

Environmental issues of the Appalachian coal region

Robert L.P. Kleinmann, Richard A. Allwes, Paul W. Jeran, Perry M. Jones, R. J. Matetic and Robert Statnick

Mining has been a significant component of the Appalachian economy for about 200 years. The region continues to be adversely affected by the environmental degradation associated with these past activities. In addition, companies today are being denied permits at sites where acid generation appears likely. And air emission limitations at power plants now threaten the economic health of many moderate- to high-sulfur coal mines. Thus, when considering the environmental impacts of mining coal in Appalachia, it is important to consider abandoned and active mine issues.

For example, abandoned mines generate acidic, iron-rich waters that adversely affect more than 6,400 km (4,000 miles) of rivers and streams in Appalachia. In contrast, operations that were active after the enactment of the 1977 Surface Mining Control and Reclamation Act (SMCRA) cause little water pollution. However, the costs of water treatment at such sites exceed \$1 million a day.

Even where water quality is not diminished, water supplies can be affected by mining. Subsidence-induced fractures can lower water table elevations or drain a surface stream dry. Subsidence can also cause damage to surface and subsurface structures.

Subsidence in the Appalachian region results from the degradation of abandoned, shallow room-and-pillar mines and from high-extraction deep mining. The former usually causes a pothole form of subsidence, which has a severe affect on a small area.

Subsidence from high-extraction mining (longwall mining) forms a broad

depression or trough directly above the mined-out area. The area of the trough is proportional to the mined-out area. Due to the hilly topography of the Appalachian region, these subsidence troughs usually cannot be detected without detailed surveying.

Several field studies revealed that the maximum vertical displacement can be as much as 60% of the extracted thickness. About 1.5 m (5 ft) of coal extracted can produce as much as 0.9 m (3 ft) of vertical movement. This maximum movement occurs over the center of the extracted area and vertical movement decreases laterally outwards. Above the edges of the extracted area, subsidence is generally less than 13 mm (6 in.) and decreases to zero within several hundred feet. In general, the deeper the mining, the greater the surface area affected and the gentler the surface deformations.

Air quality is perhaps the only environmental issue that is associated almost exclusively with active operations. The Clean Air Act has limited the burning of higher sulfur coals. This significantly affects the value of Appalachian coal reserves. Other air quality issues, such as fugitive dust, is less of a problem in the relatively humid eastern United States than in the arid West.

Water quality

Abandoned mines. Thousands of miles of streams and rivers in Appalachia are adversely affected by drainage from abandoned mines. The primary problems are high sediment loads and elevated levels of acidity, sulfate and metals, such as iron, manganese and aluminum. Contaminated drainage from abandoned coal mines is considered to be the most significant nonpoint source



Fig. 1 — A researcher evaluates plant growth in a wetland built to treat coal mine drainage.

of pollution in northern Appalachia according to the Environmental Protection Agency (EPA), Region 3. The regional significance of the problem decreases south of central West Virginia.

Comparing 1988 data with 1969 data it appears that water quality in mining impacted watersheds in Appalachia has improved. During 1969, Pennsylvania, Ohio and West Virginia had more than 14,000 km (8,700 miles) of adversely affected streams. By 1988, the total for those three states had decreased to less than 7,725 affected km (4,800 miles). Most of this improvement is due to the positive effects that legally mandated effluent treatment by active operations has had on overall stream water quality. Other contributing factors include natural amelioration, especially at abandoned surface mines, and reclamation efforts by local, state and federal agencies. Because these reclamation efforts are principally paid for through the tax the coal industry pays on each ton of coal mined, the industry has paid for most of the water quality improvement.

More recent improvements have largely been a result of passive treatment systems built at abandoned sites by state reclamation agencies, the National Resources Conservation Service (formerly the Soil Conservation Service)

Robert L.P. Kleinmann, Richard A. Allwes, member SME, and **Paul W. Jeran,** are research supervisor, civil engineer and geologist, respectively, with the US Bureau of Mines, Pittsburgh Research Center, PO Box 18070, Pittsburgh, PA 15201. **Perry M. Jones** is a geologist with the US Bureau of Mines, Twin Cities Research Center, 5629 Minnehaha Ave. South, Minneapolis, MN 55417. **R.J. Matetic,** member SME, is a mining engineer with the US Bureau of Mines, Pittsburgh Research Center. **Robert Statnick** is project coordinator with Consol Research, 4000 Brownsville Road, Library, PA 15129.

and local watershed associations using technology made available by the US Bureau of Mines (USBM) (Hedin et al., 1994) and others. These include constructed wetlands and anoxic limestone drains.

A typical constructed wetland is shown in Fig. 1. Not all of these passive systems discharge effluent-quality water, depending on site size and budget limitations. However, they have all improved water quality downstream. Before they were built, the water was discharged without any treatment at all.

More such systems will be constructed soon as part of the Department of the Interior's Appalachian Clean Stream Initiative that targets mine drainage-affected watersheds. However, passive systems can only treat mine drainage with relatively low contaminant loading. For the major contaminant sources, at-source control technology must be used.

Active mines. At active operations, major issues are the cost of water treatment and the long-term liability that postreclamation treatment requirements represent. Premine prediction of postreclamation water quality is important to mine operators. They need to factor this liability into the price of the coal. It is also important to state and federal regulatory agencies that try not to grant permits for sites where long-term water treatment is considered likely.

However, there is a high degree of uncertainty associated with predictive analysis. This is due to the difficulty in obtaining samples that are representative of highly variable strata. A USBM study (Erickson and Hedin, 1988) indicated that when one subtracted the easy-to-predict sites, the remaining sites could have been predicted as well by speculation as by overburden analysis.

Pennsylvania has reacted by becoming more conservative in the permits it issues. It is not clear that other states have yet changed their procedures. However, the Office of Surface Mining, Reclamation and Enforcement wants to see a risk-based prediction classification. Presumably, a site with a high risk of acid generation is denied a permit and a site with a moderate risk of acid generation receives a permit only if it undertakes special mining or reclamation procedures that will lower that risk. An interagency group, the Eastern Mine Drainage Federal Consortium, has begun to address the issue of how best to assess such risks and how to quantify the potential benefits of alternative beneficial technologies.

Technologies that will have to be evaluated include:

- Selective handling, to either place potentially acidic overburden under water to isolate the pyrite from oxygen, or "high and dry" and possibly capped, to minimize its contact with water.
- Alkaline addition, such as limestone, baghouse lime, alkaline combustion wastes, etc.
- Bactericides.
- Hydrologic engineering of the site to minimize acid generation and maximize alkalinity.

At sites where acid mine drainage must be treated, the principal environmental issue is how to comply with effluent limits as inexpensively as possible. Cost comparisons of alternative conventional neutralization reagents have been published (Skousen et al., 1990), although site-specific conditions always have to be considered.

Generally, at sites with flows of more than 6 L/sec (100 gpm), lime treatment tends to be cheapest. At sites with 6 L/sec (100 gpm) or less, iron concentrations and transportation costs determine the best alternative. Treatment costs can often be reduced (by as much as 30%) by using an in-line aeration and neutralization system rather than a conventional mechanical aerator and concrete basin (Ackman and Kleinmann, 1991).

Active sites with small flows of contaminated water have also found passive treatment to be cost-effective. Properly designed systems have paid for the cost of their construction in less than a year by decreasing chemical treatment costs. However, passive treatment systems are low-maintenance, not no-maintenance systems.

Subsidence, water supply

Water quality. USBM has conducted several studies examining the effect of high-extraction mining techniques on ground water chemistry (Walker, 1988; Matetic et al., 1991; Matetic and Trevits, 1992). The studies indicated that:



Acid mine drainage remains a persistent environmental problem in coal regions.

- Wells located directly above mining activity experienced slight increases in iron and manganese and small decreases in acidity, alkalinity, sodium, total dissolved solids and hardness.
- Wells that were located above gate roads or setup rooms of longwall panels experience slight increases in turbidity and suspended solids and small decreases in total iron.

Wellhead protection. Amendments to the Safe Drinking Water Act require state and local governments to establish protection areas around public water wells. Researchers are developing cost-effective methods for delineating wellhead protection areas in mining regions. By using these methods, public water supplies will be protected from the effects of mining without being overprotected, unduly limiting the extent of mining and other land uses.

Room-and-pillar mining was evaluated at Stoystown, PA, where the Upper Kittanning coal seam is being mined outside of a 550-m (1800-ft) radial protection zone established around the municipal wells. Two of the three Stoystown municipal wells obtain their water from fractured bedrock aquifers lying above the coal seam. The third well obtains a large percentage of its water from the Lower Worthington sandstone, which lies 23 m (75 ft) below the coal seam at the municipal well location.

The hydrologic impact of secondary vs. primary room-and-pillar coal mining on the capture zone for the Stoystown municipal wells was simulated using Mineflow, USBM's hydrologic model. Model simulations indicated that the mine workings have a measurable impact on the upper bedrock aquifer only in areas overlying abandoned, secondary-mined sections, particularly in sections located below stream valleys.



Researchers perform drawdown and recovery pumping tests on an observation well in Green County, PA.

Sections of the mine where primary mining was conducted have little impact on the simulated upper bedrock aquifer. This is because water entering these sections is mostly obtained from aquifers lying below the coal seam. Only a small section of the simulated well capture zone lies outside the protection zone. A mine capture zone of about 1.6 km (1 mile) long and 0.6 km (0.4 miles) wide has developed above the abandoned, secondary mine workings beneath stream valleys. These abandoned sections of the mine are more than 1 km (0.6 mile) away from the two municipal wells and have little hydrologic impact on the municipal water supply.

Residential well remediation. An important issue facing landowners, regulators and coal operators in the Appalachian coal basin is the potential for water level and yield decreases to occur in domestic wells following longwall undermining. Hydrologic-subsidence research studies have been conducted in Pennsylvania, Maryland, Ohio and West Virginia (Matetic and Trevits, 1990; Matetic et al., 1991; Trevits and Matetic, 1991; Matetic and Trevits, 1992; Matetic et al., 1995). The studies indicated that:

- Significant short-term ground water fluctuations occur when the monitoring well is undermined. Recovery begins when the longwall face is about 40% of the total overburden thickness past the well location.
- Ground water recovery occurs before the subsidence process is complete.
- The onset of ground water change coincides with the dynamic development of the tension mechanism of

the subsidence process and discontinues before or at the point of maximum tension of the subsidence process.

- Increases in hydraulic conductivity are observed at well locations directly above mining activity.

Leavitt and Gibbens (1992) demonstrated that domestic well response was strongly correlated with topographic setting. Because less stress relief fractur-

ing and smaller recharge areas exist for wells in hilltops vs. valleys, wells located on hilltops are more susceptible to water level declines and yield loss after mining. Of the 35 hilltop wells in Leavitt's and Gibbens' survey, 80% were affected and 70% had to be replaced. The high cost and effort required to locate and drill replacement wells on hilltops often make remediating the original well a more attractive option.

USBM conducted borehole tests on two hilltop wells in Greene County, PA, that had experienced substantial declines in water level without recovering within a year following longwall undermining. Results from these tests indicated that the reduced water levels and yields following longwall mining were a result of increased water outflow through fractures in the lower portions of the wells. When water outflow increased following mining, the wells were reduced to conduits for water flow as opposed to mechanisms for storing and retrieving water.

Both wells were successfully remediated by creating bentonite-sand seals in the lower portions of the wells, separating the bottom vertical fractures from the upper portion of the wells. After the seals were in place, the water level increased 4.8 and 8.5 m (16 and 28 ft) in the two wells. In one of the remediated wells, the well yield increased from 2.6 L/min (0.7 gpm) without the seal to 10.9 L/min (2.9 gpm) with the seal in place. Both of these wells are being used for residential purposes. The successful sealing of outflow fractures in wells demonstrates that low-cost techniques, such as backfilling lower portions of impacted wells, can lessen or eliminate the enhanced leaky cistern

effect that can occur in undermined, hilltop wells.

Surface water. Surface streams that overlie underground mines can also be adversely affected by fractures that intersect the streambed. Water loss can be partial or total. The effect is damaging to the stream and the underground mine. The fractures are usually not visible due to sediment. But they can be identified using electromagnetic terrain conductivity.

As an alternative to surface drainage rechanneling or liners, damaged streams can be repaired by shallow injections of grout into the streambed fracture zones. The grout fills the fractures and perches the stream. At the two sites where the USBM technique was tested, flow recovered 95% to 100% (Ackman et al., 1989).

Structural issues

SMCRA established the responsibility of coal mine operators for subsidence prevention, control and reclamation. In addition, mine applicants in the Appalachian coal region are required to predict the extent of surface subsidence and the degree of structural damage.

Structures is a broad classification. It includes residential dwellings, commercial and noncommercial buildings, and infrastructure systems, such as roads, powerlines and pipelines.

Residential dwellings are most commonly affected by subsidence. For instance, 34 subsidence insurance claims were processed by Pennsylvania from 1987 to 1990 (Allwes and Mangelsdorf, 1995). The cost to repair the residential structures as a result of damage and/or tilt exceeded \$1.4 million. It was estimated that the cost to repair or replace the foundations represented 70% to 85% of the total repair cost of residential structures.

Researchers are developing design recommendations and technology to minimize subsidence damage to existing and new residential structures. Field and laboratory studies have been conducted to measure the response of various structures to mine subsidence and to assess foundation designs and subsidence upgrade designs (Walker and LaScola, 1989; Allwes and Mangelsdorf, 1995).

Laboratory research demonstrated the feasibility and positive benefits of posttensioning masonry foundation walls. The combined use of vertical and horizontal steel tendons increased the

load-carrying capacity and bending strength of masonry walls. Limits of strength and deformation for masonry foundations for various modes of deformation were also established. These data may be used as design criteria and for assessing structural damage to masonry residential structures.

Coal combustion issues

Coal preparation plants, coal thermal dryers and coal customers are affected by the Clean Air Act, the Clean Water Act and the Resource Conservation and Recovery Act (RCRA). Particularly significant is Title IV of the Clean Air Act, Acid Deposition Control. Under this title, utilities are required to reduce SO_2 and NO_x emissions. The SO_2 emission reduction is in two phases. For 1995, the emission rate is 2.5 lbs of SO_2 /million Btu. In 2000, the emission rate is 1.2 lbs of SO_2 /million Btu, with a ceiling of 8 Mt/a (8.9 million stpy). The SO_2 emission ceiling means future utility coal use growth must be offset by reductions at existing plants. The NO_x emission rate from wall- and tangentially fired boilers is limited to 0.5 and 0.45 lbs of NO_x /million Btu, respectively.

For nonattainment regions of the United States, Title I: Provisions for Attainment and Maintenance of National Air Quality Standards also have a significant impact. For example, the Northeast Ozone Transport Commission (consisting of the 11 northeastern states and the District of Columbia) has signed a memorandum of understanding that limits NO_x emission beyond the federal acid rain provisions. In 1999, emissions will be reduced by 55% from the 1990 emissions.

In 2003, the NO_x emissions will be reduced by 65% from the 1990 emissions. The emission reductions will be enforced from May 1 through Sept. 30 of each year. To comply with these regulations, utilities will either switch to natural gas or install additional technology beyond acid rain compliance requirements.

These regulations also affect the disposal of fly ash and bottom ash. The cost to dispose of these byproducts has increased because of ground water monitoring requirements and more stringent waste disposal area design requirements. Many states have made permitting a waste disposal area difficult. This is being done to force utilities to find byproduct uses for fly ash and bottom ash.

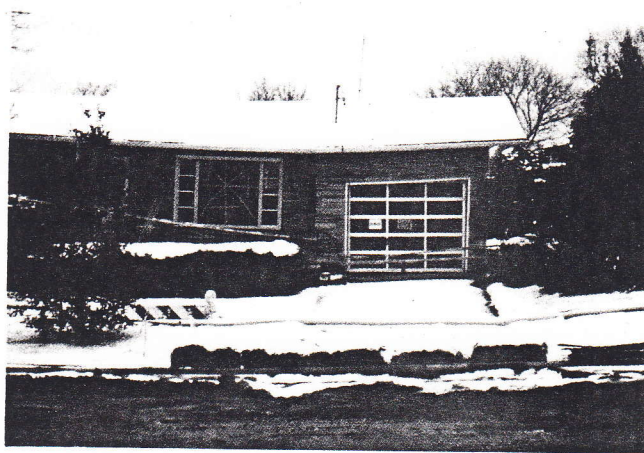
The benefits and potential problems associated with in-mine disposal of combustion wastes are being evaluated by USBM at abandoned mines and by the Department of Energy (through contracts with West Virginia University, University of Kentucky and Southern Illinois University) at active mining operations.

All of the end-user regulations increase the cost to burn coal. This increases the competition from natural gas and other nontraditional fuels.

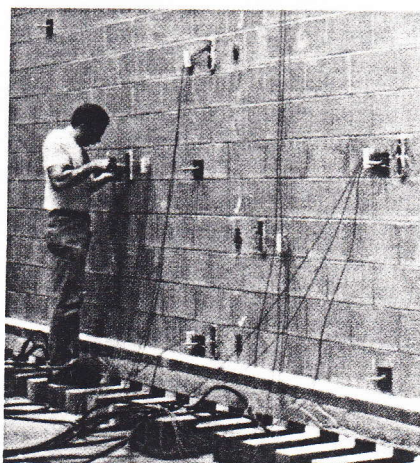
At the same time, the regulatory impact on the coal industry has increased production costs. These cost forces are counterproductive to the increased use of coal. ♦

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Residence damaged by mine subsidence.



Technician prepares testing instruments in a block wall that will be subjected to simulated subsidence.