Effects of Mine Drainage on Ground Water[a]

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Abstract

Coal mining in Appalachia has degraded both the surface and ground water. During mining, ground water is drained from the rocks and the pyrite associated with the coal beds is exposed to air. Oxidation of the pyrite produces high iron and sulfate concentration and a low pH in the water. Some of this polluted water flows directly into nearby streams and some moves into the ground-water system. When the latter occurs, the iron concentration can increase up to several hundred mg/l and the sulfates to over one thousand mg/l. Unfortunately, in most cases the cessation of mining does not stop the ground-water pollution, and it can take many decades before the ground water again becomes usable.

A detailed study of the effects of coal mining on ground water was conducted in the Toms Run drainage basin in northwestern Pennsylvania where coal mining and oil and gas well drilling have occurred for almost 100 years. The rocks of Mississippian and Pennsylvanian Age produce a multiaquifer system — three major aquifers separated by siltstone and shale beds (aquitardes). The oil and gas wells act as a conduit system permitting acid mine drainage to move downward from the strip mines to underlying aquifers. It then moves laterally down dip and discharges as springs. The acid mine drainage adversely affects the ground-water quality by increasing the iron and sulfate content of the water especially in the vicinity of the strip mines.

Introduction

The large deposits of coal in the eastern United States have been the foundation for the industrialization of the area. These coal deposits extend from northeastern Pennsylvania down to Alabama and as far west as the Great Plain. The deposits were originally developed by deep mining but since the end of World War II have been developed primarily by strip mining.

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One of the major problems in the mining of coal is the occurrence and handling of water. Wherever possible, the deep mines were developed so that this water would drain out of the mine by gravity. After mines were abandoned, the drainage of water continued.

The character of the drainage from coal mines varies from area to area and from coal seam to coal seam (Table 1). It is commonly high in iron and sulfates, low in pH, and high in acidity. When this drainage flows into a stream, it can pollute the stream by destroying aquatic life and making the water unusable for municipal and industrial water supply. Water pollution control programs have been concerned primarily with protecting and cleaning up surface waters polluted by coal mine drainage. A recent study in the Toms Run area indicates that the drainage from the coal mines is affecting not only the surface water, but in many areas also the ground water.

TABLE 1. CHARACTER OF DRAINAGE FROM COAL MINES

pH	2.3	→	7.3
Acidity	0	→	8,000 mg/l
Iron (Fe)	10	→	2,000 mg/l
Sulfate (SO_4)	20	→	3,000 mg/l

Formation of Acid Mine Drainage

Associated with the coal beds is the iron sulfide mineral pyrite, commonly also called fool's gold. This mineral usually occurs in high concentrations in the upper foot to 18 inches of the coal seam and in the overlying black shales. In a few instances it may also occur in sandstones above the coal seam. Because pyrite produces a high sulfur content in the coal, it is commonly left behind in the coal mine or in the refuse banks around the coal mine. This material is the source of the acid, iron and sulfate in mine drainage (Figure 1). Before the mining of coal, the rocks above the coal seam are usually completely saturated with ground water. As the mining progresses, the overlying rocks are fractured and the ground water drains through the rocks (Figure 2). When the pyrite is exposed to air, it begins to oxidize.

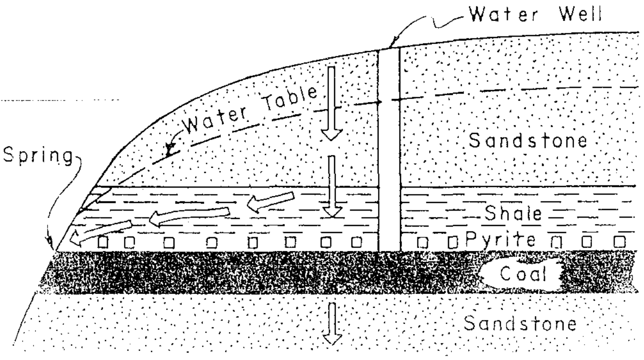


Fig. 1. Effects of coal mining on ground water – before mining.

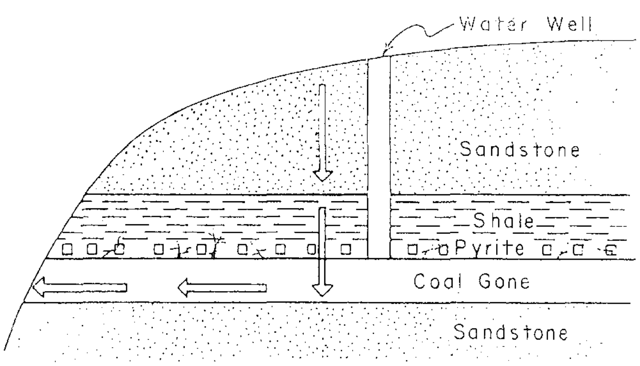


Fig. 2. Effects of coal mining on ground water – after mining.

In many cases when mines are first developed, drainage from the mine is slightly alkaline with low iron and sulfate concentrations. As the mining progresses, the pyrite is exposed to air, oxidizes, the oxidized material dissolves, and the drainage from the mine becomes acid. When moisture is present, the oxidation of the mineral pyrite is expressed in the following simplified formula:

$$FeS_2 + H_2O + O_2 \rightarrow Fe(OH)_3 + H_2SO_4$$

(Pyrite)(Water)(Oxygen)(Iron Hydroxide)(Sulfuric Acid)

Water flowing over the rocks picks up these salts and carries them out of the mine in the form of acid mine drainage.

In the western parts of Pennsylvania and parts (West Virginia, Ohio, and westward, coal beds ar associated with limestone beds. When the mine drainage flows through these rocks, it is neutralize through reaction with the limestones. The drainag that would occur from a mine under these condition could have a pH up to 7, but would be high in iron an sulfate. Although these conditions do not produce high acidity in the water, they do increase the mine alization of the water.

Pollutional Problems from Coal Mining

Acid mine drainage causes pollution by increas ing the total mineralization of the water which de creases its ability to support aquatic life or to b used for industrial or public water supplies. Pennsy vania now has over 2,300 miles of streams that ai adversely affected by coal mine drainage – which i the result of its topography, the widespread develo ment of coal mining, mining practices, and its hydr geologic conditions. These streams are normally aci Many have a pH less than 4.0. In some of thes streams, the iron concentration is greater than sever hundred milligrams per liter, and the sulfates a greater than 1,000 milligrams per liter.

As a result of amendments to the Pennsylvani Clean Streams Law in 1965, Sanitary Water Boa Regulations now require that a discharge from a active coal mine contain no more than 7 milligrams pe liter of iron, have a pH between 6 and 9, and have r acidity. Unfortunately, the vast majority of Pennsy vania's mine drainage comes from abandoned co mines. The cessation of coal mining does not neces sarily stop the pollution of the surface water or th ground water. It will take decades before most (these waters again become usable. Programs to aba this form of pollution in the surface waters of Penn sylvania are estimated to cost over one billion do lars.

Coal mining's immediate effect on ground water i generally the lowering of the local ground-water tab (Figure 2). In many cases where underlain by the co measures, ground water occurs under perched cond tions. Mining of the coal will fracture the overlyin rocks and allow drainage of the perched ground wate All water wells that have been developed in thi perched ground water will immediately go dry and, i many cases, will not return even after the coal minin has ceased.

In some cases, when the coal is mined, the unde lying or associated ground water is not drained fro the rocks. The acid mine drainage formed in the co mine will then flow into the associated ground wat through joints, fractures, or open wells. It will ir crease the mineralization of the ground water, rais the iron and sulfate concentration and lower the pH Special care must be taken by all well drillers i areas that are underlain by coal seams to make su that the well is cased and grouted through the co measures, so that it does not serve as a conduit for the downward migration of waters from the coal mines. When oil and gas wells or water wells are abandoned in areas underlain by coal seams, they should be completely grouted and records kept as to their location. The past abandonment of open wells now allows the migration of acid mine drainage downward from one aquifer to another, increasing the probability of ground-water pollution.

Toms Run Study

There has been much speculation in the past concerning the effect of coal mining on ground water. An intensive local study was conducted in the Toms Run area of Pennsylvania to determine how coal mining has effected the local ground water and its possible connection with surface-water quality.

The Toms Run Basin is located in the northeast portion of Clarion County, Pennsylvania, approximately 63 miles southeast of Erie and 95 miles northwest of Pittsburgh (Figure 3). This basin contains one of the few remaining stands of virgin white pine and has been developed as a State park. Water pollution from springs, flowing wells, and coal mine drainage is inhibiting full use of the park.

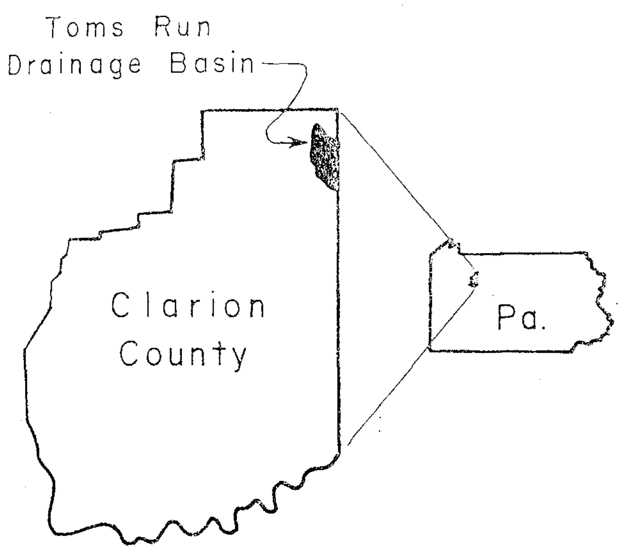


Fig. 3. Location of Toms Run Basin.

The area has been mined for coal and drilled for gas and oil for almost 100 years. Gas and oil wells have been drilled throughout the entire basin. Coal mining is limited to two areas in the basin; near the headwaters of Toms Run, and along the southwestern boundary of Toms Run (Figure 4).

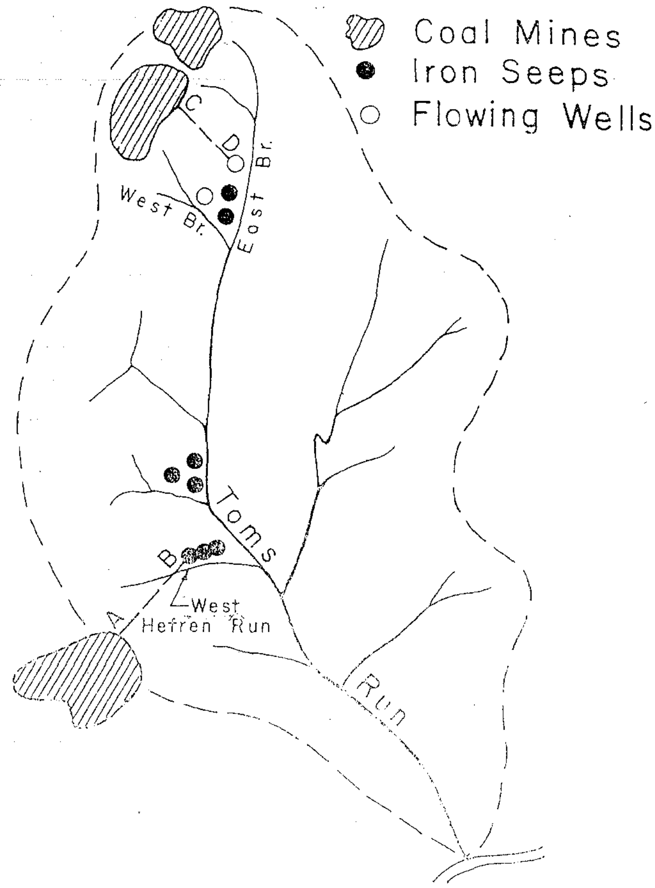
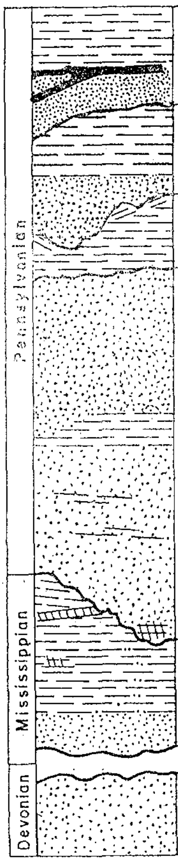


Fig. 4. Map of Toms Run Basin.

There are numerous secondary iron deposits within the drainage basin. All the deposits are in the west half of the basin (Figure 4). Along the East and West Branches of Toms Run there are iron deposits at two flowing abandoned oil and gas wells. Along West Hefren Run is the largest secondary iron deposit around a large flowing spring. All other deposits are associated with small discharges or seeps. All these discharges are rich in iron, sulfate, and acid and were originally attributed to deep flows from abandoned oil and gas wells.

Geology

Rocks of Devonian, Mississippian, and Pennsylvanian-age underlie the Toms Run area (Figure 5). Oil and gas wells have been drilled to the Bradford Sands (Devonian) at a depth of 2,300 feet. The rocks of Mississippian and Pennsylvanian age form a multi-aquifer system—three major aquifers separated by siltstone and shale beds. The Mississippian Burgoon sandstone is the lowermost aquifer in the Toms Run area. It grades up to a shale at the top. The Pennsylvanian-aged rocks are the Connoquenessing, Mercer, Homewood, and Clarion Formations. The Connoquenessing Formation has two sandstone units that act as aquifers, separated by a shale unit that acts as an aquitarde. The upper unit is one of the two major aquifers for private water supply in the area. The Mercer Formation is mainly shale with local coal stringers and acts as an aquitarde. The Homewood Formation has permeable sandstones at the base with shales and siltstones at the top. This sandstone is the other major source for private water supply in the area. The Clarion Formation contains the only mineable coal in the basin. This coal is underlain by tight sandstone and overlain by shale coal. This unit acts as an aquitarde.



	Formation	Thickness	GEOLOGIC UNITS	HYDROLOGIC UNIT
Pennsylvanian	Clarion Fm.	90–95'	Shale And Sandstone With The Clarion Coals	Basically An Aquitarde
Pennsylvanian	Homewood Fm.	30–50'	Siltstones And Shales At Top Permeable Channel Sandstone At Base	Major Aquifer
Pennsylvanian	Mercer Fm.	30–400'	Clayey Sandstone Grading Upward To A Shale	Aquitarde
Pennsylvanian	Connoquenessing Formation	190–280'	Thick Permeable Sandstone	Major Aquifer
			Shale Sequence	Aquitarde
			Thick Permeable Sandstone	Aquifer
Mississippian	Burgoon Sandstone	100–150'	Shale Grading Down To Permeable Sand	Aquifer
		←1840'→		
Devonian	Bradford Sands	10–70'	Oil And Gas Sands	Contains Brines

Fig. 5. Geologic section and hydrologic units.

The rocks in the Toms Run drainage basin are folded into a very shallow downwarp or syncline (Figure 6). The strike of the axis of the syncline is North 55 degrees East. Most of the rocks in the basin dip to the south and southeast. Although the coal beds along the southwestern edge are mostly outside the Toms Run drainage basin, they are within the structural basin and strike toward West Hefren Run.

Ground-Water Quality

The ground-water quality in the Toms Run Basin is the key to understanding the ground-water flow system and the sources of pollution (Table 2).

The ground-water quality in the Burgoon Sandstone and in the Lower Sandstone unit of the Connoquenessing Formation are the same. The water in these aquifers has a pH from 5.2 to 6.8 and is low in iron and chlorides.

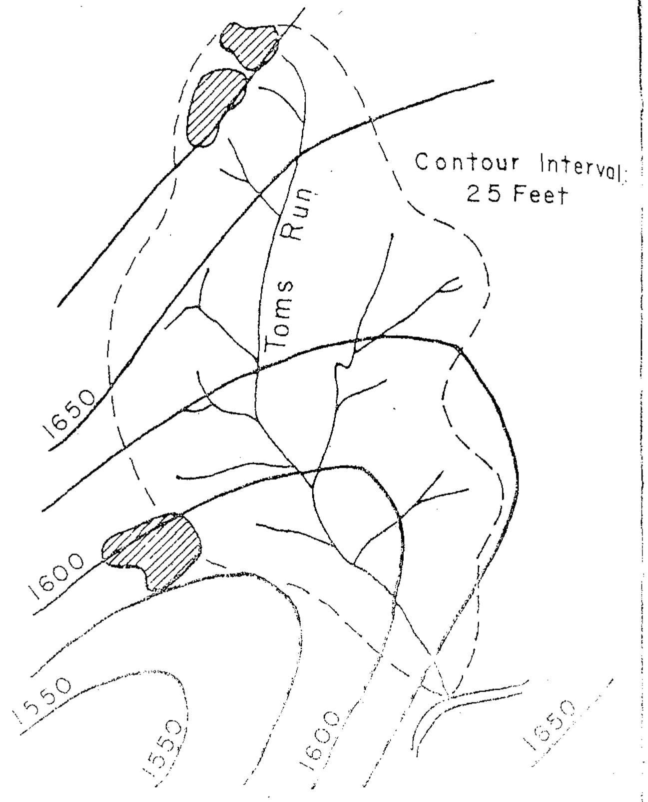


Fig. 6. Structure contours on top of Clarion coal.

In areas not affected by coal mining ground water in the Upper Sandstone unit of the Connoquenessing Formation has a pH from 6.3 to 6.8, low sulfates (3 to 16 mg/l), chloride (1 to 7 mg/l), and relatively low total iron (4 to 14 mg/l). Areas affected by coal mining have water with a low pH (2.9 to 5.4), low chlorides (1 to 7 mg/l), high sulfates (30 to 620), and total iron (25 to 160).

The ground water in the Homewood Formation in areas not affected by coal mining has a pH from 6.5 to 6.7, low sulfates (10 to 15 mg/l), chloride (0 to 2 mg/l), and relatively low total iron (10 to 15 mg/l). In areas affected by coal mining the water has a lower pH (3.0 to 5.5), higher sulfates (39 to 80 mg/l), total iron (20 to 70 mg/l), and low chlorides (0 to 2 mg/l).

Mine drainage from the coal mines has a very low pH (2.6 to 3.3) and low chlorides (0 to 2 mg/l), and very high sulfate (2,450 to 4,400 mg/l) and total iron (200 to 500 mg/l). Obviously, in the area of the coal mines, the ground water has been degraded by drainage from the coal mines.

Discharges from the abandoned oil and gas wells, the main sources of pollution, were thought to be brines from the deep oil and gas horizons. Water from these wells (in the area of the secondary iron deposits) has a pH from 2.9 to 6.3, high sulfates (24 to 678 mg/l), total iron (10 to 140 mg/l), and low chlorides (5 to 8 mg/l).

In contrast, brine from active gas and oil wells in the Toms Run area has a pH from 5.3 to 6.0, total

TABLE 2. GROUND-WATER QUALITY IN THE TOMS RUN DRAINAGE BASIN

AQUIFERS	*pH*	*Sulfate* (SO_4)	*Iron* (Fe)	*Chloride* (Cl)
Burgoon Sandstone and Lower Sandstone Unit of the Connoquenessing Formation	5.2 to 6.8	1 to 10	0.0 to 16.0	4 to 10.0
Upper Sandstone Unit of the Connoquenessing				
Nonmining areas	6.3 to 6.8	4 to 13	3 to 16	1 to 7
Areas near mining	2.9 to 5.4	30 to 620	25 to 160	1 to 7
Homewood Formation				
Nonmining areas	6.5 to 6.7	10 to 15	10 to 15	0 to 2
Areas near mining	3.0 to 5.5	39 to 80	20 to 70	0 to 2
Discharges from Coal Mines	2.6 to 3.3	2450 to 4400	200 to 500	0 to 2
Discharges from Abandoned Oil and Gas Wells	2.9 to 6.3	21 to 678	10 to 140	5 to 8
Brines from Active Gas and Oil Wells	5.3 to 6.1	67 to 253	67 to 253	42,000 to 200,000

iron from 100.0 to 1000.0 mg/l, sulfates from 67 to 253 mg/l, and very high chlorides from 42,000 to 200,000 mg/l. Thus, the water from the abandoned oil and gas wells is not coming from the deep brines, but rather from shallow coal mine drainage.

Interpretation

Drainage from coal mines has affected the water quality of various aquifers in the area. Where affected, the iron and sulfate concentrations are too high for drinking water and require extensive filtration, softening, and settling before use.

The drainage in the vicinity of the strip mines moves down to the lower aquifers along joints, fractures, and especially old abandoned gas and oil wells. This can be seen on two cross sections in the basin (Figure 4): cross section C-D in the headwaters and cross section A-B along the west side. Drainage from coal mines at the headwater of Toms Run moves down through wells to the lower units, laterally within the aquifers, then upwards to land surface and discharges from the flowing oil and gas wells (Figure 7b). Along the southwestern boundary of the drainage basin (Figure 7a) the mine drainage moves down to the Upper Sandstone of the Connoquenessing Formation and along the strike of the formation until it discharges as a contact spring along West Hefren Run.

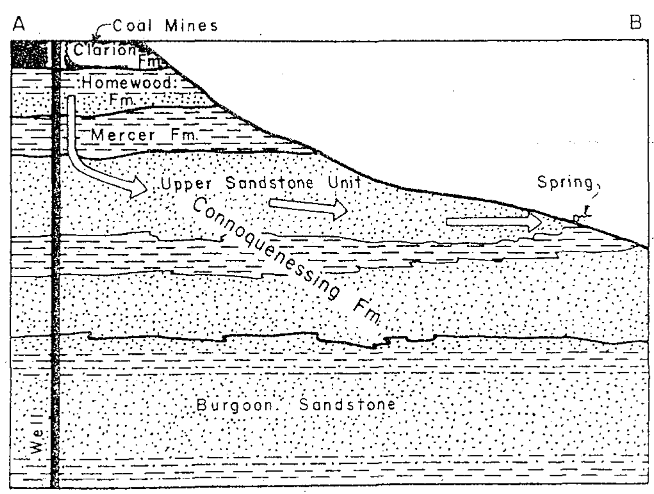


Fig. 7a. Cross section A-B – natural seepage.

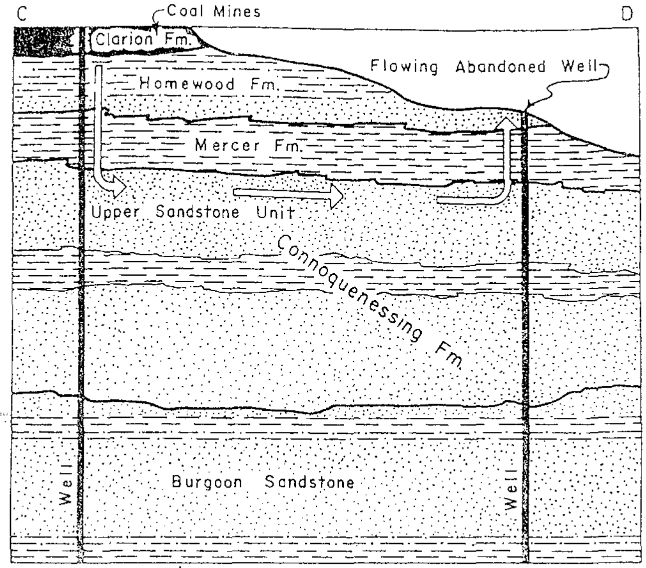


Fig. 7b. Cross section C-D – flow from an abandoned well.

Conclusions

The mining of coal in many cases produces an acid drainage with a high concentration of iron and sulfate. This drainage may discharge directly to surface water or move into the ground water and pollute it. In a study of the Toms Run area, Pennsylvania, it was found that the coal mine drainage moved down to underlying aquifers through joints, fractures and abandoned oil and gas wells and polluted the ground water. It moves down the hydraulic gradient of the aquifer and discharges as iron-rich springs or flowing wells.