Progress of environmental studies in coal mining areas of western Pennsylvania and central West Virginia

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Abstract

Two studies related to the regional environmental effects of coal mining in the Appalachian Plateau were conducted in 1998 as part of the National Water-Quality Assessment program of the U.S. Geological Survey. The study area of about 20,000 square miles included parts of the Allegheny and Monongahela River basins in the north and the Kanawha River basin in the south. Water in domestic wells downgradient from fully reclaimed surface coal mines was compared to water in similar wells at unmined sites. As expected, pH was lower and the concentration of sulfate was greater at mined sites in both areas, although the pH difference was greater in the southern area. Median concentrations of iron and manganese exceeded federal drinking-water standards at mined sites in both areas and at unmined sites in the southern area. Median concentrations of radon near reclaimed mines were about half those at unmined sites.

Surface water was sampled during summer base flow at about 180 sites that drain between 5 and 80 square miles; the sites also were sampled during 1979-81. Median pH in 1998 was 7.9 in the north and 7.4 in the south, about 0.5 unit higher than in 1980 in both areas. Median concentrations of sulfate increased from 38 mg/L to 56 mg/L in the north and from 46 mg/L to 77 mg/L in the south, in apparent contradiction to the generally lower sulfur content of geologic units in the southern area. Among 52 basins where mining occurred both before and after 1980, the sulfate concentration more than doubled in 13 (25 percent), including greater than five-fold increases in 5 (10 percent). For 16 mined basins where no mining has occurred since 1980, the median decrease in sulfate concentration was 18 percent, from which the half-time for oxidation of mining-related pyrite is estimated to be about 65 years.

Introduction

During 1998, the U.S. Geological Survey (USGS) conducted two studies related to the regional environmental effects of coal mining in a 20,000-square-mile area of the Appalachian Plateau. One study addressed ground-water quality downgradient from surface coal mines that have been fully reclaimed. The second study examined changes in water quality in streams during the past 20 years. Both studies were within the surface drainage basins of the Allegheny, Monongahela, and Kanawha Rivers in Pennsylvania and West Virginia.

This paper presents preliminary results of these studies. Many individuals in several USGS offices participated in the design and execution of these studies, and several reports are scheduled for completion during 1999 to address the results in greater detail. Both studies were carried out as part of the USGS National Water-Quality Assessment (NAWQA) program, the goals of which are to describe current water-quality conditions, identify water-quality trends, and develop an understanding of the natural and human factors that produce them. NAWQA works at a regional scale, typically in basins from 10 to 10,000 mi^2, to examine fresh, flowing water that might be used by people. The NAWQA design emphasizes integration of information about surface- and ground-water systems using a nationally consistent approach to sampling, processing, and analyzing water, bed sediment, aquatic biota, and habitat (Gilliom and others, 1995). Chemical analyses address a wide range of constituents that include both regulated contaminants and natural or unregulated constituents. Analytical detection levels for many constituents are lower than those in most regulatory programs. All sampling follows published protocols and includes careful quality-assurance measures.

NAWQA assessments begin by identifying the natural and human-related features of the land and hydrologic systems that provide a unifying framework for understanding the factors that govern water-quality conditions. A study area typically is subdivided first by physiographic province, second by bedrock geology, and finally by major land use. Samples are then collected from representative sites within selected environmental settings, which are the land areas characterized by unique, homogeneous combinations of natural and human-related factors.

The environmental setting for the studies reported here is the layered sedimentary rocks of the northern Appalachian coal region, where coal has been mined for more than 100 years by an evolving suite of technologies (Messinger, 1997; Eychaner, 1998). Coal and associated rocks in the northern part of the study area generally contain more sulfur and are more likely to produce acid mine drainage than the geologic units in the southern part.

Ground water study

The objective of the ground-water study was to examine the environmental effects of surface mining and reclamation as practiced over the past 15 years. The targets for sampling were recently-constructed domestic wells in good physical condition or similarly constructed monitoring or public-supply wells that are immediately downgradient from surface coal mines where reclamation was completed between 2 and 12 years earlier. This roughly brackets the period when current reclamation practices have been in use and assumes enough time has elapsed for ground-water flow to stabilize. The practices of mountaintop removal and valley fill were not addressed because most mountaintop operations are outside the study area and few of these sites in the area have been fully reclaimed.

All wells were selected by a random process. At sites near reclaimed mines, 58 wells were sampled (table 1). At other sites within the same geographic area and geologic formations, but not close to mines or other probable sources of contamination, 25 wells were sampled to measure the unmined reference condition. Samples were analyzed for major ions, trace elements, nutrients, organic carbon, radon, and indicators of ground-water age.

Table 1. Median concentrations of selected constituents in ground water in

surface mining areas

Constituent and units of measurement	Allegheny and Monongahela River Basins		Kanawha River Basin	
	Unmined (15 wells)	Mined (30 wells)	Unmined (10 wells)	Mined (28 wells)
pH, standard units	7.0	6.9	6.8	6.2
Iron, mmg/L	27	840	585	955
Manganese, mmg/L	49	214	146	247
Sulfate, mg/L	18	72	6	20
Radon, pCi/L	530	236	280	115

The quality of ground water in wells in the coal mining areas sampled for this study is generally suitable for most domestic purposes. Most constituents were present at concentrations far lower than federal drinking water standards. As expected, pH was lower and sulfate was greater at mined sites in both areas. Although sulfate concentrations were generally higher in the northern area, the pH difference between mined and unmined sites was greater in the southern area.

Median concentrations of iron and manganese exceeded the federal drinking-water standards of 300 and 50 mmg/L, respectively, at mined sites in both areas and at unmined sites in the southern area. For the southern area, the high iron and manganese concentrations at unmined sites and the lower pH overall were both unexpected, because the geologic units there generally contain less sulfur than those in the northern area and thus have a lower potential to produce acid mine drainage.

In both areas, median concentrations of radon near reclaimed mines were about half those at unmined sites. Increased permeability of rock material in surface-mined areas could allow this natural radioactive gas to escape more easily into the atmosphere. The formerly proposed federal drinking-water standard for radon was 300 pCi/L.

Surface-water study

Stream water quality has improved in most of the Appalachian coal region as regulatory policy and mining practice have changed over the past 20 years. The objective of the surface-water study was to measure these changes in water quality and relate them to differences in geologic setting and mining practice. Baseline information is available from USGS studies during 1979-81 that assessed water quality in 12 study areas in the Appalachian coal region (Britton and others, 1989). Within the NAWQA study area, stream water samples were collected between 3 and 15 times at more than 400 sites.

The present study was limited by available resources to a single sample at each site, so the effort was targeted to summer low flow conditions, when mine drainage is a large fraction of total streamflow. Each sample collected during July-September 1998 was matched to the one previous sample (from 1979-81) that was most similar in discharge and season. About 180 sites were sampled to assess changes. At about 60 of the sites, more extensive data were collected, including ecological communities and sediment chemistry, to provide a more complete baseline for future assessments.

Sites were selected for sampling on the basis of a three-factor categorical design of geology, mining method, and mining date within the surface drainage basin above each site. Geology is represented here by the contrast between the Allegheny-Monongahela River and the Kanawha River drainage basins, which roughly correspond in West Virginia terminology to the northern and southern coal fields. Mining method was identified as underground, surface, or both, and mining date was identified as before the historical sample, after the historical sample, or both. Reference conditions in both study areas were identified as basins that had never been mined.

Sampling sites were selected on the basis of information in four geographic information system (GIS) databases, supplemented by field reconnaissance, existing topographic maps, and other information where available. The databases identified mine locations during 1890-1996, coal production during 1981-95, permits for mine discharges during 1990-96, and abandoned mine lands. Each database provided only point locations, many locations were imprecise or obviously wrong, and different databases provided inconsistent information. Chemical analyses of samples for some sites also were inconsistent with the categories identified using GIS.

Basins were identified as representing a single combination of mining method and date only if none of the data sources provided any contrary evidence. Particular effort was spent in identifying basins not affected by any mining. Most basins were classified as representing a mixture of methods and dates of mining. The present analysis ignored more precise divisions of the mining method and any measure of the extent of mining disturbance in a basin.

The actual practice of coal mining throughout this large area over two decades is much more complex than can be captured in this design. A more complex design, however, would require the collection of data from much smaller drainage areas for many different treatment and reference conditions. Such a design would demand resources far beyond those available to this study, yet would provide little information on cumulative or regional effects.

The study was planned to resample roughly equal numbers of basins in each category of the design, but that proved impossible (table 2). The long history of mining throughout the study area has left few basins in the target size range, between 5 and 80 mi^2, where mining was conducted by only one method and during one period, even for the simple categories used here. Most of the analytical possibilities of this study will depend on quantifying the degree to which each activity occurred in the sample basins.

Results given below are based on the 136 stream sites for which comparable data for both time periods had been assembled by the time of this writing. Some statistics could change when the full dataset becomes available.

Median pH of summer base flow in these streams has increased about 0.5 unit from 1980 to 1998 in both the northern and southern parts of the study area. During the 1998 sample period, median pH among all sample sites was 7.9 in the north and 7.4 in the south. Alkalinity of the streams also increased and was reflected in decreased concentrations of iron and manganese. These effects would be expected as active mines ensure that their discharges to streams comply with current permit limits and as efforts are made to control the worst cases of acid drainage from abandoned mines.

Table 2. Distribution of stream sampling sites by design category

Mining Method	Mining Date		
	Before 1980	After 1980	Both
Allegheny and Monongahela River Basins (127 sites)			
Underground	9	0	5
Surface	12	11	14
Both	11	5	27
Unmined	--	--	33
Kanawha River Basin (51 sites)			
Underground	6	0	3
Surface	2	1	2
Both	3	0	28
Unmined	--	--	6

Median concentrations of sulfate among all sites, however, increased from 38 mg/L to 56 mg/L in the north and from 46 mg/L to 77 mg/L in the south, reflecting continued mining activity, and in apparent contradiction to the generally lower sulfur content of geologic units in the southern area and the ground-water data described above. Sulfate is a good indicator of the total disturbance of a basin by mining, because most sulfate is produced by oxidation of pyrite minerals to acidic iron sulfate, and mining increases the amount of pyrite minerals that are available for oxidation. Among 52 basins where mining occurred both before and after 1980, for example, the sulfate concentration more than doubled in 13 (25 percent), including greater than five-fold increases in 5 (10 percent). In both northern and southern basins, sulfate concentrations of less than 20 mg/L were common in unmined basins.

Acid loads from the pyrite reaction are neutralized at regional scale by both alkaline minerals naturally present in mined areas and by engineered additions of alkalinity. Acid production will continue, however, in proportion to the amount of available pyrite, and after mining ends, acid production will gradually decrease as the available pyrite is consumed. Like many chemical reactions, the process can be expected to follow a negative exponential rate function. For 16 mined basins where both land use data and stream chemistry indicate that no mining has occurred since 1980, the median decrease in sulfate concentration was 18 percent; the concentration decreased by at least 50 percent in only two basins. The median half-time for mining-related pyrite oxidation in these basins, therefore, is estimated to be about 65 years. That means that about each 65 years, half of the remaining mining-related pyrite will have reacted as the basin gradually returns to a pre-mining rate of sulfate production. Individual basins, of course, can vary widely from this regional estimate.

Opportunities for further study

The absence of an adequate database that describes where, when, how, and how much the land has been disturbed by coal mining throughout the Appalachian coal region was a major impediment to the design and analysis of these studies, as it would be for any extensive study of the cumulative effects of coal mining at multiple scales. The West Virginia tax mapping project offers much of the needed information, but that project is not scheduled for completion for more than five years, and the availability and consistency of data for other states is unclear.

The understanding of ground-water flow in the fractured bedrock of the Appalachian Plateau is incomplete, although ground-water age-dating techniques applied during the past 3 years have contributed new insights and new questions. It is clear that most shallow wells in the area capture water moving along multiple flow paths with differing travel times. A clear understanding of flow processes in undisturbed rocks is a necessary foundation to understanding changes in the system that result from large-scale mining and reclamation.

Because chemical concentrations in streams vary with stream discharge, a more complete understanding of water-quality changes over the past 20 years would require additional samples collected under different flow conditions at the sites in the surface-water study. Alternatively, similar studies could be extended into other areas where baseline data exist and large mining operations continue, such as the Guyandotte and Big Sandy River basins.

References Cited

Britton, L.J., and others, eds., 1989, Summary of the U.S. Geological Survey and U.S. Bureau of Land Management national coal hydrology program, 1974-84: U.S. Geological Survey Professional Paper 1464, 183 p.

Eychaner, J.H., 1998, What's normal?—Constituent concentrations in West Virginia streamflow, ground water, streambed sediment, and fish tissue, *in* West Virginia Non-Point Source Conference, Charleston, 1998, Proceedings: West Virginia Division of Environmental Protection and West Virginia Soil Conservation Agency, p. 38-53.

Gilliom, R.J., Alley, W.M., and Gurtz, M.E., 1995, Design of the national water-quality assessment program—Occurrence and distribution of water-quality conditions: U.S. Geological Survey Circular 1112, 33 p.

Messinger, Terence, 1997, Water-quality assessment of the Kanawha-New River basin, West Virginia, Virginia, and North Carolina—Review of water-quality literature through 1996: U.S. Geological Survey Water-Resources Investigations Report 97-4075, 27 p.