DISCHARGE WATER HANDLING AND TREATMENT: PROBLEMS AND SOLUTIONS AT A LARGE PITTSBURGH SEAM COAL MINE

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ABSTRACT

Recently, a large Pittsburgh seam longwall mine was nearing depletion of a major portion of its current reserves and had begun to develop in a different direction from its original portal area to access additional reserves. This meant that a large area of the mine would be abandoned and sealed. However, continued use of the original mine portal area required that the water accumulating in the abandoned mine would eventually need to be pumped to the surface. This would be in addition to the discharge water associated with the new portion of the mine. Several pumping and sump options were investigated to handle the quantity and quality of the anticipated discharge water. This paper describes some of these options, their advantages and disadvantages, and the final engineering decisions. Some problems and unanticipated outcomes, as well as the eventual solutions are discussed, including: (1) estimates of pump requirements, (2) water pool size, (3) eventual water quality, (4) anticipated inflows, and (5) integration into the overall mine water system.

INTRODUCTION

The act of creating openings and subsiding strata during coal mining almost always produces inflows of unwanted ground water. These water inflows into the underground mine sometimes present considerable problems to mine operators. Depending on amounts and location of inflows, the water needs to be removed from active mining areas. Environmental concerns, law, and regulation require coal mines only to discharge water of an acceptable water quality. However, contact of the ground water with contaminates in and around the coal seam, especially minerals such as pyrite, often requires costly water treatment facilities to meet current criteria. As a result, many operators choose to store as much water in abandoned portions of the mine and/or use this discharge water in the coal preparation process, which can minimize or eliminate treatment costs. Due to abandoning a major portion of a large Pittsburgh seam longwall mine, one operator was challenged to devise a new handling system to deal with the accumulating water in the abandoned portion and the eventual inflows from the projected future mining areas. The following describes the engineering processes that resulted from the initial evaluation and actual outcomes of the collection, pumping, and treatment systems.

BACKGROUND

The mine is located in Waynesburg, Greene County, Pennsylvania, west of the Monongahela River in the extreme southwestern corner of the state. The mine geology is relatively simple. Structurally, the area is dominated by gentle folding represented by the Waynesburg Syncline to the southwest and the Belle Vernon Anticline near the center of the reserve area. Axes of these folds are oriented N 40 degrees E and the dips are gentle ranging from 0 degrees at the crests and troughs of the folds to nearly 2 degrees on the western limb of the Belle Vernon Anticline. The Pittsburgh No. 8 is the lower member of the Pittsburgh Formation of the Monongahela Group and generally occurs at about 600 feet below the surface. It is characterized as a major coal seam varying from 0 to 12 feet. However, it averages 6.0 to 7.0 feet in thickness over most of the reserve area and gradually increases in thickness to the east of the reserve. A major sandstone channel is present across the reserve between the portal area and the new reserve. The mine currently utilizes one longwall section and several development sections. The Pittsburgh coal seam in the general area dips in the western direction. As the mine began to deplete their reserves in the southern area, the mine developed the new reserves in the eastern direction. The mine had previously sealed the western portion of the mine in the early 90's, south of the main portal. This area is the lowest elevation in the mine. The relative locations of these areas are depicted on the map in Figure 1. The western area that was to be sealed is approximately 7,270 acres (11.4 square miles). The mine sealed the southern end of the mine near the number 1 portal. These seals adjoined the western seals and thus sealed off a majority of the depleted reserves. Sealing of the depleted reserves allowed the mine to use the sealed area as a water storage area. The mine had been utilizing the western sealed area as a natural sump or water storage area since the early 90's. This system was convenient for water handling.

The general quality of the active mining discharge water was acceptable for discharge. However, it was suspect due to the short residence time prior to being pumped out the mine. Water samples in the sealed area were taken at an abandoned capped shaft and the results of these analyses also indicated good quality water.

Prior Operating Plan

As the current mine dewater system became unable to handle the total mine discharge, new options were considered for the removal of mine water. The new pumping system design had to encompass many design considerations. Some of the considerations are listed below:

- Safety and operational risks
- Water system integration
- Future mine plan design
- Minimize operating and capital investment
- Maximize efficiency and minimize operational delays

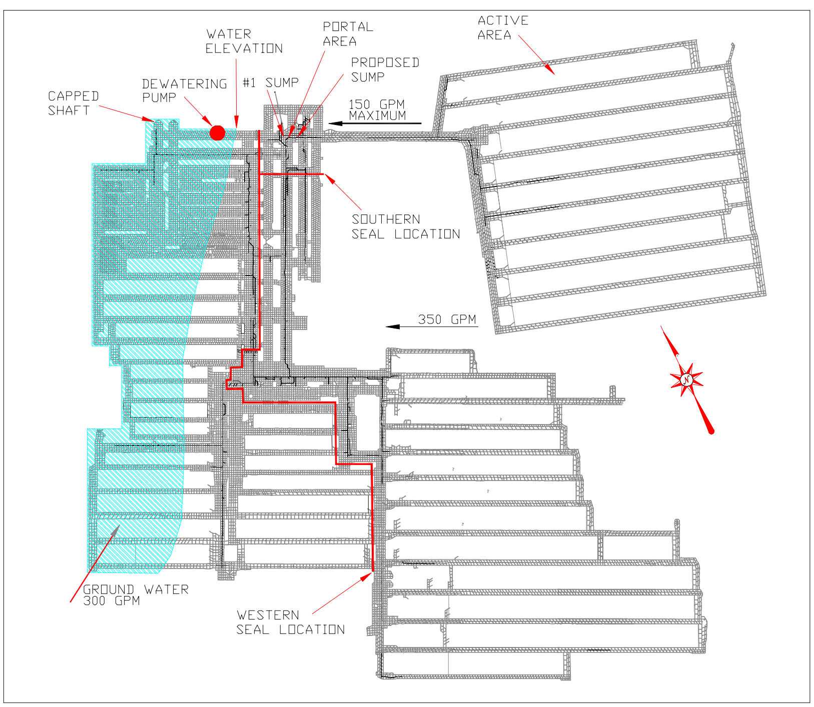

Figure 1 Mine Map With Flow Diagram

The existing pumping system, consisting of a small, above-mine floor storage sump, and the #1 sump pumps located at the main portal area, was delivering about 300 gpm of water to the surface. All of the water pumped to the surface was collected in a series of ponds and then used by the coal preparation plant as make-up water. Water from this sump was the only water pumped from the mine with the nearby sealed area accumulating the remainder of the mine make of ground water. This original system had a number of problems. The #1 sump was small and the system was under-designed to handle the amount of water and solids that was being developed. The system was down frequently due to maintenance problems requiring the water to be directed to the abandoned workings behind the western seals. This original sump was limited in size and would fill up with solids periodically. The high head pumps would only last several months, due primarily to the abrasive material in the water. The discharge line to the surface would burst on an average of six times a year because of the high head and the age of the line. Also, the #1 sump was very inefficient and required a high amount of maintenance to remove accumulated solids. After a cursory evaluation, other system options were investigated.

Determining Requirements of Pumping System

Prior to the design of a pumping system, a general flow diagram was developed (Figure 1). The data for this diagram was gathered in several ways. The ground water inflow behind the seals was determined by a meeting with several foremen that managed the water when the mine was active in that area. The foremen indicated that the water flow, after the initial mining, was fairly consistent at approximately 300 gpm. The water inflow, pumped via pipeline from the southern end of the mine, was approximately 350 gpm. The water from the active eastern reserves was determined to be about 150 gpm. The total maximum projected flow was calculated to be 800 gpm. An 1100 gpm flow rate was selected for the design flow. The 1100 gpm flow rate allows for approximately a 33% increase on the total flow.

Using a piezometer, water levels were taken from the abandoned shaft to record the water elevations in the sealed area. An attempt to calculate the water inflow rate into the sealed area using the water level increase was difficult. The natural sump, located behind the western seals, had several sources of water inflow. This area was the natural low spot of the mine and consisted of previously retreated room and pillar, longwall panels and associated standing entries. Inflows of natural ground water and discharge from active mining areas pumped via a pipeline system into the area, accumulated there.

Theoretically, the groundwater inflow rate could be calculated by documenting the rise in water level in the sump and subtracting out the known mine discharge inflow. However, the required data is very difficult to obtain. This is due to difficulty determining the volume of the sump given the caving and remaining pillars.

A reasonable approximation can be made of the volume of the standing entries. However, determining the volume in the caved areas is more speculative. This is due to problems obtaining the height within the caved area, which can be filled with water, and estimating the void space within the broken rock in the gob. The gob void space calculation was attempted using the following analysis: The gob was defined in area to originally have a 7-ft mining height. It was assumed that the main contributor for sump capacity in the gob area would be the "caved zone" area as depicted by Peng and Chaing and Singh and Kendorski[1,2]. The contribution of the "fractured zone" and other subsided areas of the gob were considered to be negligible. The height of the caving zone can be estimated by formulas and bulking factors given by Peng[1] and Chen[3]. In this case, a caving height of 5 times the mining height and a bulking factor of 1.25 were used. This results in a maximum water fill height of 35 feet from the original bottom with 25% of this volume being available for water storage. This calculation could be assumed across the width of the longwall panel and added to the volume of the standing entries. Therefore, at various water pool elevations, and given the original coal bed bottom elevations, the total water storage volume available could be estimated at incremental, measured, sump pool heights.

The main point of determining the volume of the inflow into the sealed area was to develop a good engineering estimate of the total flow rate that would need to be pumped. While a reasonable estimate was made, the ground water inflow rate of the sealed gob was very difficult to determine precisely by this volume method.

Two General Options

There are two general locations that the water can be pumped out of the mine. The first is the active area of the mine. The second is the sealed area of the mine. The barriers between these two areas are ventilation seals. Under 30 CFR part 75 ventilation seals cannot be used to bulkhead water. This requirement prevents water flow from the sealed area to the active area by gravity flow methods. The main objective was to remove water from the sealed area and active area with the lowest overall cost. There are many constraints that one must satisfy prior to project commencement. The problem solution is classified by Option 1 and Option 2.

Option 1: Option 1 included constructing a new sump at the bottom of the main portal area. The new sump location was targeted near the bottom of the shaft. The scope of the new sump would include installation of a borehole to pipe the water to the surface, new pumps, and increased sump storage capacity. The borehole would replace the old line that was encased in the concrete floor in the slope track entry. The borehole was selected in lieu of running a new pipe down the track or belt entry of the mine slope. The pump design was driven by water samples taken of the existing discharge water. A water analyst classified the sample as highly abrasive. Horizontal centrifugal split case pumps were selected due to the high abrasive properties of the water. This approach was conservative considering that the water would have a longer retention time to settle suspended solids. The increased sump size was designed to increase the time for the solids to settle. The sump was designed as a dual compartment sump to allow pumping in conjunction with sump cleaning. The new sump design encompassed all the requirements of an efficient underground sump but still required periodic pump maintenance and cleaning of the sump. The borehole water would still be pumped into the series of ponds and then be utilized as preparation plant makeup water. The new sump would handle the water from the active area while an additional pump would be required to discharge the water from behind the seals.

Option 2: Option 2 considered using the sealed area as a natural sump. The sealed area has some inherent advantages and disadvantages associated with its use as a main sump. The natural sump has more available storage area for groundwater and active area water storage. The water quality appeared sufficient for use in the coal preparation plant as well as for underground. A benefit of having the additional water available is water interruption insurance and as an offset for city water purchases. The water from the sealed area would compliment the water system with the ability to store water and supply water when the preparation plant required additional make up water. Storage capacity is also very important to the operation in times of high water demand and periods of drought, which has affected the city water supply in the past. The pump design in the natural sump area assumes that the water in the sealed area would settle a majority of the abrasive solids. Permitting the solids to settle out in the sealed area would eliminate the material handling problems and sump cleaning problems associated with Option 1. The use of the natural sump as the main sump would, of course, also eliminate the need for construction of the new sump. However, placement of the pump is more difficult in this option because this area is not in an active area of the mine. Optimum sites for pump placement were limited and remote from the surface water system. A concern with this option was that the water quality data for the natural sump was limited and could be different than the sampling results indicated.

Pump Placement and Design

There were two options for the placement of the pump in the sealed area. The pump could be placed in the capped mine shaft or in a drilled borehole. A cost-benefit analysis was completed on the locations in question. Placing the pump in the shaft had several obstacles to overcome. The shaft was approximately one mile away from the main water system and the surface pipeline to the ponds would need to cross Tenmile Creek, a Norfolk Southern railroad line, and several non-owned properties. This option actually was less risky than placing the pump in a drilled borehole. Drilling a borehole into sealed area of the mine can be very difficult because the exact underground location cannot be explored. Since the shaft already existed, placing the pump into a shaft would be less problematic than a borehole. The cost of installing the pipeline from the pump/shaft location to the discharge point was the item that made the shaft option unfeasible. The placement of the pump in a borehole that could be placed nearer the surface ponds was determined by the mine as the most viable option.

The borehole was located on the western side of the mine property at an intersection of the mine entries adjoining solid coal in anticipation of greater borehole and opening stability. The overburden in this area was 800 feet. Pump design limited the choice of pump type to a vertical turbine line shaft. The line shaft pump was designed to set 805 feet into the mine. The surface pipe was designed to flow into either of two make-up ponds for the preparation plant. Figure 1 depicts the location of the pump borehole relative to the underground workings.

The final consideration in the pump design is the construction materials selection. Water samples that were taken in the abandoned airshaft indicated that water was normal groundwater. There was no special material pump material required for the water quality that was sampled. It was anticipated that the water samples may not be representative of the entire sump. The different types of material construction ranged from cast iron to stainless steel. The stainless steel construction was two times the cost of cast iron. Cast iron was selected for the material construction due to the cost differential.

Conclusion of Collection/Pumping Options

Option 2, using the abandoned area as the main storage sump and pumping through a borehole, was selected because it was the most economical and overall had less inherent risk. The design was confirmed and project timeline was constructed. At that time the water level in the sealed area was rising fast and the water was expected to reach the ventilation seals within three months. The project schedule was very critical to operation of the mine. A specification was written and contract was placed with a local drilling contractor.

Actual System Operation

The project experienced a few delays but was completed on schedule. The pump was set and the pipe was installed to the coal preparation plant storage ponds. The system was put into operation and water samples were taken. The field pH of the water was 5.7, which was lower and more acidic than expected. Iron levels were also unexpectedly high in the range of 2,000 ppm. Visually, besides these obvious parameters, other aspects of the water appeared normal. The water quality deviation was considered to be a combination of the sampling method and possibly the contact of the water with the concrete shaft lining. Also, the water may have been stratified taking the agitation with the commencement of pumping to provide a more representative sample of the overall water quality. The water quality indicated that treatment was necessary prior to discharge or use in the preparation plant. The results of the analyses are tabulated in Table 1.

Table 1 Mine Water Quality

Parameter	Result	Units
pH, field	5.7	S.U.
Alkalinity	240	mg/l as
Acidity (Hot)	2,400	mg/l as
Total Suspended	200	mg/l
Total Dissolved	24,000	mg/l
Sulfates	12,000	mg/l
Iron, Ferrous	1,950	mg/l
Iron, Total	2,000	mg/l
Manganese	10	mg/l
Aluminum	<1	mg/l
Chloride	3,500	mg/l
Sodium	4,500	mg/l
Calcium	350	mg/l
Magnesium	490	mg/l
Osmotic Pressure	410	MOS/KG

Investigation of Water Treatment Methods

Upon recognition that water treatment would be required, a simple caustic soda (NaOH) storage and feed system was initially installed to operate on a temporary basis. The injection point for 50% NaOH was just below the overflow from one of the make-up water storage ponds which cascaded down a rock ditch to the fine refuse tailings pond. This treatment system provided satisfactory results for pH adjustment without the need for automatic control. Because of the large retention time in the slurry impoundment, adequate aeration was provided to oxidize the ferrous iron. However, the chemical cost was extremely high, which led an investigation to alternative treatment methods. In addition to the high chemical cost for treatment with caustic soda, there were problems associated with the sludge particles due to the fluffy nature and the very low density of the settled sludge. The fine refuse tailings pond, where this sludge accumulated, is designed to return water back to the coal preparation plant to be used as make-up water to pump the slurry from the thickener underflow to the impoundment pond. Therefore, the light floc particles, created from a caustic soda treatment system, would present long term problems for the return water quality.

A refined actual groundwater inflow rate was needed for the water treatment plant design. This further analysis of the flow rate was needed prior to making the high capital investment for water treatment facilities. Also it was thought that the water quality from a larger zone would need to be determined to be sure the early samples were representative of the large body of stored water. A pumping test was setup with two objectives. The first objective was to determine groundwater inflow rate and the ability of the current pumping rate capacity to adequately lower the water elevation in the sump, given the existing inflows. The second objective was to determine whether any changes would occur to the water quality over a longer pumping period. The test was setup for a two-week period. This pump period was thought to be adequate to determine if the water quality was going to change over time. The inflow rate was determined by following parameters:

- Assume a constant vertical volume in the sealed area.
- Assume ground water inflow equal to the water pumped minus inflow from active area.
- Pump rate of 1,100 gpm.
- Active area inflow equal to 100 gpm.
- Change in depth while pumping.
- Change in depth while pump shut off.

- Time the pump is pumping.
- Time the pump is shut off.

This constant vertical volume method was chosen as the only reasonable method that could measure the actual ground water inflow rate. The test method was to operate the pump and measure the time in which the water elevation drops. Then shut the pump off. The amount of time for the pump to lower the water level a predetermined distance was measured. The following table 2 is the test that was performed prior to determining a water treatment plant design flow rate.

Table 2 Dewater Pump Flow Rate Test

Q1=	1100	Pump Rate(gallons/minute)
Q2=	335	Groundwater Inflow(gallons/minute)
Q3=	100	Mining Water Inflow(gallons/minute)
D1=	1.27	Change in Depth While Pumping(feet)
D2=	1.04	Change in Depth while Waiting(feet)
T1=	5760	Time the Pump is running(minutes)
T2=	7200	Time the Pump Shutoff(minutes)
Total GPM	**435**	

The pump test indicated the ground water inflow rate was 335 gpm. The equation for Table 2 is as follows:

$$T1*D1*(Q1-Q2-Q3)=T2*D2*(Q2+Q3)$$

This equation is simply a flow balance equation. Verification of the actual ground water inflow rate indicates that the pump met the required flow rate. The total flow rate as seen in Table 2 is 435 gpm. This total flow rate also indicated that the pump rate is not too excessive. However, the pump still needed to be replaced since the pH was below 7. An order was placed on a stainless steel pump to reduce the operational risk to the pumping system. The water quality variation over the two-week pump period was minimal, indicating that no significant change in quality was expected in the future. Therefore, the water treatment facility was designed as per the data in Table 1.

Lime Treatment System

It was decided to evaluate the alternative concept of a lime treatment system. The capital, operating and maintenance costs for an installed lime treatment system were determined and compared to similar costs for a caustic treatment system. A preliminary budget cost for an installed lime treatment system was provided by Chester Engineers. A tabulation of all the costs for these two treatment systems provided the data required to compare the internal rate of return. On this basis, the lime treatment alternative provided a return on investment in less than one year.

To provide support to justify the preliminary tabulation discussed above, bid specifications were prepared, submitted to qualified bidders and proposals received. A design/build contract was awarded to the most qualified bidder based on evaluated costs.

The basic treatment process that was selected included the following steps:

1. Pre-aeration: An on-site bench scale treatability study was conducted to determine if there would be a benefit from pre-aeration of the mine water. Alkali requirements were measured initially on the mine water without aeration to establish a baseline. Additional samples were then aerated at a rate of 1 liter/minute for 10, 20, 40, 60, 120, and 240 minutes. The alkali requirements for each were then measured in a step titration process identical to that which had been completed on the initial sample. The findings indicated that there would be a benefit from pre-aeration through savings of approximately 12% of the lime. The lime reduction benefit increased steadily through the sample aerated for 60 minutes and leveled off thereafter. As a check to confirm this process benefit, the total inorganic carbon was measured on the samples. The initial sample contained 97.4 mg/l of inorganic carbon and after 60 minutes of aeration, the concentration was reduced to 29.8 mg/l.

Pre-aeration has been utilized in many acid mine drainage treatment systems in Southwestern Pennsylvania that operate on Pittsburgh Seam Coal. Often there is a limestone formation in close proximity to the coal seam providing alkalinity to the mine water. Pre-aeration of this water drives off the CO_2 and reduces the carbonic acid content. An additional benefit is derived from reduction in carbonate scale formation, which would otherwise occur on system components. Pre-aeration was selected to improve lime utilization and reduce scale formation.

2. Post-aeration: A survey of the most commonly used methods to oxidize the ferrous iron in coal mine drainage treatment systems showed the following types available:

- Fixed-mount surface aerators.
- Floating surface aerators.
- Submerged-turbine aerators.
- Fixed-mount combined surface/submerged turbine aerators.

For a lime treatment system using a circular concrete reactor for this neutralization/aeration step, the floating surface aerator concept was eliminated due to potential solids build-up within the tank. The surface aerator and the combination unit both have upper impellers that create a splash effect in the tank. To counteract this effect, the freeboard in the reactor needs to be increased. Another adverse effect from surface aerators is the creation of a fine iron colored mist that is easily transported to the surrounding area by the wind. To counteract this effect a tank cover is normally installed. Because of these conditions a submerged-turbine aerator was selected as the preferred method for the application. There is a slight efficiency penalty to pay according to the equipment manufacturers, but operational concerns became paramount, leading to the decision to select the submerged-turbine type. With this method, external positive displacement blowers are used to provide the air. They are located in an adjacent building that also houses the motor control center and the programmable logic controller.

The submerged turbine aerator system is designed to provide an oxygen transfer rate of 158 lb of O_2 per hour assuming up to 2000 mg/l of ferrous iron and 1100 gpm of mine water influent.

3. Lime Silo and Slurry System: Neutralization for the mine water is provided through a packaged 50-ton hydrated lime storage, feed, and slurry system. The system includes the following components.

- Truck fill line with operator station panel.
- Silo level sensors for the dry lime.
- Dust collector.
- Bin activator.
- Discharge isolation knife gate valve.
- Volumetric screw type feeder for up to 2000 lb/hr.
- Lime slurry make-down tank, 1000 gallon capacity.
- Slurry tank mixer.
- Slurry level sensor.
- Lime slurry pumps.
- Silo exhaust fan.
- Silo electric heater.
- Silo light fixtures.
- Silo skirt insulation.
- Silo panel with indicator lights and disconnects.

From this system a 10% lime slurry is pumped in a continuous loop from the lime slurry make-down tank with a return back into this tank. Lime slurry from this loop is fed into the neutralization/aeration tank based on demand. The control system for this includes a pH controller, a pH probe, and a 4-20 ma. modulating V-notch control valve. A predetermined range for the pH setpoints is provided in the programmable controller.

The complete treatment system as described provides gravity flow from the pre-aeration tank through the post-aeration tank and from there down a riprap channel and into the fine refuse tailings pond.

The performance of the system is measured essentially by the efficiency of iron conversion from the ferrous form to ferric iron. In addition, lime utilization is tracked by comparing actual usage to theoretical.

There are no discharges from the fine refuse tailings pond and only two NPDES outfalls from the entire site. The parameters that are regulated at these locations include pH, suspended solids, iron, manganese, aluminum, and osmotic pressure.

SUMMARY

As this Pittsburgh seam longwall mine proceeded to abandon a major portion of depleted reserves and mine remaining reserves from its original portal area, it was faced with the problem of handling the ground water being produced from the abandoned area plus the additional water from its future mining. A natural sump that had been used to store excess ground water over the years was beginning to reach capacity and would soon spill over into the active portal area. This required that the operator pump the all the water being produced from both the abandoned and new mining. However, the existing pumping system was undersized and faced a number of other problems. Several alternatives were analyzed. Based on a number of perceived advantages the decision was made to utilize the sealed natural sump portion of the mine as a main collection area. Two options were analyzed to pump from the sealed area, with pump in a borehole configuration being the final choice. Attempts were made to quantify the pumping system design parameters: quantity and any special considerations due to water quality. The quantity question was successfully estimated and later confirmed by a more precise estimation method. However, the actual water quality was much poorer than anticipated, apparently due to inherent problems with the sampling method used to determine the quality of the water stored in the sealed area. This required a temporary treatment facility until the

required design of a final treatment facility could be determined and procured. Due to acidity of the actual water the original cast iron pump needed to be replaced with a stainless steel pump. The final treatment method chosen was a hydrated lime treatment system, which provided an acceptable make up water to the coal preparation process and worked in concert with that process to result in a final mine water cycle which requires little discharge of water. The relatively small discharges from the system meet the requirements for NPDES discharges.

[1] Peng, S.S. and Chaing, H.S., 1984, Longwall Mining, John Wiley & Sons, New York, 708 pp.

[2] Singh, M. M. and Kendorski, F.S., 1981, "Strata Disturbance Prediction for Mining Beneath Surface Water and Waste Impoundments", Proceedings of the 1st Conference on Ground Control in Mining, West Virginia University, Morgantown, WV, July 27-29, pp. 76-89.

[3] Chen, J., Mishra, M., Zabrosky, C., and DeMichiei, J., 1999, "Experience of Longwall Face Support Selection at RAG American Coal Company", Proceedings of the Longwall USA 1999 International Exhibition and Conference, Pittsburgh, PA, September 21-23, Coal Age, pp. 53-77.