The Use of GPS and GIS in Documenting Subsidence

Impacts from Longwall Mining [1]

by

Lois Uranowski and Thomas Mastrorocco [2]

Abstract: The localized effect underground longwall mining has on surface water flow was evaluated using a combination of data gathering and displaying tools, specifically Global Positioning System (GPS) and Geographic Information System (GIS) applications. GPS was used to locate monitoring points in streams and springs and to attach site specific attributes to each location. GIS was used to combine and display the data with various surface and mine maps. Applying GPS to the study of mine subsidence allows collection of large amounts of data in the field that can be combined and collectively presented in a GIS format. The ten-month study included studying a perennial stream, its tributary and seven springs above two longwall panels. The results of the study showed that, directly after mining, flow in the stream tributary was significantly reduced (95%) with a return to near-normal flow within two months after mining. Also, the study on the effect longwall mining had on springs showed that springs located along hilltop ridges would be most susceptible to a lowering of the ground water table. New springs were formed during the study at elevations less than 10 feet above the stream elevation. One interesting observation was that a spring actually showed a temporary increase in flow prior to mining. This may be attributed to the advancing subsidence wave causing tensional fractures in front of the mining face.

Additional Key Words: mine subsidence, global positioning system (GPS), geographical information system (GIS), surface water hydrology, longwall mining.

Introduction

High extraction mining, principally long wall mining, is the primary form of underground mining in the Appalachian region. Long wall mining results in planned subsidence where subsidence occurs in the overlying strata and can propagate to the ground surface. Removal of the coal causes rock strata above to sag or bend, and fracture and dilate to various degrees. These rock strata adjustments are dependent on location, both vertically and laterally, in the mining area. Surface subsidence is manifested on the surface as a gentle, almost imperceptible, trough with accompanying tension and compression zones. Tension cracks are most prevalent at trough edges and at areas in front of the mining face.

The effect of long wall mining on hydrologic resources in the Appalachian region has been well documented. (Carver and Rauch 1994; Hill and Price 1983; Kendorski 1993; and Bai and Kendorski 1995). Water wells, springs and streams have been shown to be impacted both in the short and long term. These impacts are directly related to the topography, mining, and pre-mining hydrology of the region. Impact of longwall mining on the overlying hydrogeologic system has been shown to be localized with regard to the passage of the mining front (Johnson 1997). Most significant impacts occur during the period of maximum subsidence or shortly after the mine face passes under the area. (Carver and Rauch1994)

Prior studies have shown that recharge commences soon after the panel has passed over the area. This recharge is primarily due to compression of the subsidence-induced fractures (Hill and Price 1983) or closing of the fractures by mine subsidence progression away from the area (Kendorski 1993; and Van Roosendaal, *et al* 1990). Two or three years after mining has occurred, recovered streams display a more uniform base flow, probably due to the increased storage capacity in shallow aquifers and thus, more sustained and uniform baseflow discharge (Carver and Rauch 1994)

[1] Paper presented at the American Society for Surface Mining and Reclamation 17th Annual National Meeting, Tampa, Florida, June 11-15, 2000.

[2] Lois J. Uranowski, and Thomas Mastrorocco, Physical Scientists, U.S. Department of the Interior, Office of Surface Mining, Division of Program Support, Three Parkway Center, Pittsburgh, PA 15220

Proceedings America Society of Mining and Reclamation, 2000 pp 340-344
DOI: 10.21000/JASMR00010340

https://doi.org/10.21000/JASMR00010340

Physical Setting

The location of the study area is shown in Figure 1 and is mostly wooded with steep to moderate slopes. The monitoring points include a perennial stream (Beham Run), one of its tributaries, and seven springs. As shown in Figure 2, Beham Run transverses the two longwall panels involved in the study. The tributary of Beham Run runs approximately parallel with one of the panels.

The mine is located in the Northern Appalachian Plateau Region of western Pennsylvania. The stratigraphic column includes Permian-age Allegheny Group. These sedimentary formations are composed of interbedded shale, sandstone, limestone and coal. Mining operations in the study area consist of longwall mining of the Pittsburgh seam which is typically 6.5 feet thick. Two longwall panels encompassing the study area are shown in Figure 2. The figure shows these panels overlaid by the surface contours as well as the locations of the monitoring points. The mine panels average 1000 feet wide and about 7500 feet long. Overburden depths ranged between 560 and 680 feet below the surface. The coal bed in the study area has a southeastern dip of less than one degree. Figure 2 also shows the progression of the mining face during the study period.

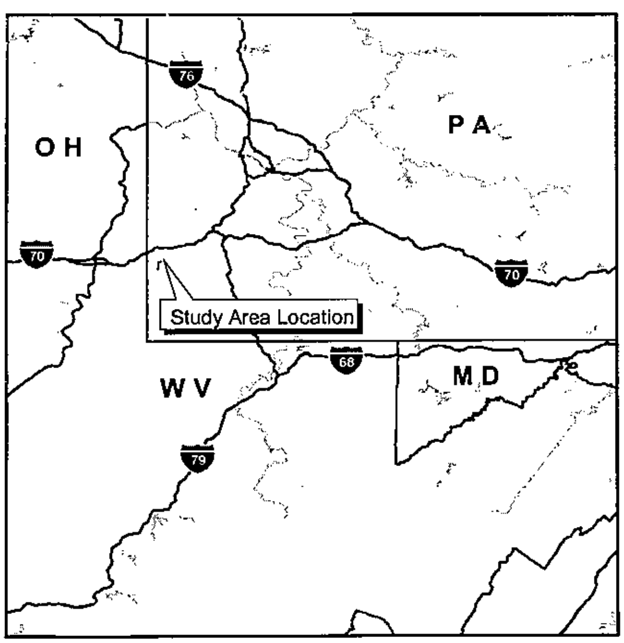

Figure 1. Location of study area in southwestern PA.

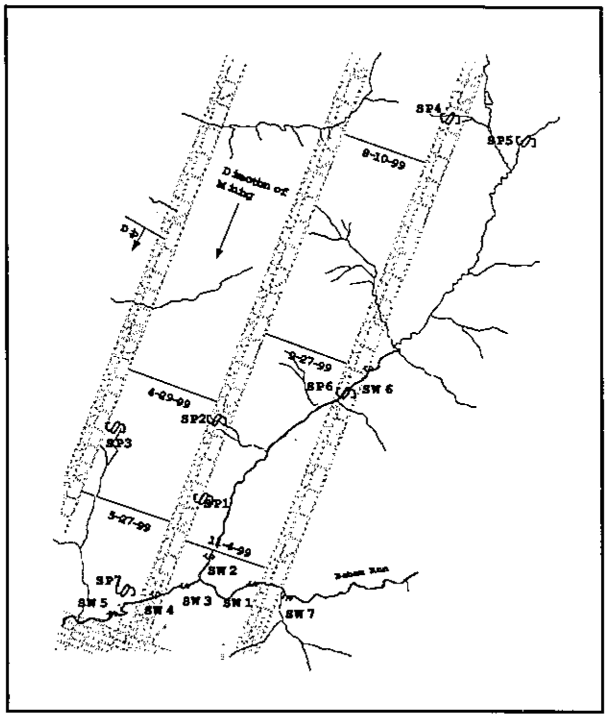

Figure 2. Longwall panel layout, monitoring point locations and topography.

Global Positioning System (GPS)

The evolution of GPS started in the early 1970s as a U.S. Department of Defense (DOD) concept. The program was aimed at filling the military's need for improved navigation and positioning. The first operational GPS satellites were launched in 1989. (McDonald 1999) The system was fully online in 1995 with 24 operational spacecraft, a ground control segment, and user equipment providing navigational services worldwide. Today the GPS space segment operates continuously with between 24 and 27 satellites. Until May 1, 2000, DOD included an intentional degradation of civil signal accuracy by a technique called selective availability, introducing errors of 150 -300 feet (50 - 100 meters) horizontally. This induced error was corrected by postprocessing differential correction. Presently the non-degraded signals received by the GPS unit in the field have horizontal accuracy between 15 and 30 feet (5 to 10 meters). Post processing will provide accuracy to about 5 feet (1.5 meters) horizontally. The user equipment stores field data attached to a location that is real world referenced. It is this feature that is responsible for much of the exponential growth of GPS use in scientific studies and has been utilized in the present study. Applying the technology to the study of the impacts of mine subsidence allows the collection of locations with specific field data or attributes attached to that specific location.

Geographic Information System (GIS)

Subsidence impact features, in this case stream/spring water flow alternations associated with longwall mining, were documented and mapped using GPS and GIS tools. The mapped features were classified as surface water monitoring sites and spring sites, and assigned unique identifiers. Flow attributes were collected over a ten-month period, and were integrated with a basemap of the mine depicting the progression of the longwall mining. The GIS helped evaluate the ongoing impacts on flow quantities from the sites as the longwall panels were developed. An animated GIS display allowed examination of the data qualitatively, including an assessment of lag times involved with the onset and restoration of effected flows.

Methods of Investigation

GPS equipment used for the study included a TSC1 Asset Surveyor with a ProXL Receiver and a Geo Explorer II, both products of Trimble Navigation Systems. Published information states that the accuracy of the units is within 2 to 5 feet in the horizontal. Error in the vertical direction is three times greater then in the horizontal. To optimize accuracy, the software in the GPS units was configured to record positions only when strict criteria were met. These criteria included simultaneously tracking a minimum of four satellites with good satellite geometry. The geometry is important since evenly distributed satellites in the sky provide the most accurate results. The field data that contained the intentionally degraded signal was post-processed to increase accuracy from ± 300 feet (± 150 meters) for the uncorrected data to within 2 to 5 feet (0.7 to 1.5 meters) for corrected data.

This level of accuracy of the collected data for the study was achieved except where steep topography restricted satellite signals. Several of the monitoring points were located in steeply sloping hillsides (Springs 1, 2 and 7) or at the valley bottoms (SW6 and Spring 6). Recorded error in accuracy in these locations increased to about 5 feet in the horizontal direction. For the purposes of the study, this error was found to be within acceptable limits. GPS was used to locate all monitoring sites shown on Figure 2 including coordinates, elevations and identifiers. Discharge measurements were then attributed to each monitoring point in the GIS map. The map includes surface topography and mine layout information.

Streamflow measurements were taken by three methods, based on stream channel shape and depth. The Marsh-McBirney flow meter was used to determine velocity for the velocity-area method. A portable Parshall flume (1-inch width) methods was also used to calculate flows. Low flows in springs and at stream monitoring points were determined using the volumetric method where volume/time period was obtained using a calibrated container and stopwatch. In Spring 6 flow was sufficient to use the Parshall flume.

Results and Discussion

The study utilized GPS to locate the monitoring points. Field discharge measurements were calculated. GIS compiled the monitoring points, flow data on various maps. The displayed data led to several conclusions pertinent to the general areas of hydrologic impact on surface water flow and on springs.

Hydrologic Impact on Surface Water Flow

Seven monitoring points were utilized to determine the effect that advancing longwall panels had on stream flow. The locations of the monitoring points are shown on Figure 2. Beham Run flows nearly perpendicular to the direction of mining near the endgates of both longwall panels. Four monitoring points (SW 1, 3, 4, 5) were located along approximately ½ mile stretch of Beham Run. Two monitoring points (SW 6 and 2) were located along a tributary of Beham Run that flows parallel to Panel 6. One monitoring point (SW7) was located in Beham Run upstream outside the angle of draw and the potential mine subsidence area. This point was used as a control.

Stream flow data is presented in Table 1. The drought of 1999 impeded determination of quantitative subsidence impacts on streamflow for some of the monitoring points. Flow rates were affected by the drought conditions during three of the eight sample events. During the drought conditions June through August 1999, mining progressed under monitoring points SW 4, 5 and 6, precluding the quantification of the effects of longwall mining at these stream locations.

Computing the difference in flow between two monitoring stations shows stream flow gain/loss between the points. Comparing this difference for pre and post mining shows the effect longwall mining has on the stream flow. This difference in stream flow between two points, found as a percent, was calculated

Table 1. Stream flow rates

Field Dates	Flow at Monitoring Points (gpm)						
	SW1	SW2	SW3	SW4	SW5	SW6	SW7
04/29/99	895	425	1421	1263	1280	368	756
05/27/99	291	101	322	442	497	72	324
07/07/99*	20	1	0	0	75	8	2
08/10/99*	2	0	0	0	0	0	0
09/27/99*	0	58	0	0	5	6	0
11/4/99	54	29	208	150	176	1	134
12/01/99	53	21	116	118	63	9	110
01/06/00	843	273	1136	931	1240	227	758

* Flows affected by drought conditions

for the tributary of Beham Run. Pre-mining flow rates between upstream monitoring point SW 6 and the downstream monitoring point SW2 showed a gain in flow that averaged 21% (i.e., the flow downstream averaged 21% greater than the upstream flow). After the mine face had passed directly under SW6 in October 1999, data shows significant lost of water between the two points. In November 1999 flow loss between the SW 6 and SW2 was 97%, indicating significant water loss at SW6. However monitoring over the following two months showed the flow returned to near pre-mining levels with a flow gain of approximately 17% encountered.

Flow data between upstream point SW7 and monitoring locations along Beham Run (SW 1, 3 and 4) were similarly analyzed. In May 1999 discharge rates showed an 11% gain between upstream point SW 7 and SW1. Data collected in December 1999 showed flow losses between the points was 51%. Mining under the stream occurred in November 1999. Flow recovered to near pre mine levels in January 2000 with a 10% gain between points recorded. Moving further downstream, the differences in stream flow between the monitoring points SW3 and SW4 did not vary appreciably between pre and post mining rates.

Hydrologic Impact on Spring Flow

Seven springs were monitored during the study. The locations of the springs are shown in Figure 2. Field reconnaissance done prior to mining identified five springs in the study area. Four of the five springs (SP 1 through 4) were located within the subsidence zone. These springs are referred to in this report as pre-existing springs. One spring (SP 5) was located outside the area of mining influence and therefore, outside the angle of draw. Two new springs (SPs 6 and 7) developed after mining had passed over the area.

Table 2. Spring flow rates

Field Dates		Flow rates (gpm)					
	SP 1	SP 2	SP 3	SP 4	SP 5	SP 6	SP 7
04/29/99	0.8	1.8	-	-	-	-	-
05/27/99	2.7	0.4	26.9	-	-	-	-
07/07/99	0	0	0	0.3	0.1	-	-
08/10/99	0	0	0	0.6	0.1	-	-
9/27/99	0	0	0	0	0.5	5.7	-
11/4/99	0	0	0	0	2.0	9.7	-
12/01/99	0	0	0	0	4.0	8.8	-
01/06/00	0	0	0	0	20.0	14.4	3.0

Collected spring flow rates are listed in Table 2. Flow from SP 1 actually increased after mining from a pre-mining rate of 0.5 gallons per minute (gpm) to 2.7 gpm after mining passed under the spring. The spring went dry shortly after mining with no flow recorded over the next eight months. SPs 2 and 3 had flow in May 1999. Mining passed under both springs in April/May 1999 and flow from the springs was found to have ceased two months after being undermined. SP 5 is outside of the subsidence zone and flow rates show a steady increase over a seven-month period from less than 1 to 20 gpm. The possibility exists that fracturing of rock strata adjacent to this spring has altered the ground water pathways, allowing the water to flow toward this spring. Another possibility is that this increase is a natural occurrence associated with seasonal variations in the ground water. Further field measurements are necessary to conclusively answer this question.

Based on field documentation and observations, two springs developed during the study period. SP 6 was evident during the September 1999 data collection and had an initial flow rate of about 5.6 gpm. The rate increased over a three-month period to over 14 gpm. Mining in the immediate area did not occur until about a week after the initial flow was recorded. The spring most probably appeared as a result of alterations of ground water levels caused by mining activity. The location of the spring is at the edge of the panel and would be within the tension portion of the subsidence trough. SP 6 is located within 40 feet horizontally and 10 feet vertically of the tributary of Beham Run.

SP 7 is actually two springs located within 100 feet of each other and feeding into one water course. For data collection purposes, the flow rate from both springs was combined. The springs were discovered during the September 1999 field exercise and noted as small seeps with minimal flow. Over the following three months, the flows increased to a point where an actual rate could be determined. The January 2000 reading was 3 gpm. The springs feed a low-lying farm field along Beham Run and have created a ponded area.

There is an average elevation difference of 134 feet between the newly developed springs and the springs that have become dry since mining was found. This infers that mining has caused additional fracturing of the overburden. This increased hydraulic conductivity and storage has drained the upper reachers of the ground water causing a lowering of the ground water level. The flow has been reestablished at a lower elevation as evidenced in SPs 6 and 7.

Conclusions

The purpose of the study was to determine the effect longwall mining has on surface and ground water systems. The integrated use of both GPS and GIS applications aided in both the data collection and interpretation phase of the study. GPS was used to locate and attach attributes to the monitoring locations. GIS was used as a presentation tool to collectively review data on one concise map. The effect on surface hydrology is presented for both the stream and spring flow.

The study found that longwall mining has an effect on stream flow that can be significant in the short term. The difference in flow between a portion of the tributary of Beham Run was found after mining to be -118%(from a gaining to a losing flow). However, the stream returned to near premine flow rates within two months after mining. This is in agreement with conclusions reached by other authors (Carver & Rauch 1994; and Hill and Price 1983). Additionally, the study found longwall mining had minimal effect on a portion of Beham Run.

Springs in the study area were affected by the longwall mining. The four pre-existing springs located within the expected zone of subsidence went dry after mining. Flow has not returned to these springs in the six months after mining. The mining-induced fracturing of the overlying rock strata has apparently lowered the ground water elevations such that springs along the ridges of hill sides are the most affected.

Two springs developed in the study area and appeared within a few months after mining. The locations of the springs are134 feet lower in elevation than the pre-existing springs, supplying clear evidence that the water table has lowered due to the longwall mining. Carver & Rauch (1994) found that springs located over 30 feet in elevation above nearby perennial streams were dewatered after longwall mining. He also reported that the reestablishment of a new flow system was evidenced by appearance of new springs or increased spring discharge at lower elevations.

References

Bai, Mao and Kendorski, Francis S. 1995. Chinese and North American High-Extraction Underground Coal Mining Strata Behavior and Water Protection Experience and Guidelines. p. 209-217. In: 14th Conference on Ground Control in Mining. (Morgantown, WV, August 1-3, 1995).US Bureau of Mines, USMSHA.

Carver, Leslie, and Rauch, Henry. 1994. Hydrogeologic Effects of Subsidence at a Longwall Mine in the Pittsburgh Col Seam. p. 298 -307. In: 13 Conference on ground Control in Mining. (Morgantown, WV, August 2-4, 1994). US Bureau of Mines, USMSHA

Hill, Gregory J. and Price, Donald R. 1983. The Impact of Deep Mining on an Overlying Aquifer in Western Pennsylvania. GWMR/Winter 1983:138-143.

Johnson, Kenneth L. 1997. Effects of Longwall Mining on Streamflow in the Pittsburgh Seam Basin. p. 25-32. In: 16th Conference on Ground Control in Mining. (Morgantown, WV, August 5 - 7, 1997). USNIOSH, USMSHA.

Kendorski, Francis S. 1993. Effect of High-Extraction Coal Mining on Surface and Ground Waters. p. 412-425. In: 12th Conference on Ground Control in Mining. (Morgantown, WV, August 3 -5, 1993). US Bureau of Mines, USMSHA

McDonald, Keith. 1999. Opportunity Knocks, Will GPS Modernization Open Doors? GPS World 10(9):36-46.

Van Roosendaal, D.J., Brutcher, D. F., Mehnert, B. B., Kelleher, J. T., and Bauer, R. A. 1990. Overburden Deformation and Hydrologic Changes Due to Longwall Mine Subsidence in Illinois. p. 73-82. In: Proceedings of the 3rd Conference on Ground Control Problems in the Illinois Coal Basin. (Mt Vernon, Il, August 8-10, 1990). Dept of Mining Engineering, Southern Illinois University.