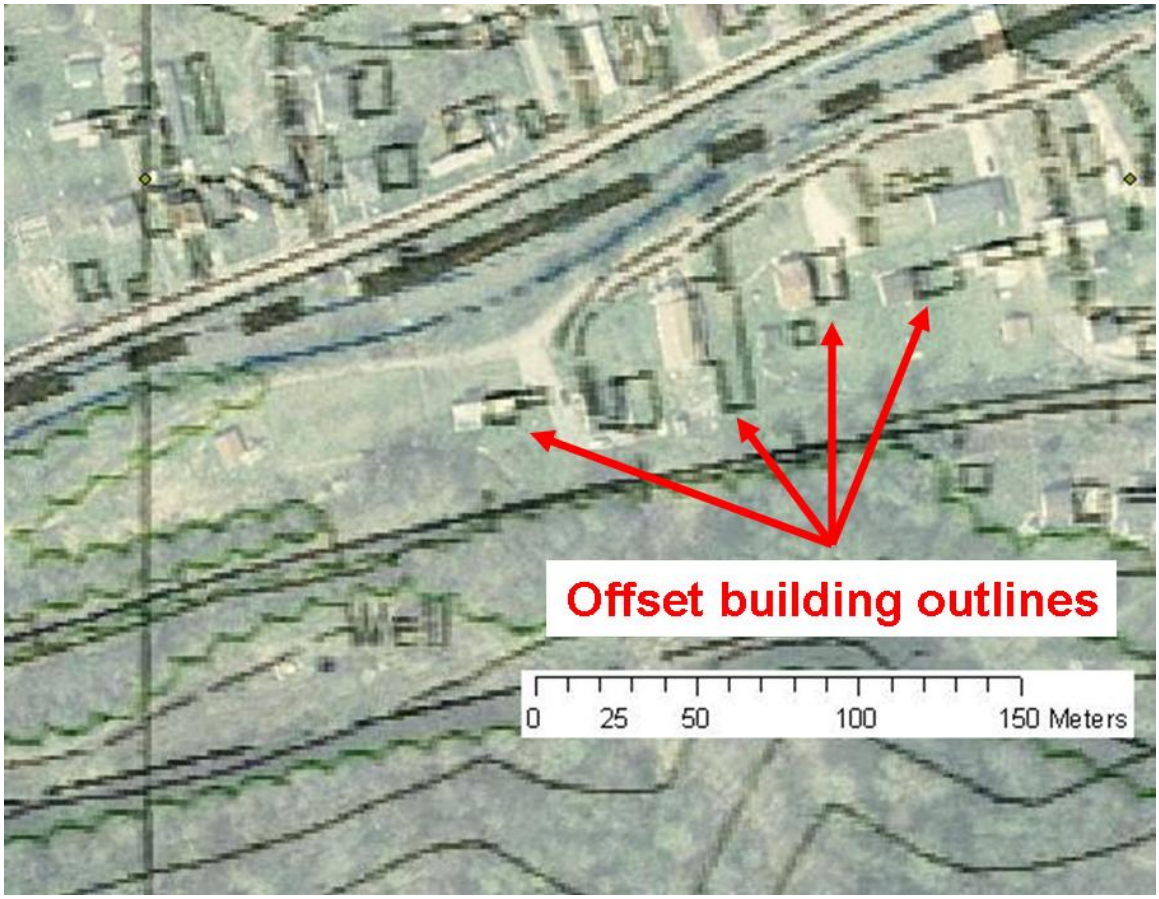

Figure 7: Buildings depicted on this map were offset when the map's coordinate grid was used to georeference it. Eventually, the map grid was discarded in favor of buildings and transportation features, which produced better results.

A slightly different problem is apparent in Figure 8. Here, a mining map's coordinate grid was aligned to coordinate tic marks, shown in red. This produced good agreement with transportation features depicted on a USGS topographic map, shown as a background layer. However, in this case the elevation contours are shifted to the north, producing an inaccurate picture of the physical topography for this site. In this case it was decided that the coordinate grid likely was correct, and that the contour layer had somehow been misaligned.

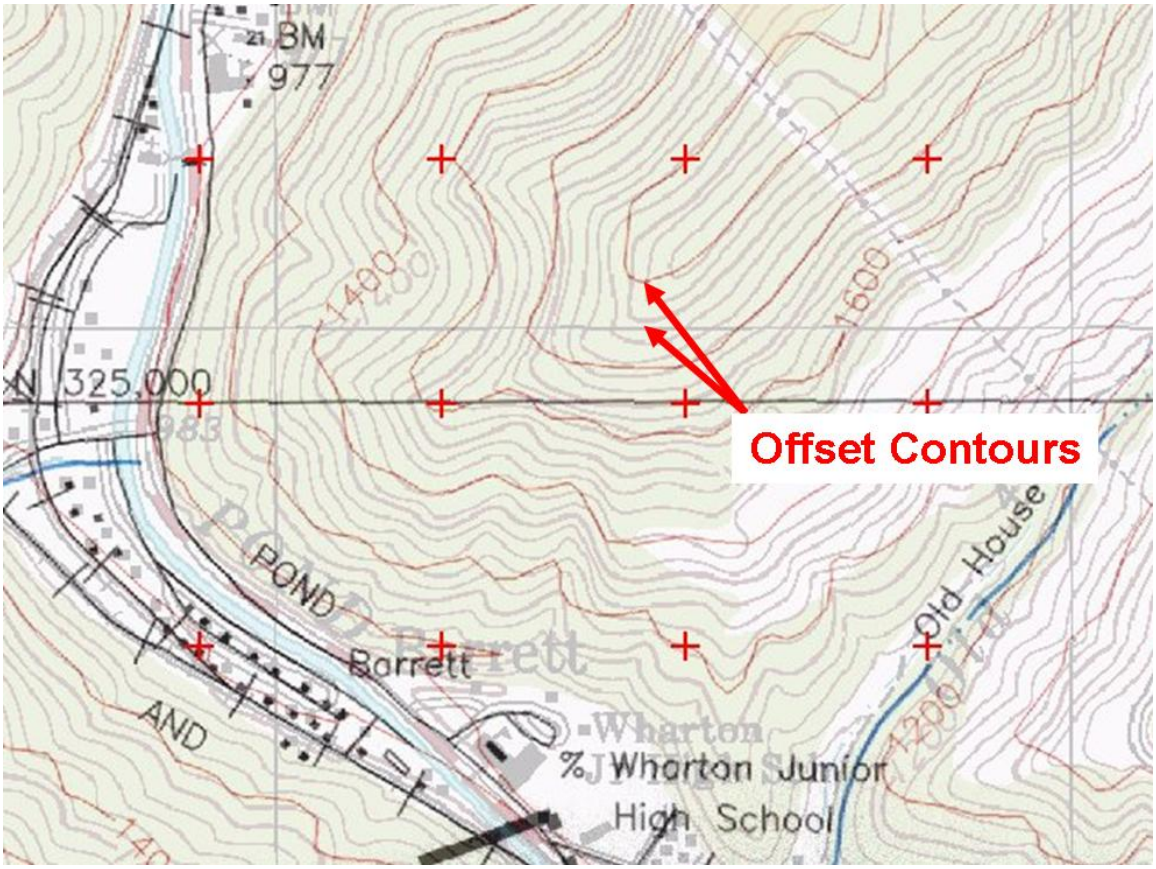

Figure 8. Offset of contours comparing a georeferenced permitting map and a USGS digital topographic map.

The impact of misaligned elevation contours is more pronounced in Figure 9, in which valley fills no longer occupy the valley, and streams run along the sides of ridges. The sediment control ditches are also badly misaligned.

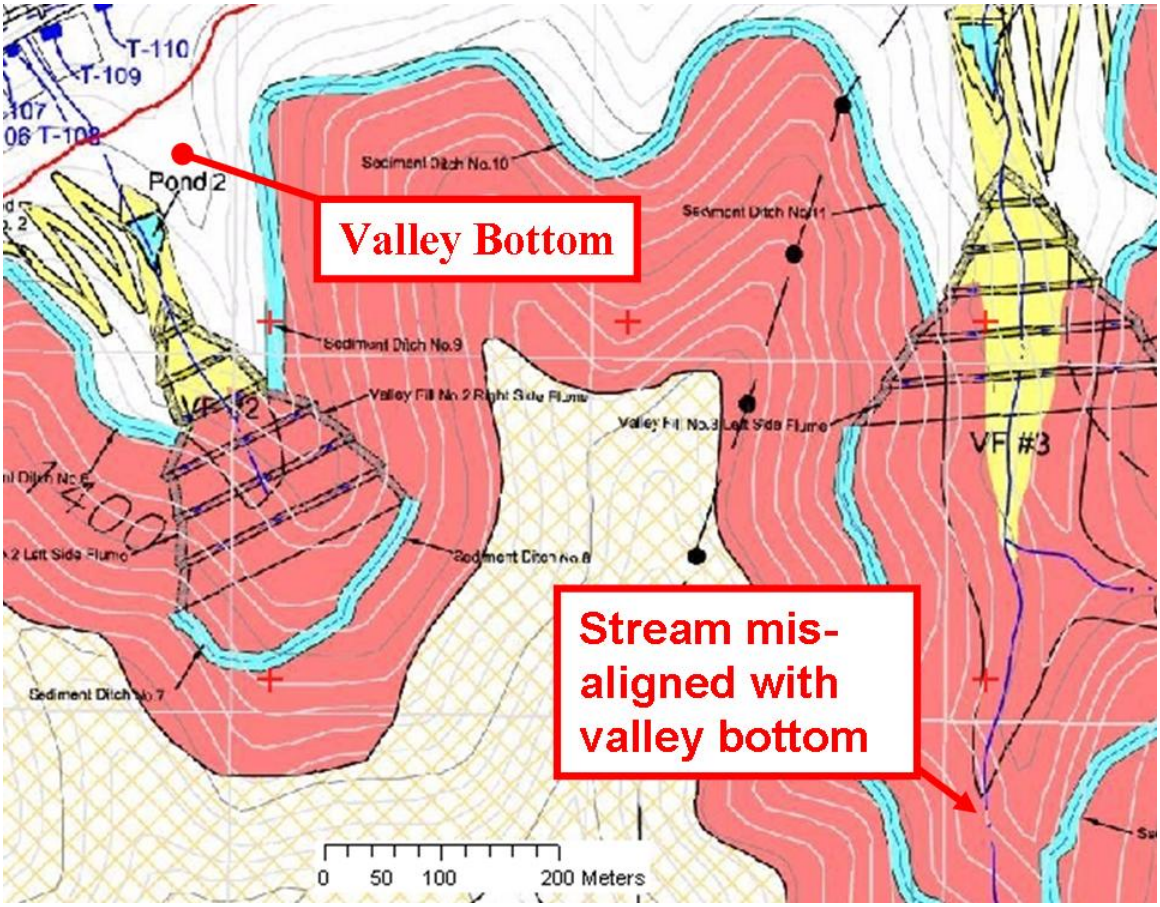

Figure 9. A permit map with contour lines that do no align properly.

Based on these examples, it seems apparent that any single data layer used to construct the map can be placed incorrectly, and that misalignment can occur between entire groups of data layers obtained from different sources. These cases represent errors within a single map that were revealed during the georeferencing process. Other errors can become apparent when maps depict adjacent operations. Figure 10 shows two permits issued to the same company that share a common boundary. Though both permits were issued on the same day, maps for the two permits do not depict the boundary in a consistent way. Maps for both permits contain excellent reference points that allow them to be accurately georeferenced. The upper right permit map contains features from USGS maps as a background, and the lower left permit map includes a State Plane coordinate grid. In examining each map, it appeared that they were created using different techniques, perhaps representing a transition from manual methods to CAD software. However, neither map could be judged significantly inferior to the other, and as a result the mismatch could not be resolved and remains in the database.

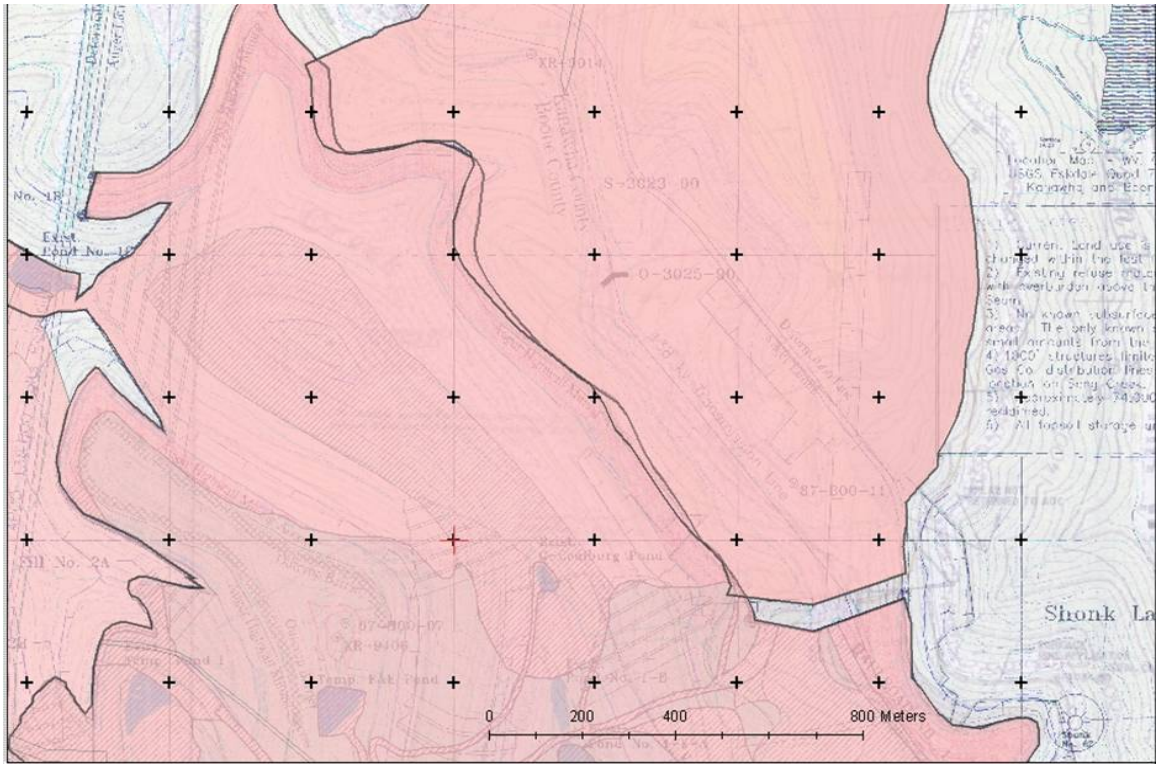

Figure 10: Two permit maps from the same company that are misaligned.

Finally, the adoption of CAD software in the mining industry has resulted in maps that present an appearance of precision, and perhaps an unconscious assumption of high accuracy. However, it is just as easy to produce an inaccurate map using CAD as it is to draw one by hand. Figure 11 shows part of a permit map with detailed building outlines created using CAD software. Previous experience suggested that maps with detailed building footprints often used low-altitude aerial photographs and were very accurate. However, during the georeferencing process, it became apparent that many structures on this map were not positioned correctly. Figure 12 shows the CAD map with an underlying aerial photograph, illustrating accurate building placement at points A-D. However, buildings at points 1-4 (and many others) were shifted from their actual locations in a variety of directions. Hopefully, features within the permit boundary are positioned with greater care.

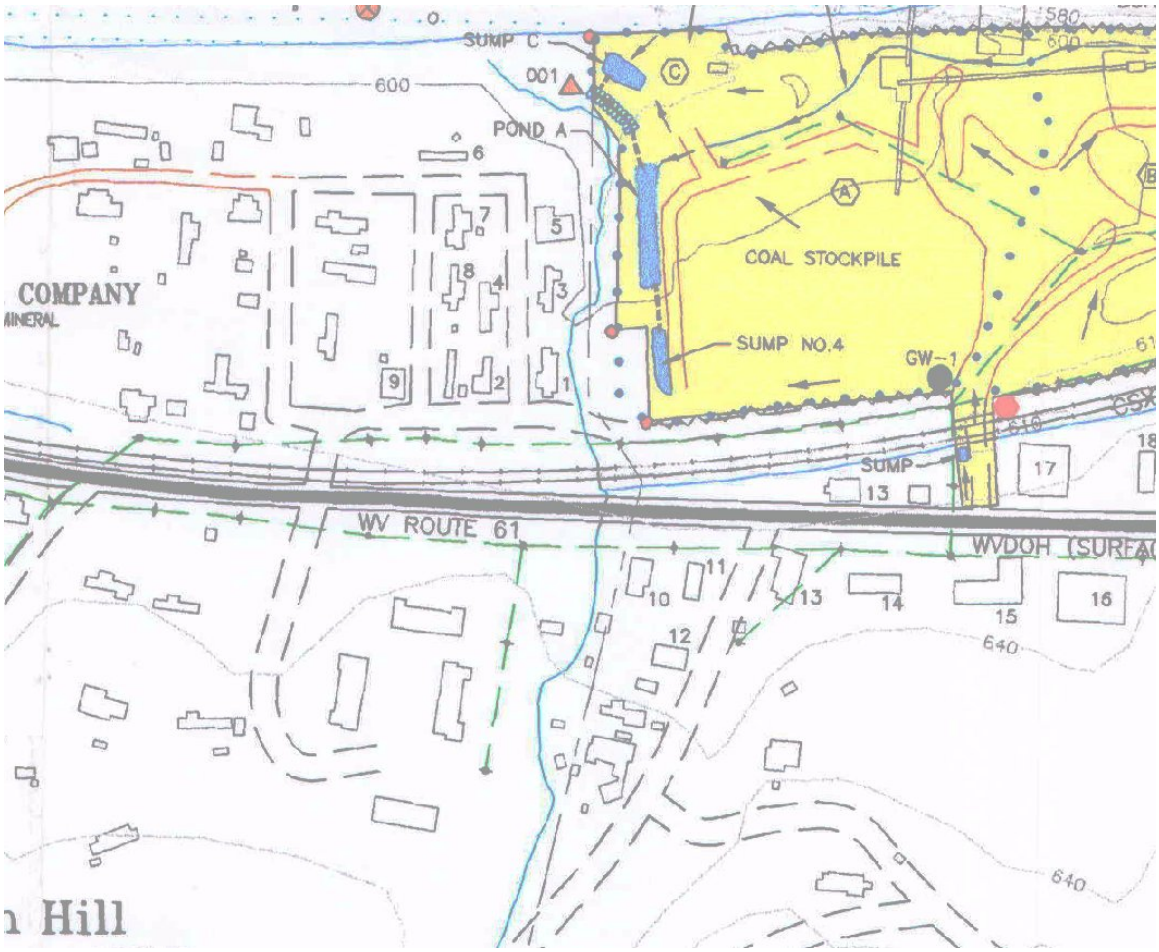

Figure 11. Maps created using CAD software present a precise appearance, and convey an impression of high accuracy.

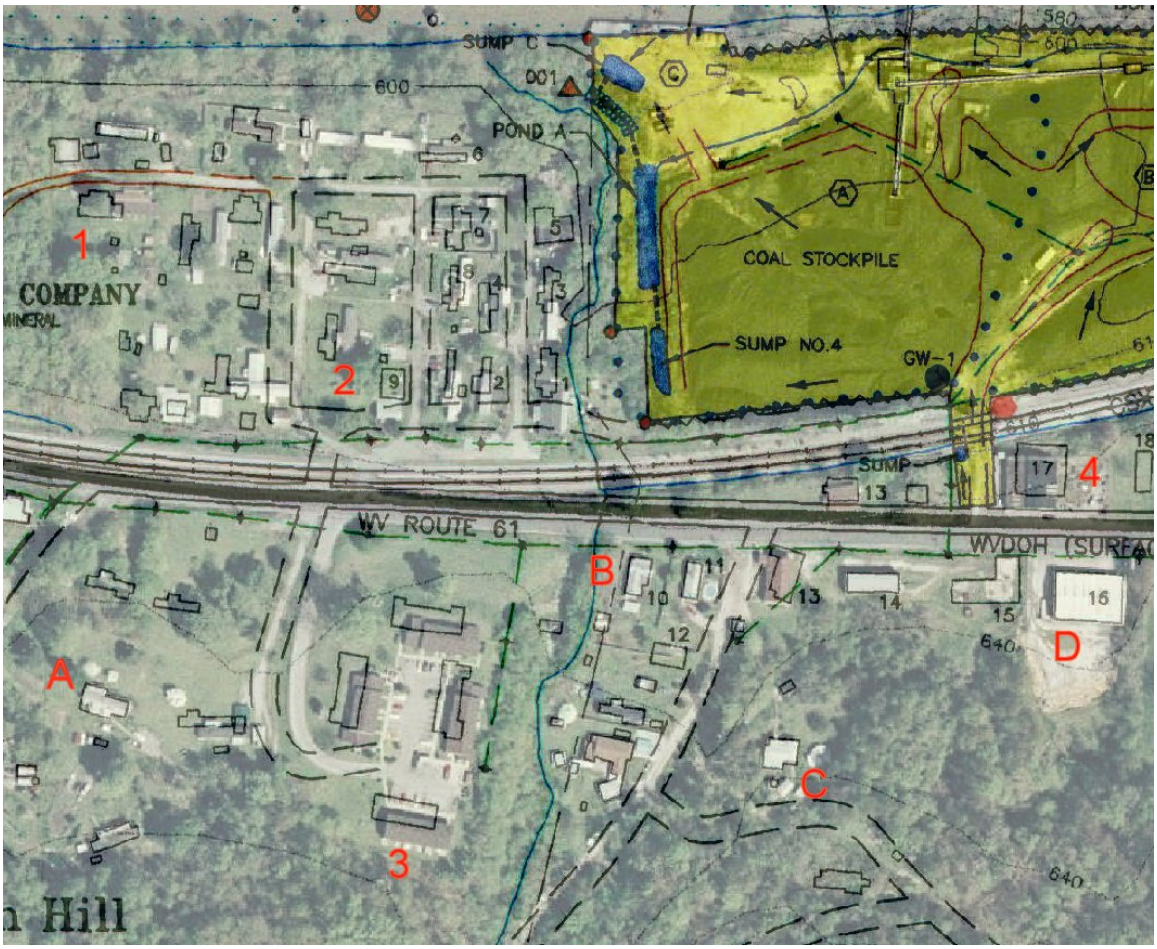

Figure 12. Same map as Figure 11 shown overlaid on an aerial photography basemap. Buildings at points A - D show accurate placement, while buildings at points 1 - 4 are shifted in a variety of directions. The initial impression that this is a highly accurate map is, therefore, wrong.

Some error discovered in WVDEP's map automation projects can not easily be explained as accidental. The coup de grâce is shown in Figure 13. This situation was discovered in mid-February of 2008 while converting permitting documents for a bond forfeited site from paper maps to digital data to be included in the Agency's mining geospatial data archive.

The left panel of Figure 13 is a DRG with colors removed and the boundary separating Boone and Lincoln Counties highlighted in yellow for clarity. The right panel of Figure 13 shows a permitted area map received from the mining company. On that map the county boundary is depicted in red. No "official" change in the boundary between Boone and Lincoln Counties occurred during the time period this area was mined. The county line between the points where the red line revision was made had been skillfully removed prior to submittal of the blueline.

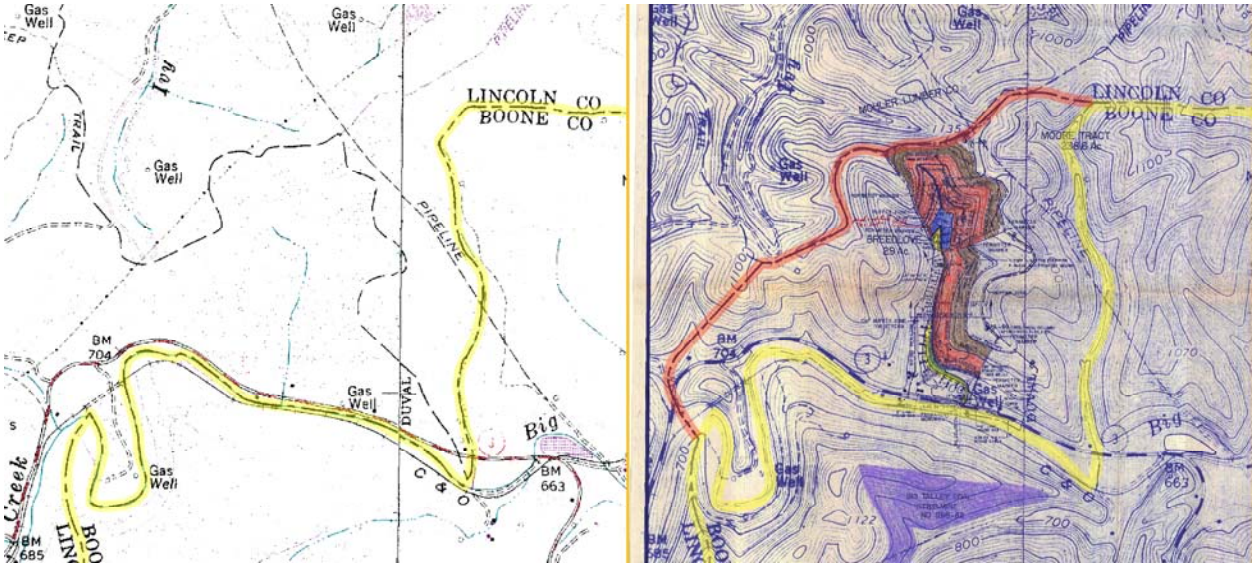

Figure 13. Left panel is a portion of a DRG with colors removed and the county boundary highlighted in yellow. The right panel is a section of a scanned blueline permitting map on which a new "interpretation" of the county line is depicted in red.

As required by SMCRA, all maps comprising the examples presented above were certified by either a licensed land surveyor or a professional engineer.

Passage of the Miner Act

Because of the unacceptable number of mining accidents and resulting fatalities (13) in 2006, Congress drafted and passed additional legislation. The Mine Improvement and New Emergency Response Act of 2006, also known as the MINER Act, was signed by President George W. Bush on June 15, 2006. MSHA summarizes this legislation as follows: *"the most significant mine safety legislation in 30 years, amends the Mine Safety and Health Act of 1977 and contains a number of provisions to improve safety and health in America's mines."*

The MINER Act includes the following key provisions:

- Require each covered mine to develop and continuously update a written emergency response plan;
- Promote use of equipment and technology that is currently commercially available;
- Require each mine's emergency response plan to be continuously reviewed, updated and re-certified by MSHA every six months;

- Direct the Secretary of Labor to require wireless two-way communications and an electronic tracking system within three years, permitting those on the surface to locate persons trapped underground;
- Require each mine to make available two experienced rescue teams capable of a one hour response time;
- Require mine operators to make notification of all incidents/accidents which pose a reasonable risk of death within 15 minutes, and sets a civil penalty of $5,000 to $60,000 for mine operators who fail to do so;
- Establish a competitive grant program for new mine safety technology to be administered by NIOSH;
- Establish an interagency working group to provide a formal means of sharing non-classified technology that would have applicability to mine safety;
- Raising the criminal penalty cap to $250,000 for first offenses and $500,000 for second offenses, as well as establishing a maximum civil penalty of $220,000 for flagrant violations;
- Give MSHA the power to request an injunction (shutting down a mine) in cases where the mine has refused to pay a final order MSHA penalty;
- Create a scholarship program available to miners and those who wish to become miners and MSHA enforcement staff to head off an anticipated shortage in trained and experienced miners and MSHA enforcement;
- Establish the Brookwood-Sago Mine Safety Grants program to provide training grants to better identify, avoid and prevent unsafe working conditions in and around the mines. These grants will be made on an annual, competitive basis to provide education and training for employers and miners, with a special emphasis on smaller mines.

Conspicuously missing are provisions related to mapping. Figure 14 shows the historic signing by President Bush in Washington, DC. This legislation failed to consider the role played in recent mining disasters by inaccurate paper maps or lack of sufficient ground control.

Figure 14. President George W. Bush signs the MINER.

Geospatial Thinking in SMCRA and the MINER Act

To evaluate the intent of the MINER Act and compare it to SMCRA with regard to mapping, the number of occurrences of spatially related, spatial extent, geospatial data quality, and spatial occupational terms were counted. Figures 15 – 18 depict the results of this exercise.

Figure 15 shows the very limited use of general spatially related terms in the MINER Act. This demonstrates that the focus of that legislation was entirely non-spatial (the term "***plans***" was the only general spatial term used and only three times). SMCRA legislation contains significantly more occurrences of "***plans***" plus ***"survey"*** and ***"maps/map"*** [60 occurrences total].

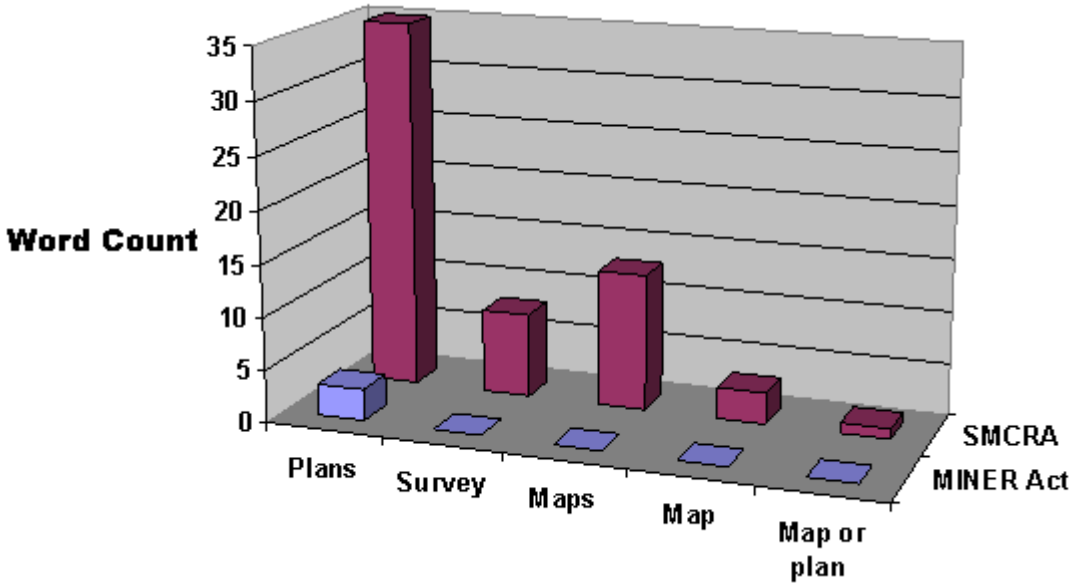

Figure 15. General spatially related terms.

Word count of all spatial extent terms in the MINER Act is again very low compared to SMCRA. SCMRA's frequency of use of ***"location"*** and ***"area"*** [256 total] clearly indicates the intent of that Act to integrate geospatial extent concepts in that legislation (see Figure 16).

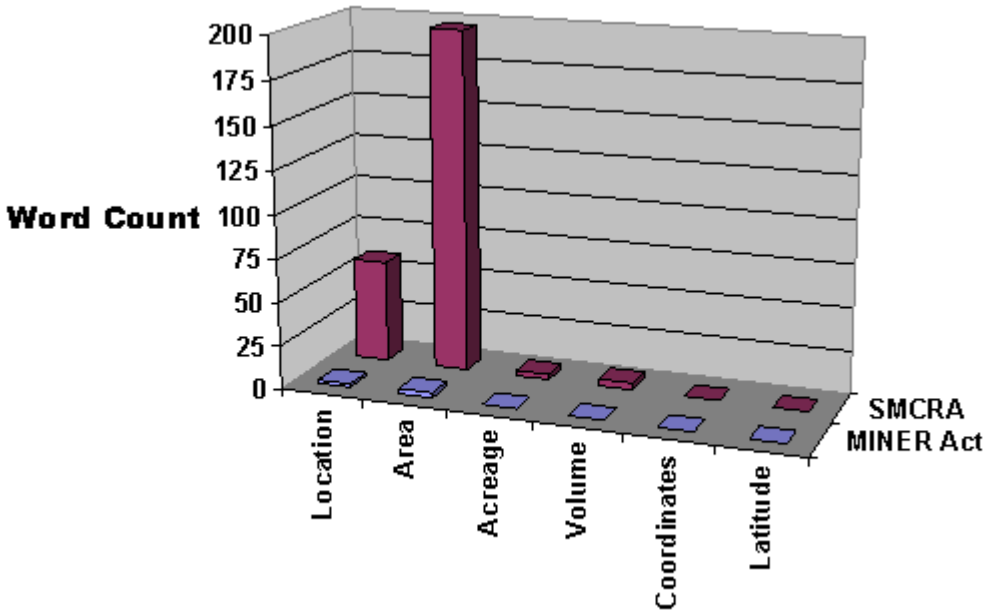

Figure 16. Spatially extent terms.

The largest problem with both legislative initiatives is illustrated by Figure 17. Both Acts fail to address geospatial data quality with only a single mention of the term accuracy in SMCRA. Precision, scale and datum were not used in crafting either SMCRA or the MINER Act.

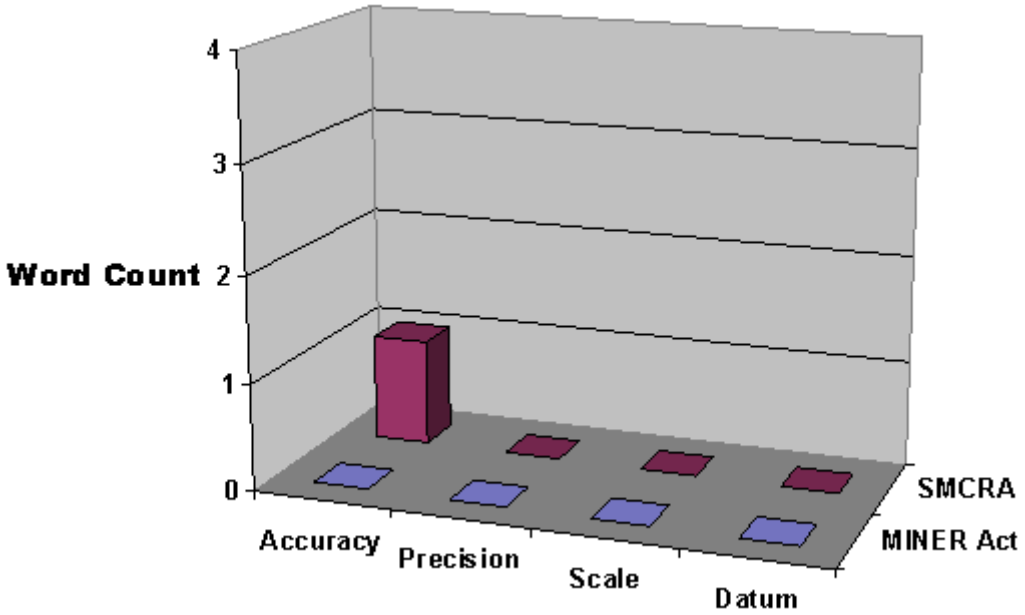

Figure 17. Geospatial data quality terms.

Without properly conveying the intent that data provided to regulator authorities in the permitting process follow reasonable standards for accuracy and/or precision, SMCRA opened the door to submittal of poor quality geospatial data. Unfortunately passage of the MINER Act did nothing to shut that open door. Also, SMCRA contained no best practices language that compelled permitting process submittal of geospatial information change over time with the adoption of newer technologies. As a result, thirty-one years after enactment of SMCRA, the permitting process remains largely inspection of the paper map in today's age of digital GIS.

Both laws contain references to the occupational term ***"engineer"*** [SMCRA 56 occurrences, MINER Act 14]. Neither contains any mention of ***"surveyor"***.

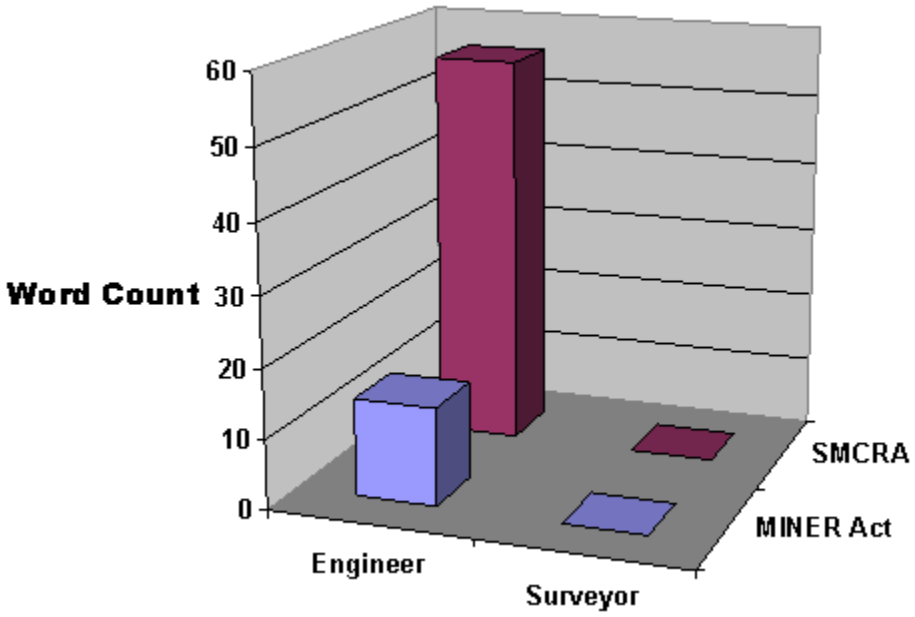

Figure 18. Geospatial occupational terms.

Zero to very little use in both Acts of coordinates [0], latitude [0], datum [0], accuracy [1], precision [0], and scale [4] demonstrate that creators of SMCRA and the MINER Act were certainly not mapping professionals. Lack of use of these terms (and geospatial concepts in general) in the MINER Act was unexpected since geospatial nomenclature became ubiquitous in the time between signing of SMCRA and the MINER Act. By 2008 location-based services (LBS) in car navigation systems and cellular phones-based services capable of providing turn by turn guidance to restaurants via integrated GPS receivers exist even in small towns in the Appalachian coal fields.

State Regulatory Inertia.

The author believes that the number of State agencies receiving paper or digital mine maps and producing mining related geospatial datasets is cause for great inertia in discovery of the cause and effect relationship between antiquated mapping standards/techniques and recent mining accidents and fatalities in West Virginia. Table 1 provides an overview of the situation in Mountain State but is likely typical of many coal mining States in our country. From that table it is evident that mining geospatial datasets, taken as a whole, are critical to West Virginia state government from a decision support context. Six separate databases contain mining related data. They are administered by one federal and five separate State agencies. MSHA is

conspicuously missing and currently lacks geospatial expertise most likely because of focus on inspections and violations rather than permitting.

Table 1. Sources for State and Federal government geospatial datasets derived from mining maps in West Virginia.

Level of Government	Agency	Abbreviation	Dataset
State	Department of Environmental Protection	DEP	$^{GIS}DEP_1$
State	Office of Miner's Health, Safety and Training	MHST	$^{GIS}MHST_2$
State	Geologic and Economic Survey	GES	$^{GIS}GES_3$
State	Department of Military Affairs and Public Safety	MAPS	$^{GIS}DHS\&EM_4$
State	State Tax Department	TAX	TAX_5
Federal	Department of Interior's Office of Surface Mining	OSM	$^{GIS}OSM_6$

Examination of hardcopy and digital data exchanges facilitates further understanding and illuminates why so many sources exist. Table 2 depicts the source of mining geospatial data for each agency, whether other agencies utilize data it produces and how it receives data from, and provides data to, other parties. Several important facts become apparent with examination of Table 2. Sneakernet transfers (paper map copies or magneto-optical copies of digital datasets) account for all exchanges except a single, very new experiment being undertaken jointly by OSM and States.

The sneakernet limits the use of mining-related geospatial data in the decision making process because of the obvious lack of synchronization between sources (see update frequency column) resulting from manual data transfers at excessively long time intervals.

Table 2. Current exchanges of West Virginia mining hardcopy and digital datasets.

Receiving Agency	Provider	Update Frequency	Paper or Digital Source Data	Supplied Mining Data	Produced Digital Dataset	Data Layer *Name* or Description	Exchange Mechanism (Sneakernet or Electronic)	External Recipients of Produced Layer
DEP	Mining companies	Variable as required by SMCRA	C	Mining permit boundary (surface)	1	*perbd*		DHS&EM
								OSM
				Mining Limits (underground)		*minli*	N/A	
				Valley fills		*vallf*		
				Drainage control		*drain*		
	GES	Provided as a courtesy annually	3	Mined area	GES_3 mirror in DEP_1	Mined area		N/A
MHST	Mining companies	6 month intervals, required by WV§22-A-1	Some CAD files, C	Progress maps mostly on paper, digitally as a courtesy by a few operators	2 2	????		GES
	GES	Provided as a courtesy annually	3	Data initially provided by MHST has value added by GES	GES_3 mirror in $MHST_2$	????	N/A	
GES	Mining companies	Voluntary by industry and citizens	C	Mined area	3	Mined area		DEP, TAX
	DEP	Copied as required by GES	1	????				
	MHST							
DHS&EM	DEP	Digital copy requested once	1	*perbd*	DEP_1 mirror in $DHS\&EM_4$	????		N/A
	MHST							
	MSHA							
	Mining companies & private rescue teams							
TAX								

The new OSM/States experiment replicates WVDEP's UTM Zone 17, NAD83 *perbd* SDE/Oracle dataset automatically to OSM's National Coal Mining Geospatial Data test server

located in Denver, Colorado. The OSM server also uses ESRI's SDE-based but its underlying relational database technology is Microsoft's SQL Server. During the initial phase of this project, periodic replication will occur at some yet to be decided frequency and West Virginia's data will be commingled with Commonwealth of Virginia and OSM's Knoxville, TN produced permit boundary data in other map projections. Mining data from Montana, Colorado, New Mexico, Arizona and Utah have also been successfully integrated. The batched processing of these heterogeneous datasets involves automated transformation of the geospatial data's graphics into a common projection and datum with dynamic extraction of a subset of each participant's unique tabular attributes on-the-fly by OSM's computing infrastructure. This now successful experimentation is the beginning of a nationwide mining geodatabase.

The coal surface mining permit boundary layer is the first of many coal mining geospatial layers that will become part of a national coal mining geospatial dataset. The cooperative effort to create a national dataset began by establishing the OSM/States joint National Coal Mining Geospatial Committee. The Committee's work has resulted in successful creation of an ASTM standard for coal mining permit boundaries (2007) and a draft standard for underground mining extent. Concurrent with development of additional standards in 2008 and beyond, the Committee will work on a coal mining CAD template to interchange geospatially referenced CAD data into the national coal mining data layers thereby facilitating interoperability with GIS.

In West Virginia, recent discussions have begun to explore how State agencies might share coal mining-related geospatial data electronically via ESRI's ArcGIS Server-based geospatial services. The obvious result of elimination of the existing sneakernet will be far better decision support for State government activities and simplification of the complex workflows identified in Tables 1 and 2, respectively. Following the Commonwealth of Virginia's decision to require digital submittal of all permitting data in 2007, the Mountain State has also announced January 1, 2009 as the date when all submittals must be electronic thereby finally eliminating paper-based mapping in the permitting process.

Federal Inertia

SMCRA ties contemporary coal mining geospatial data production workflows to last century's geographic thinking and paper-based permitting submittals lacking sufficient enacted limitations on accuracy and precision. State programs are built upon SMCRA. Passage of the

MINER Act was a golden opportunity to rectify geospatial data submittal and accuracy problems but the "mapping cause and effect in disasters" disconnect presented in this paper remained undiscovered. Why?

Because both OSM and MHSA have oversight responsibilities of different facets of mining at the federal level, federal inertia exists to discovery of cause and effect between mapping and mining accidents. Creation of a national coal mining GIS could become a possible "fabric" for facilitating adequate, timely communication between federal partners. The national coal mining geospatial initiative has already established an OSM/MHSA collaboration baseline. An MHSA employee has participated in creation of the existing and proposed ASTM coal mining geospatial data standards.

Conclusions

A cause and effect relationship between antiquated mapping standards/techniques and recent mining accidents/fatalities has been established. Representative examples of problematic geospatial information provided in the permitting process have been presented. The potential misunderstanding that moving from paper-based permit mapping to CAD's digital data world has, or ever will, solve submittal of poor quality geospatial information issues has been addressed. A review of geospatial concepts in SCMRA and the MINER Act was completed by counting the number of occurrences of spatially related, spatial extent, geospatial data quality, and spatial occupational terms in both Acts. The lack of progress in federal mine safety legislation regarding geospatial issues between passage of SMCRA and the MINER Act was successfully documented. The importance of mining geospatial information in decision making processes in both state and federal regulatory processes has been highlighted. The fact that exchange of mining geospatial data among state and federal partners remains mostly sneakernet with an excessively long refresh cycle has been documented.

While efforts to address some problems are ongoing, fixing all mining related geospatial issues still eludes regulatory authorities thirty-one years after passage of SMCRA. An opportunity to move to the use of modern geospatial techniques existed but was not realized with passage of the MINER Act. The only certain solution and the fix with the shortest timeline remains legislative modernization. If undertaken, the following list should be considered:

- All coal mining permit mapping should be submitted digitally.
- Digital mining maps submitted in the permitting process should be composed of data layers compatible for inclusion in a national coal mining geographic information system (GIS).
- Minimum standards for accuracy and precision should be established for each submitted national coal mining GIS-compatible data layer reflecting current best practices thereby not imposing significant additional cost to industry.
- Submitted data layers must be accessible by regulators, the mining industry and oil and gas extraction interested parties (to prevent future pipe line strikes like the 2006 Black Castle strip mine fatality, explosions from mining into an active gas well, lightning strikes of oil and gas wells, etc.).
- Due diligence must be given to documenting all underground mined areas to prevent blowouts, impoundment failures, flooding from adjacent works, etc.
- Surface survey control of underground mines must be extended along the axis of progressing mining to minimize the amount of time required to accurately drill in an accident like Quecreek or Sago.
- **National mining geospatial datasets should be used in concert with personal location technology and mine site thermal and gas sensors to allow instantaneous calculation and display of best route to exit a mine during a disaster.**

All sites with past, existing or future mining will some day be designated "mined lands." With the constant evolution of technologies moving us toward societal GIS, we will be remembered as having had the foresight to fix mining related geospatial data quality issues only if we leave the best record possible of mineral extraction activities as our legacy.

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