HYDROLOGIC ASPECTS OF ACID MINE DRAINAGE CONTROL

By Kenneth J. Ladwig[1]

INTRODUCTION

Water is obviously a principal component of the acid mine drainage (AMD) problem, functioning as a reactant in pyrite oxidation, as a reaction medium, and as a transport medium for oxidation products. The role of water as a transport medium is the focus of one segment of the Bureau of Mines AMD program.

Describing the contaminant transport process serves two basic purposes. The first is to develop site-specific characterizations of the hydrology, including defining recharge areas and flow paths, estimating rates and volumes of mine water flow, delineating lateral variations in water quality, and determining contaminant loads at the discharge. The site-specific data are critical to the success of any abatement procedure, regardless of the technical approach chosen. Efficient and cost-effective abatement requires knowledge of sources of spoil water recharge, zones of acid production, and movement of water through the acid-pro-producing zones.

The second purpose is to examine in greater detail the interaction between acid production and hydrologic transport. While field studies are by nature site specific, data obtained from several mines will be used to develop a more generalized conceptual understanding of the transport process. The conceptual model will then serve as the basis for improved reclamation and abatement technology. Of central importance in this phase of the study are (1) the interaction of the mine water with the other components involved in acid generation and (2) the hydrochemical evolution of the mine water.

We investigated the transport process at both underground and surface coal mines, with most of the underground mine work being done in the northern anthracite field of eastern Pennsylvania. The purpose of this work is to describe the hydrogeochemical processes occurring in a flooded mine complex. The initial phase of this work was reported in RI 8837 (4).[2]

The surface mine work was done principally at reclaimed surface mines in Pennsylvania and West Virginia. Why reclaimed sites? The fact that many reclaimed mines in these States are still producing considerable volumes of AMD attests to the shortfalls of past and current reclamation practices. By monitoring these sites, we can examine what went wrong, determine what steps might be taken to deal with the current problem, and develop methods for avoiding similar problems in the future.

Described in the following sections are results of a case study conducted at a reclaimed surface mine in West Virginia and a summary of the underground mine study in eastern Pennsylvania. The emphasis is on developing a practical monitoring program and then intergrating the site hydrology with the AMD abatement plan. While it is unlikely that simple hydrologic modification alone will eliminate the problem, a thorough knowledge of site-specific hydrology is fundamental to the development and execution of a successful abatement plan.

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[2]Underlined numbers in parentheses refer to items in the list of references at the end of this report.

SURFACE MINE CASE STUDY

SITE DESCRIPTION

A small abandoned mine site in Upshur County, WV, was monitored to evaluate the use of bactericidal treatment to control AMD. The Lower Kittanning seam was mined from the U-shaped, 6-ha site in the late 1970's. Although the site was completely revegetated, including the highwall, the area was not regraded to approximate original contour. Average spoil thickness was about 7 m. Present topography consists of a 12-m slope at the highwall, a relatively flat bench over the mined area, and a 12-m outslope leading to a toe-of-spoil seep (fig. 1).

METHODS

The methods used are standard procedures for surface and ground water monitoring. Relative to perpetual water treatment and AMD abatement costs, the methods are not expensive, nor are they technically complex. As will be illustrated, monitoring can yield valuable information on acid production and movement at a surface mine site. Some type of spoil water monitoring is highly recommended prior to initiating abatement plans.

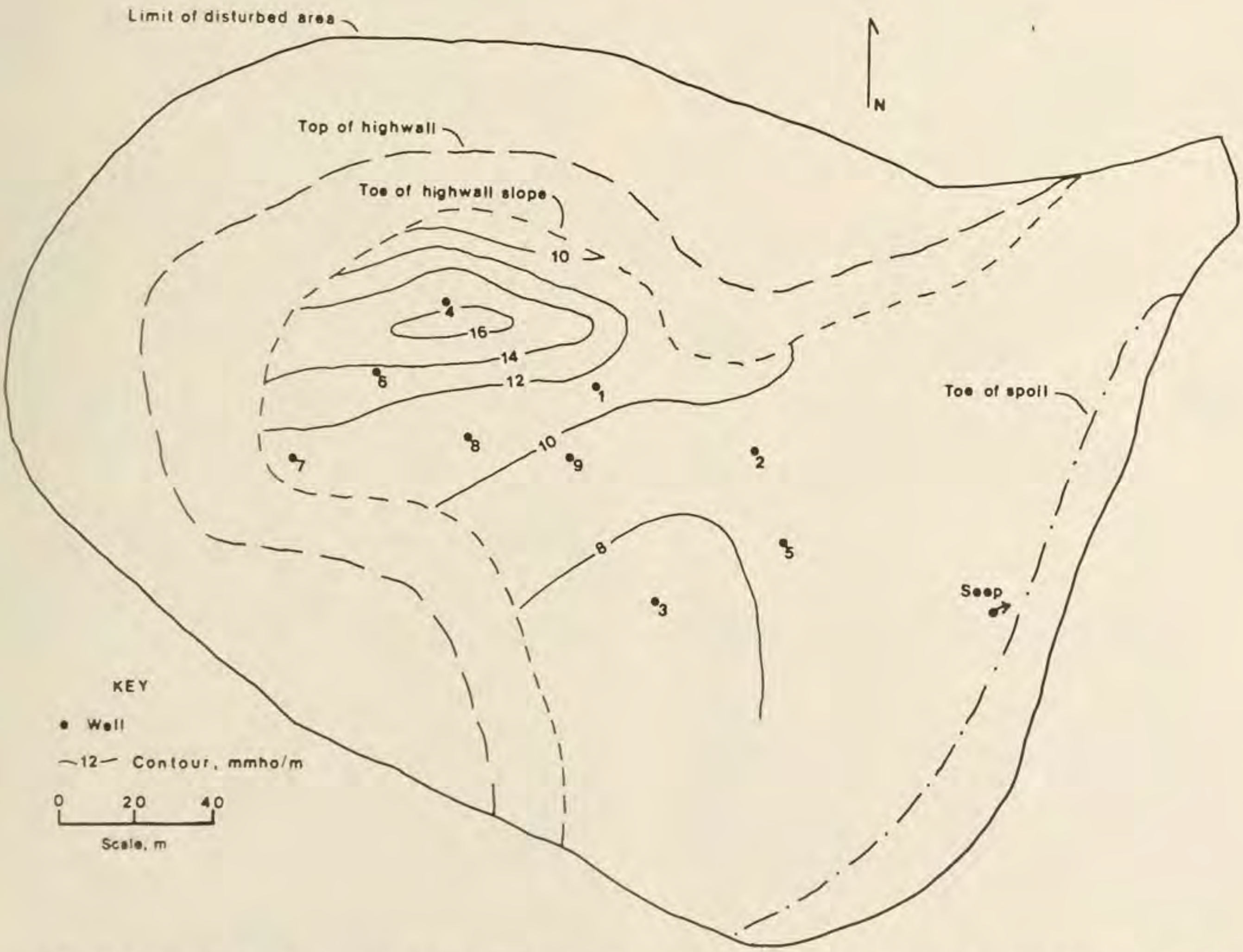

FIGURE 1. - Map of surface mine study site in Upshur County, WV, showing surface features, well locations, and results of an electromagnetic induction survey.

Following initial site reconnaissance to locate all seepage points and describe surface features, a series of electromagnetic induction (EM) surveys were used to describe subsurface features. EM can be used at surface mines to help determine spoil thickness and variations in thickness across a site, and to locate wet zones, mining relicts (highwalls, sidewalls, unmined blocks), mine floor structures, and zones of acid-producing material (3). While they do not eliminate the need for monitoring wells, EM surveys help identify potential trouble areas. Detailed surveying at the Upshur site took just under 2 days to complete.

Monitoring wells were installed to define spoil water flow conditions and spoil water quality. Spoil borings were drilled to the mine underclay, and wells were constructed from 2-in polyvinyl chloride pipe, slotted along the lower 10 ft. The borings were backfilled and the wells were sampled using standard procedures (5).

Spoil samples were collected from several depths during drilling of the monitoring wells. The samples were used to characterize the distribution of materials present on the site and to help reconstruct the backfilling sequence. All samples were visually classified in the field. Selected samples were subjected to laboratory tests, including leaching tests using the method described by Caruccio (2).

Seepage discharge was monitored for flow rate and water quality. Both sampling and flow monitoring were done as near to the point of seepage as possible to minimize mixing with surface runoff. As a compromise between cost, accuracy, and maintenance requirements, flow gaging was done with a simple V-notch weir constructed from plywood and stainless steel (1). The weir was inexpensive and reliable.

RESULTS

The EM surveys revealed an area of high apparent conductivity (greater than 14 mmho/m) on the northwestern part of the site (fig. 1). Progressively lower conductivities were observed in the direction of the seep. Although the cause of the high conductivity was not immediately known, the area enclosed by the 14-mmho/m contour on figure 1 was targeted as a possible trouble spot. A more detailed description of the geophysical survey is given elsewhere (3, site SM1).

Following the geophysical survey, a series of spoil borings were drilled. Spoil samples collected during drilling showed the material in the area of high conductivity (wells 4 and 6) contained significant proportions of a fine-grained, black material. In fact, the entire thickness of spoil at well site 4 was comprised of the black material. Holes drilled outside the high-conductivity zone (wells 1-3, 5, 7-9) contained predominantly weathered sandstone.

The Kittanning coals in the study area are "dirty" seams, and the black material found at well sites 4 and 6 was believed to be coal cleanings or shaly partings. Laboratory tests on the spoil material showed the mean sulfur content of the black material (1.24 pct) was considerably higher than that of the sandstone spoil (0.12 pct). Samples of the underclay were also analyzed and found to have a sulfur content similar to that of the shaly material (1.20 pct). Of 29 spoil samples analyzed, 6 had negative neutralization potential (4 samples from wells 4 and 6, and 2 outslope samples). These data again point to the area inside the 14-mmho/m contour in figure 1 as a primary trouble spot.

Final confirmation was provided by monitor well water samples. The poorest water quality on the site was found in well 4 (fig. 2). Mean sulfate and acidity concentrations at well 4 were about twice as high as the average concentrations for the spoil and seep. Mean iron concentrations at well 4 were more than twice the mean spoil concentration and more than six times the mean seep concentration.

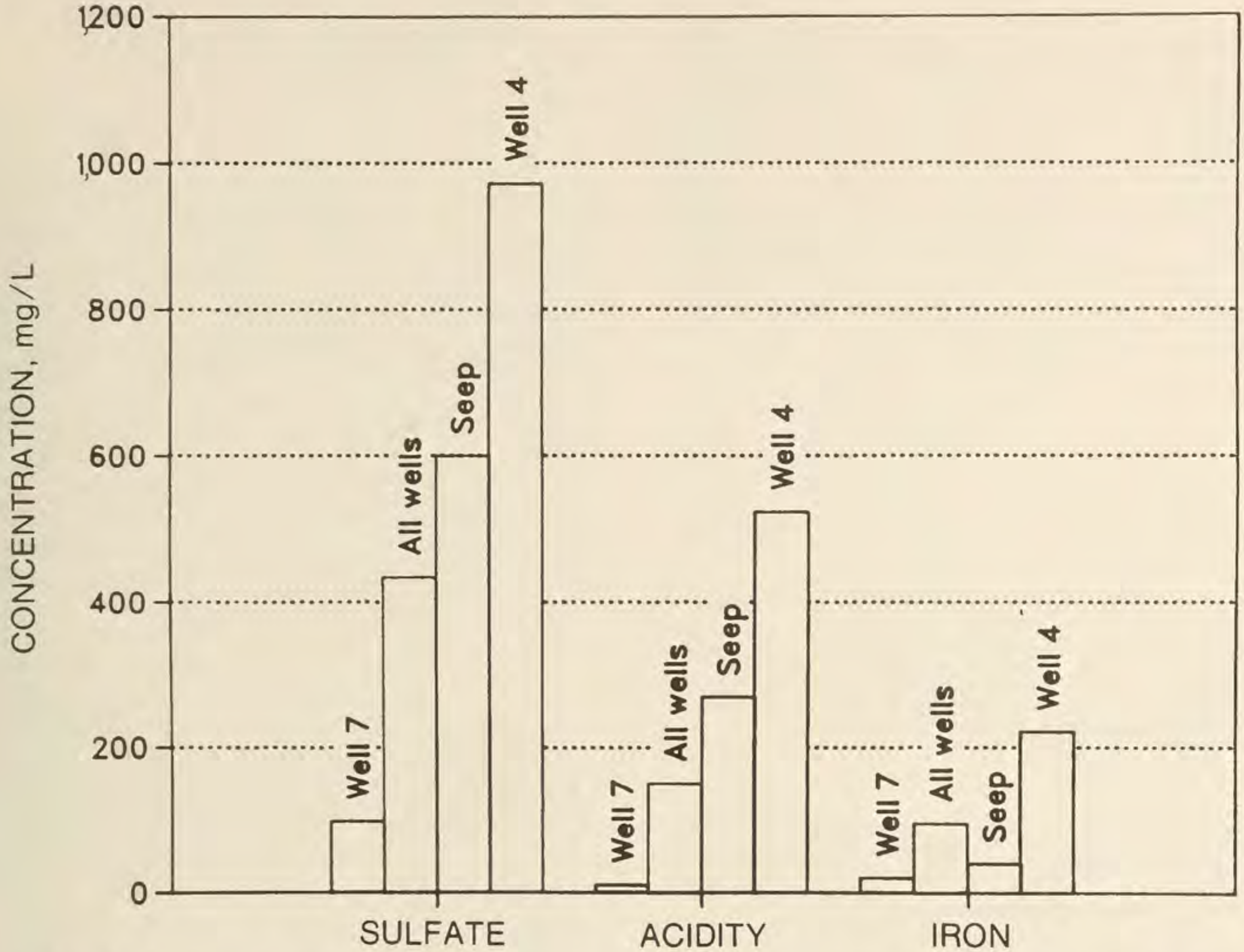

FIGURE 2. - Mean sulfate, acidity, and iron for well 7, well 4, the seep, and averaged for all of the wells drilled into spoil.

Conversely, good-quality water was found on the southern part of the site, particularly near well 7 (fig. 2). The well 7 area receives direct inflow of highwall seepage, as well as infiltration recharge through inert sand soil. As a result, there is much less contamination evident. As this recharge continues to migrate through the spoil, the water leaches some contaminants and mixes with water of poorer quality prior to discharge.

The water quality at the seep lies between that found in the well 4 area and the well 7 area (fig. 2). Flow at the seep is perennial and anomalouly high for such a small site. Total seepage discharge for the 1983 calendar year was 10 million gal, or about 50 pct of the total precipitation for the same period.

Principally two factors contribute to the high volume of discharge. One is the uncontrolled highwall seepage into the spoil on the southern part of the site. The water level in well 7 is the highest on the site at all times of the year, indicating this is a perennial source of recharge. The second factor is the absence of adequate surface water diversions on top of the highwall and on the mining bench. Surface water from a small recharge area above the site flows onto the highwall and down a channel on the highwall slope. Flows in the channel as high as 15 gal/min have been observed following a rainstorm. All of the channel flow infiltrates directly into the spoil before reaching the bottom of the slope. The mining bench itself is graded back toward the highwall, further stimulating ponding and infiltration at the base of the highwall slope.

DISCUSSION OF RESULTS

The hydrologic study at the Upshur site suggests at least two avenues for site improvement. The first is to attempt to abate acid production at the source. The primary source of acid production at the site appears to be relatively well defined. Abatement procedures targeted directly at the acid-producing area may be the most cost-effective means of obtaining a significant reduction in seep contamination.

Application of an organic compound is currently being tested at the site to inhibit AMD production. The bacteria-inhibiting compound, potassium benzoate, has been applied at the surface on the northeastern part of the site. (The use of organic compounds such as benzoate to inhibit bacterial catalysis is described elsewhere in these proceedings.) The effect of the application is being monitored in lysimeters and wells and at the seep.

The second approach is a simple reduction in recharge to the site. For example, subsurface drains to remove clean highwall seepage prior to flow through the spoil and minimal regarding to promote runoff rather than infiltration would greatly decrease the total volume of water discharged at the seep. Installation of these controls would reduce mean flow by an estimated 50 to 75 pct and very likely change the character of the seep from perennial to intermittent. Although contaminant concentrations at the seep might increase following flow reduction measures, we expect the reduced volume would more than offset the increased concentration, resulting in a net decrease in contaminant load.

The case study presented here illustrates the use of relatively inexpensive ground water monitoring for targeting AMD abatement measures. Data obtained from such studies are an integral part of the Bureau of Mines research on improving existing abatement technology. As an end product, this work, in conjunction with research on overburden analysis, pyrite reactivity, and spoil air, will be used to develop predictive methods to avoid the pitfalls associated with current mining and reclamation practice.

UNDERGROUND MINES

To study the AMD problem at underground mines, the Bureau initiated a field investigation of the mine water system in the Wyoming Basin of the Northern Antracite Field. The purpose of the study was to evaluate the effect of mine flooding on AMD formation. Specific project goals included identification of sites where pyrite oxidation may still be occurring and mapping patterns of contaminant flow.

Between 1980 and 1982, nine abandoned mine shafts were monitored for vertical variations in the chemical composition of the mine water system. Each shaft intersected several coal seams. Monitoring included the collection of shaft water samples, downhole Eh and pH measurement, fluid resistivity logging, spontaneous potential logging, and fluid temperature logging. In addition to the shaft logging, the four major outfalls in the Wyoming Basin were monitored on a weekly basis from October 1982 through September 1983. These data were compared with available historical data for the outfalls.

Water quality at the outfalls in the Wyoming Basin has exhibited marked improvement since inundation of the mine complex. For example, between 1968 and

1980 sulfate concentrations decreased by 49 pct at the Buttonwood Outfall (fig. 3). At all of the outfalls, pH has increased to near neutral and net acidity has decreased.

Weekly monitoring indicated water quality was similar at three of the four outfalls (Buttonwood, South Wilkes Barre, and Askam), despite large differences in respective recharge areas and predicted residence times (table 1). The similarity may reflect a long-term trend toward uniformity coupled with the general improvement in water quality. The Nanticoke Outfall, which exhibits sulfate concentrations 25 to 35 pct higher than the other three outfalls, discharges the "youngest," or most recently formed, mine pool. If a trend toward uniformity does exist, the Nanticoke Outfall water quality may be expected to improve more rapidly than water quality at the other outfalls.

TABLE 1. - Mean pH, sulfate, and flow for the four outfalls in the Wyoming Basin for the period October 1982 through September 1983

Outfall	pH	Sulfate, mg/L	Flow, gal/min
South Wilkes Barre	5.9	1,200	25,380
Buttonwood........	5.9	1,020	5,690
Askam.............	5.9	1,130	5,650
Nanticoke.........	6.0	1,640	2,900

No significant seasonal trends in contaminant levels were observed, despite order of magnitude variations in flow. The absence of seasonal trends again implies a uniform source. Thorough mixing of the surface water recharge with the bulk mine pool apparently occurs prior to outfall discharge.

The shaft monitoring revealed marked changes in water quality with depth within the basin. In five of the nine shafts studied, water was layered into two major zones separated by sharp changes in Eh, pH, and water quality parameters. An example of the vertical change in pH and sulfate is shown in figure 4.

The stratification appears to be related to discharge elevations at the time of inundation, as well as to present flow conditions. In each case, the sharp change in water quality occurred just above or below seams with mined barrier pillars. Relative positions of mined barrier pillars, outfall installations, and natural structural features combine to create an environment more favorable to flushing in the shallower parts of the mine system. As a result, the least contaminated water was found in the upper zones of the system, while the poorest quality was observed in flow-restricted, deeper zones.

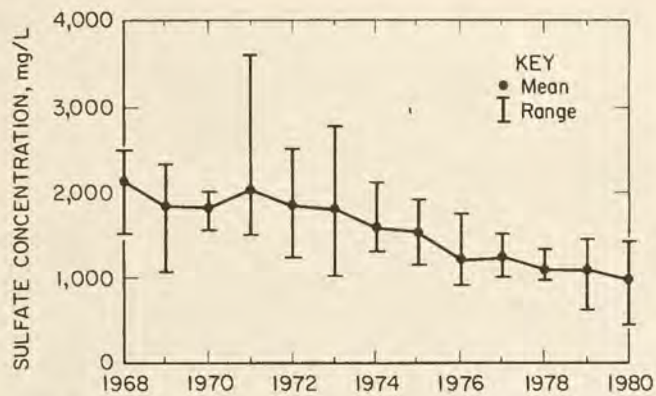

FIGURE 3. - Mean and range of sulfate concentrations at the Buttonwood Outfall.

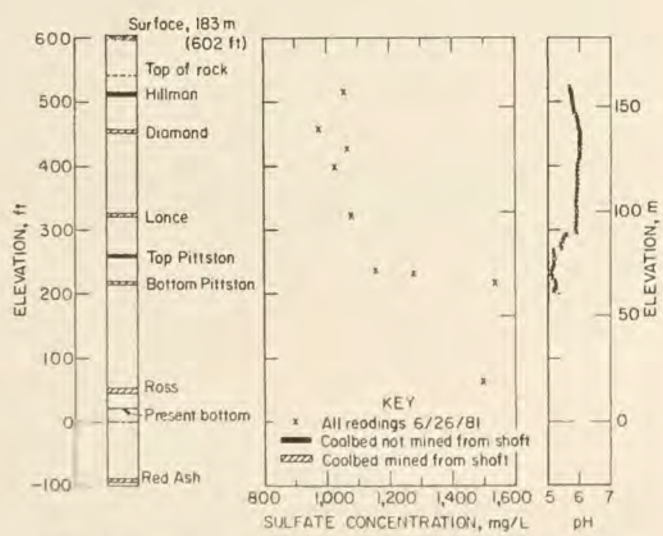

FIGURE 4. - Vertical profile of pH and sulfate in Gaylord shaft, Wyoming Basin.

The improvement in water quality appears to indicate a decrease or cessation of pyrite oxidation, along with neutralization and flushing of preexisting contaminants. The rate of flushing and minimum contamination levels attainable are difficult to quantify. Pyrite oxidation is still occurring at the surface in old refuse piles and strip pits, and these oxidation products are continuously washed into the subsurface flow system. The recharging pollutants are probably confined to small, near-surface flow systems and may tend to control the minimum contamination levels attained at the discharge points.

In addition to the surface contaminants, the reservoir of oxidation products in the flooded mine complex will continue to discharge for many years. Stimulation of flow from the deep zones by the addition of fully penetrating discharge structures may increase the rate of flushing but would aggravate the pollutant load on the surface streams if the discharge is left untreated. The construction of additional outfalls would also lower water levels, increasing the unflooded volume of the mine complex and possibly renewing pyrite oxidation in these areas.

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