Groundwater can bring an underground mining operation to its knees, but it can be controlled with ingenuity, co-operation and grout expertise. **Brad Crenshaw, P.E. P.G., Ground Engineering Contractors, Scott Langley, White Oak Resources LLC, Vic Daiber, P.E. P.L.S., Pittman Mine Services LLC, and Donald Rigby, Avanti International, US,** answer the risk-reward question.

White Oak Resources LLC (WOR) No. 1 mine is located within the Illinois Basin near Dahlgren, US. The company is currently in the process of developing a longwall operation in the Herrin No. 6 seam. Development work consists of a shaft for employee access and ventilation, a slope for coal and material handling, a 2000 short tph preparation plant and underground works. After completion of the development work, WOR plans to conduct longwall operations in 1400 ft (427 m) wide by 12,500 – 18,000 ft (3810 – 5486 m) long panels. This article focuses on work associated with the new slope being constructed by Pittman Mine Services LLC. The 16˚ slope will be 3700 ft (1128 m) long to reach the seam that lies at a depth of approximately 960 ft (293 m). The slope is excavated at 22 x 21 ft (6.7 x 6.4 m). Ultimately, arches and lagging are placed and backfilled with concrete. The slope is divided into two compartments by a steel and concrete deck. The upper portion contains a 72 in. (1.83 m), 6700 short t conveyor system for coal handling. The 8 ft high by 18 ft wide (2.4 x 5.5 m) lower portion will be used for the delivery of equipment and supplies using a 125 short t hoist.

Initial boring data indicated that groundwater inflows to be encountered during construction could be managed by typical collection and pumping methods, without the need to grout any of the water-bearing layers. However, after excavation of the slope began, drilling for drop-holes (used for power and concrete pours) along the slope centreline revealed groundwater inflows much greater than the initial boring data indicated, requiring WOR to reassess how to manage water inflows encountered during construction, including the consideration of grouting.

Once the slope excavation reached the water-bearing layer, significant water inflows were encountered that could not be managed by typical methods leading WOR to the decision to grout the water-bearing layer.

Geology

The Illinois Basin is a Paleozoic depositional and structural basin. It consists of inter-bedded sequences of sedimentary rock, primarily limestone, dolomite, sandstone and shale. Bituminous coal is present within the Pennsylvanian rocks of the basin.

The groundwater bearing formation that was encountered at the WOR No. 1 minesite is known as the Mount Carmel formation. At this site, the formation is a sandstone layer lying at a depth of about 350 ft (107 m) and approximately 70 ft (21 m) in thickness. The top of the formation is a transitional inter-bedded sequence of sandstone and shale. The bottom of the formation is bound by a competent limestone with underlying shale and claystone layers. The Mount Carmel formation is poorly graded and incompletely cemented. Site data indicated a hydraulic conductivity of approximately 1×10^{-4} cm/sec. Additionally, the upper boundary shale formations acted as a confining layer, resulting in a confined head of approximately 320 ft (98 m).

Once the slope encountered the formation, approximately 350 lineal ft (107 m) of excavation would be within the Mount Carmel sandstone.

Problem background

After the realisation that the Mount Carmel formation would be water bearing, testing and modelling was performed to estimate the potential ground water inflow that could be encountered during mining. Based on data collected during testing of drop holes, it was determined that the slope could experience between 300 – 500 gallon/min of groundwater inflow over the exposed length of the formation. This volume of inflow would slow mining to an unacceptable rate. Therefore, WOR and Pittman decided to take measures to mitigate groundwater inflow volume.

White Oak Pittman cut sequence

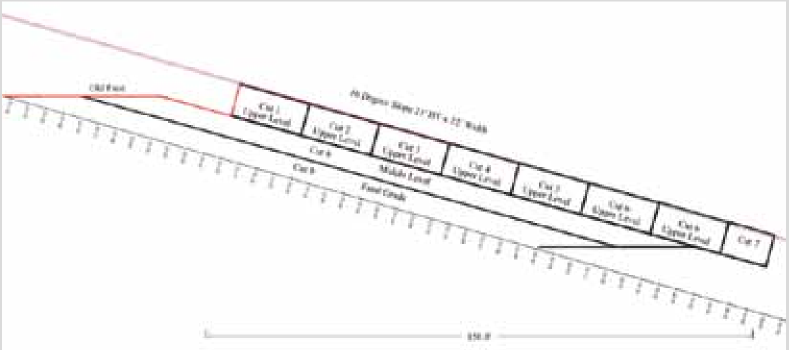


Figure 1. Typical 150 ft (46 m) cut sequence.

During the construction of the White Oak No. 1 slope, a continuous miner machine and a bolting machine was used. The miner machine cut sequence is seen in Figure 1 for 150 ft (46 m) intervals. After each cut on the upper level, the bolting machine bolts the roof and ribs. After cuts 8 and 9, the bolter rib pins and hangs wire mesh for the safety of the workforce. As mining progressed towards the Mount Carmel sandstone, it would take two of these type cycle (300 ft [91 m]) to get through the 80 ft (24 m) thick sandstone that contained significant amounts of water. This water would slow the cutting sequence by turning the floor rock into mud or sand. To remedy the slowing of the process, several companies were called in and evaluated. GEC was selected because its materials would flow further in a 100 ft (30 m) drill hole and not setup like other companies' poly materials, since they expand much faster and do not travel as far. A new sequence for Pittman and GEC had to be developed that would meet White Oak's project schedule.

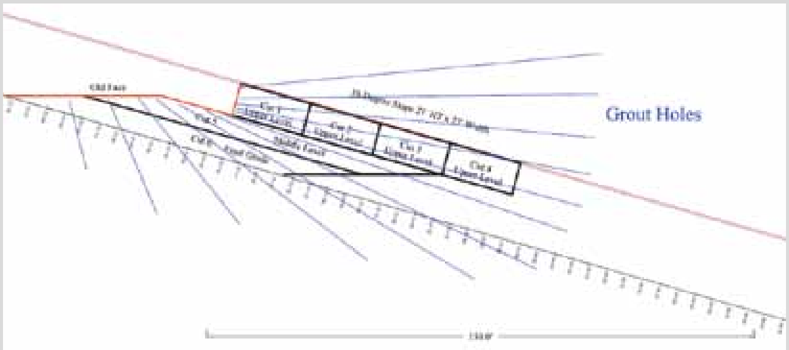


Figure 2. Revised 150 ft (46 m) cut sequence.

The length of the next extension was reduced to half. This would allow GEC to drill holes anywhere from 10 – 125 ft (3 – 38 m). These holes would be grouted and would provide a grout curtain for cuts 1 through to 6. This process did slow the mining but kept the water inflows to where mining could continue. This process continued over 4 – 5 times to get through the Mount Carmel sandstone.

Continued opposite

Dewatering wells

The initial step in the groundwater mitigation programme was the installation of 10 dewatering wells. The goal of this activity was to decrease groundwater inflows into the slope to a level which would not significantly impact construction. Dewatering wells were installed approximately 50 ft (15 m) apart, alternating approximately 30 ft (9 m) off slope centreline, along an approximately 400 ft (122 m) long section of the slope that would encounter the Mount Carmel formation. Dewatering wells were installed to a depth of approximately 430 ft (131 m), which corresponded to the bottom of the formation. The number of dewatering wells, as well as the distance at which they could be located from the slope, was limited by the initial plans included in the water discharge and surface disturbance permits. This resulted in only 10 of the 20 desired wells being installed at less than optimum locations.

Upon initial startup of the dewatering wells, around 300 gallon/min of water was pumped. This resulted in a 250 ft (76 m) reduction of the hydraulic head from 300 to 50 ft (91 to 15 m). After the wells had been operating for 30 days, a steady state pumping rate of 60 gallon/min maintained the hydraulic head of 50 ft (15 m).

Grouting

Although dewatering reduced the potential for groundwater inflow based on the reduction in pumping volumes and hydraulic head, WOR still had concerns about dealing with the remaining groundwater associated with the Mount Carmel formation. To accomplish this, the company evaluated and eventually chose to proceed with a grouting programme. The goals of grouting were as follows:

- Primary goal: reduce the potential for groundwater inflow volumes, which would significantly affect safety or production rates of slope excavation.
- Secondary goal: provide a long-term mitigation measure to groundwater infiltration into the slope excavation to minimise long-term pumping and treatment of water during mine operations.

Another critical factor was that the grouting project would extend the construction timing of the slope. As the slope excavation was in such close proximity to the Mount Carmel formation, additional excavation would have to be delayed to allow for the completion of the grouting project.

WOR and Pittman chose Ground Engineering Contractors (GEC), a company with experience, skilled personnel and ready access to the tools and products required, to complete the grouting project. GEC provided grout engineering and design through Paddy Cochrane Pressure Grouting Consultant (PCPGC) and was helpful in explaining the difference between cement grout, chemical grout and acrylamides.

Grouting overview

Based on the initial discussions between WOR, Pittman and GEC, and

White Oak Pittman cut sequence (continued)

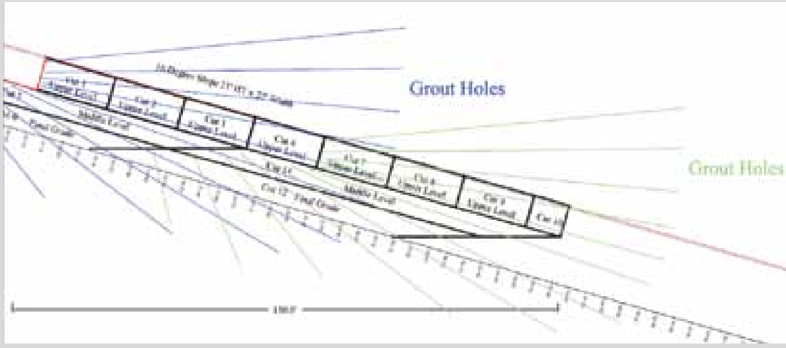


Figure 3. Revised 150 ft (46 m) cut sequence.

After the green grout holes were completed, the mining machine began cutting cuts 7 – 12, which completed the 150 ft (46 m) cycle. This approach provided a grout curtain for the cutting of rock to continue. After this was done the floor was poured behind, arches set and welded down, arch lagging installed, deck beams and Q decking installed and the deck floor poured. Advancement of belt and conveyor structure was bolted to deck and the whole process repeated. One benefit seen was that, while Pittman was doing the steelwork, GEC was drilling the next set of holes. This did cut some of the downtime in a 150 ft (46 m) cycle and allowed both parties to be more efficient, saving costs for White Oak.

Microfine grout being delivered to the underground agitation/pumping plant.

the evaluation of fractures in the upper part of the Mount Carmel formation exposed during slope excavation, it was decided that consolidation grouting techniques using microfine cement would be used in this project.

The most timely and cost-effective location to stage the grouting project was determined to be from within the slope excavation. Working from within the slope excavation would require GEC to communicate very closely with Pittman to co-ordinate the various construction and grouting processes.

Mining/grouting sequence

The typical construction sequence of the slope consists of 150 linear ft (46 m) of mining with a continuous miner.

Surface grout plant. Due to the space constraints and logistical issues associated with the underground space, all cementitious grout was mixed on the surface and pumped via slicklines for underground injection.

After mining, the invert (including rails), arches, lagging, decking and conveyor were constructed for a corresponding length of slope. Mining and construction are not conducted concurrently. The grouting process reduced the typical construction sequence from 150 to 75 ft (46 to 23 m). This was due to the grout cover length, which required fanning of the grout hole drilling pattern. The grout cover could be constructed to a distance of approximately 90 ft (27 m) beyond the mining face with a reasonable number of grout holes and with a grout hole spacing of approximately 10 ft (3 m) (at the termination of the grout hole). This method allowed a 75 ft (23 m) construction cycle with a 15 ft (4.6 m) plug at the face. Based on production rates onsite, this sequence was determined to be the most efficient as slope construction by Pittman approximately matched the grout cover installation production of GEC.

Installation of grout covers began upon the completion of mining. GEC's equipment was mobilised to the work area, and holes were drilled and grouted using a primary, secondary and tertiary/verification hole sequence. While GEC performed drilling and grouting work, Pittman performed slope construction work corresponding to the area that had just been mined.

Underground agitation/pumping plant. All cementitious grout was mixed on the surface and delivered underground for injection. Once underground, the grout was continuously agitated and pumping rates and pressures could be more precisely controlled than if grouting was conducted via surface pumps.

Although this process slowed slope construction, it minimised schedule disruption of Pittman crews.

Grouting summary

Grouting began approximately 10 ft (3 m) above the Mount Carmel formation. Initially, US Grout microfine cement supplied by Avanti International was used. Good grout penetration was recorded during the first cover and verification holes indicated limited residual groundwater inflow. However, after low grout penetration during the second cover, PCPGC and GEC recommended changing to AV-100 acrylamide grout, also supplied by Avanti. This decision was based on the assumption that the formation had graded from an inter-bedded sandstone/shale to a pure sandstone, resulting in the hydraulic conductivity transitioning from being controlled by secondary porosity (fractures/bedding planes) to being controlled by primary porosity (interconnectivity between sand grains).

Ultimately, four grout covers were constructed. Although groundwater inflow within the area past the third grout cover was not significant enough to stop mining, this area did exhibit the highest groundwater inflow rate within the formation. Therefore, the decision was made to install the fourth grout cover, which extended through the remainder of the formation. This final zone also targeted the transition zone, where the roof of the excavation was in the water-bearing sandstone and the floor had progressed through to the underlying shale and claystone layers.

The following quantities of grout holes and grouting materials were installed:

- 12,689 lineal ft (3868 m) of grout hole drilling.
- Injection of approximately 22,050 lb (10 t) of microfine cement.
- Injection of approximately 22,000 gallons of acrylamide grout.

The grouting programme and the dewatering wells limited the steady state groundwater inflow into the slope to approximately 50 gallon/min during the mining process. Current inflow, after completion of mining and backfilling, is less than 30 gallon/min.

A unique challenge: using grouting in proximity to dewatering

A highly unique aspect of the overall project was grouting in close proximity to dewatering wells. WOR sought to maintain the dewatering wells in operation during the remainder of slope construction (as this was one aspect of the groundwater infiltration mitigation program). GEC and WOR were concerned the grouting project and associated grout covers could intercept these wells, rendering them useless.

PCPGC and GEC developed monitoring programmes for detection of both cementitious and acrylamide grouts to determine if grout was entering the wells. The monitoring programme for cementitious grout was based on elevated pH levels within the wells, while the monitoring programme for acrylamide grout was based on detection of fluorescein dye, which was placed in the grout before injection. This monitoring programme resulted in only two wells being lost to grouting.

Key aspects of the grouting programme

Grouting can be an expensive and time-consuming element of underground work. This is especially true when the grouting is an unexpected element of the project and must be performed from the mining face. However, there were several aspects of this project that minimised the costs and increased the success of the programme.

Equipment preparation and planning

Underground work can be very difficult from an equipment and material staging standpoint. For this reason, GEC performed nearly all of the grout mixing and material handling on the surface. Grout was delivered underground to agitation and pumping plants after being mixed on the surface. Equipment preparation time for the project was about a week and a half, and involved making sure all equipment was in compliance for work in an underground coal mining environment. Upon arrival onsite, GEC and Pittman worked together to modify equipment to provide the most efficient system of delivery and underground use.

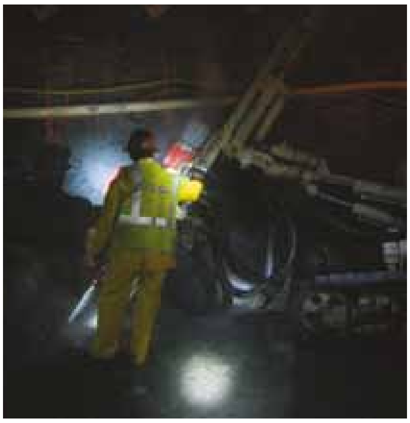
View from the platform of the agitation/pumping plant looking toward the working face. The underground pumping operation was generally 200 – 300 ft from the injection point. This was because the plant could easily be moved on rail to the end of the finished invert and because the area between the end of the finished invert and face was highly congested with mining equipment and grout hole drilling equipment.

Versatility

It was originally anticipated that grouting would be carried out using microfine cement, but a switch was required to acrylamide grout. This switch was key to the success of the grouting programme. This was possible due to PCPGC and GEC's ability to suggest alternatives due to their experience with various forms of grouting within numerous geologic conditions, combined with WOR and Pittman being open to the suggestions of the grouting contractor and grouting designer.

Conclusion

Dealing with primary and secondary porosity is one of the most difficult issues in groundwater control. It often requires the consideration and implementation of numerous mitigation processes and procedures. Successful grouting projects require all parties involved to entertain ideas and to work together to implement those idea in a co-operative manner. Dewatering and grouting at WOR's No. 1 mine allowed slope construction to proceed through the sandstone layer while minimising the impact to the construction schedule. Production proceeded efficiently with no major events at 50% of normal advance rate. The success of this project is attributable to the significant amount of planning, technical expertise, investment and co-operation of WOR, Pittman and GEC. WC



Grout hole drilling performed using an Airtrack drill rig. Drill through packers were used so that large volumes of water could be controlled if encountered.