Evaluation of Natural Amelioration of Acidic Deep Mine Discharges in the Uniontown Syncline, Pennsylvania

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Abstract

In several areas of western Pennsylvania, abandoned deep mine discharges that were reliably described as highly acidic in the 1960s and 1970s have shown natural amelioration of CO_2 acidity. A number of different factors, including mine flooding and overburden chemistry, may cause improvement in mine water quality.

We are studying the hydrologic and geochemical factors responsible for improvements over time in the quality of water discharges from abandoned deep mines. The project is focused on the study of a set of mine water discharges associated with abandoned, interconnected deep mines in the Uniontown Syncline of Western Pennsylvania. This area was studied extensively under Pennsylvania's Operation Scarlift in the early 1970s, and one year of monthly water quality data are available from 1974-75. The mined-out coal basin of the Uniontown Syncline is unique in that different mining methods were employed in the same coal seam over the basin. The resulting discharges are from flooded and unflooded abandoned underground coal mines.

This paper presents an overview of the hydraulic system in the mine network of the Uniontown Syncline along with a summary of selected data from the 1974-75 and 1998-99 studies. Preliminary interpretations of these data in relation to the Scarlift data are also presented.

Introduction

In several areas of western Pennsylvania, deep mine discharges that were reliably described as highly acidic in the 1960s and 1970s have shown natural amelioration of CO_2 acidity and decreases in Fe, Al, Mn, and SO_4 concentrations. The nature and extent of natural amelioration varies significantly between abandoned coal mines.

In this project we are investigating the hydrologic and geochemical factors responsible for natural amelioration of water quality from abandoned deep mines. The project aims to identify the dominant hydrologic and geochemical factors responsible for improvements over time in the quality of water discharges from abandoned deep coal mines. This is being accomplished through the study of a set of mine water discharges associated with abandoned, interconnected mines in the Uniontown Syncline, Fayette County, Pennsylvania. Nearly all deep mining in this basin was completed prior to 1960, and an extensive study of mine pool discharges (Ackenheil and Associates, 1977) in this basin was conducted in 1974-75 in conjunction with Operation Scarlift (Scarlift). The degree of mine water quality improvement over the ca. 25 years since the 1974-75 study is being assessed, and hydrogeologic and geochemical factors responsible for water quality changes are being investigated. New water quality monitoring was initiated in July 1998 at 21 of the discharge sites studied previously, and will be continued for two years.

Description of location and AMD discharge sites

The specific set of mine discharges in this study originates in the Uniontown Syncline, Fayette County, Pennsylvania. The synclinal axis runs parallel and to the west of Chestnut Ridge, as shown in Figure 1. The syncline plunges from the north and from the south creating a canoe-shaped coal basin. The Youghiogheny River (Yough) splits the basin into two distinct regions: the northern portion and the southern portion.

Mine drainage discharges were monitored under Scarlift on both the north and south sides of the Yough. The Uniontown Syncline was chosen due to the availability of historic mine water discharge data and because it features distinct areas of differing coal mining methods and mine geometry. Another reason for selection of the study area was that Scarlift indicated water quality differences between abandoned mine drainage (AMD) on the north and south side of the Yough.

The mines in the northern portion are low-cover mines developed updip from the surface, in which AMD discharges drain freely at the lowest elevation of the mine. Deep mining in the northern portion of the basin was complete by the 1930s, and the discharges have existed since that time.

The mines in the southern portion cover a larger area and include mines with up to 600ft of overburden. The deep mines were developed either downdip from the coal outcrop or updip from deep shafts. Deep mining in the southern portion was mostly completed by 1960, though some coal was left in place. Pumping which kept water levels below the surface was terminated by 1961 and the discharges in the southern portion began subsequently (Graziani, 1999).

Of the more than 130 discharge sites identified in the Scarlift study by Ackenheil and Associates (1977), 21 sites were chosen from sites of differing mine geometry. Monitoring sites were chosen to provide a cross section of data from both the northern and southern portion of the coal basin. Maps, past site descriptions, and flow rates were used to evaluate the similarity of sites.

Overview of the Hydraulic system

The nature of the hydraulics responsible for AMD discharges in the abandoned coal basin of the Uniontown syncline can be placed into two categories: flooded and unflooded. Schematic sketches of the mine configurations that result in flooded and unflooded mine discharges are found in Figures 2a and 2b. The difference in flow characteristics between discharges from unflooded and flooded deep mines is distinctive.

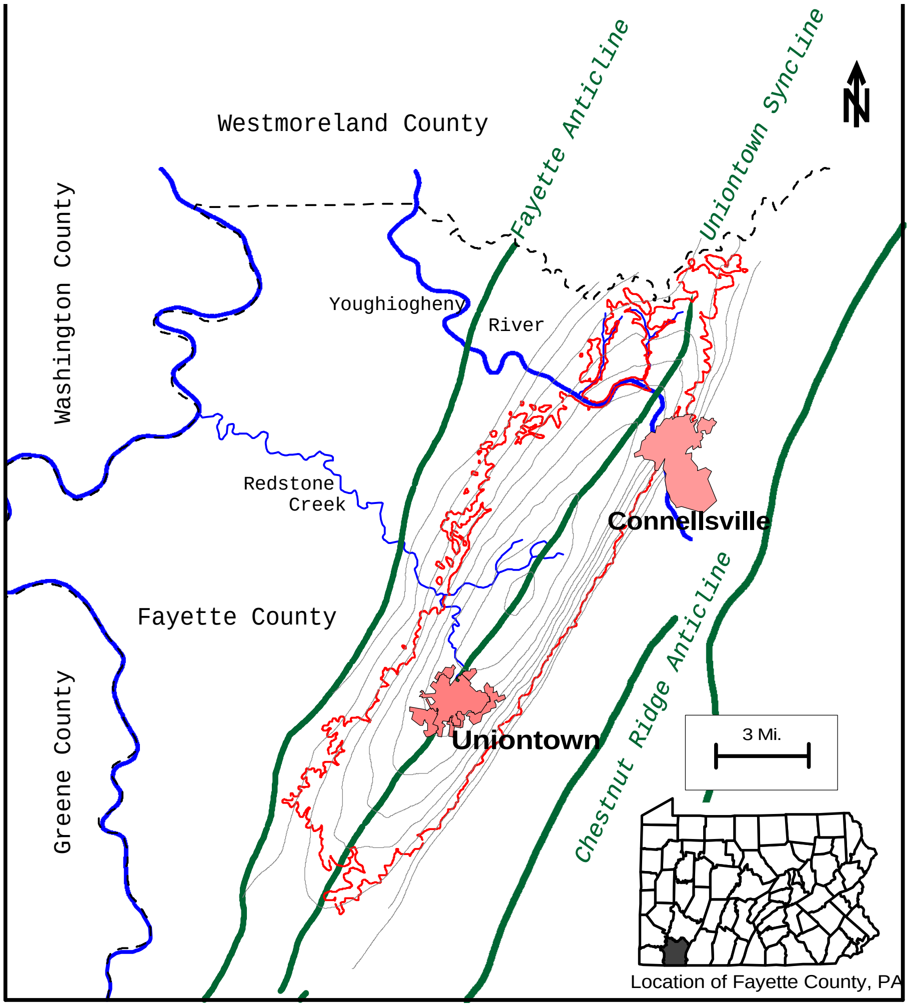

Figure 1. Location of the Uniontown Syncline. Elevation contours of the Pittsburgh Coal seam are also shown.

Unflooded Mines

Discharges on the north side of the Youghiogheny River (North Yough) originate primarily from unflooded mines (see Figure 2a). The mines have less than 200 ft. of overburden, with drainage areas less than 500 acres, and typically dip upward from the discharge at an approximately 1% grade. The North Yough discharges fluctuate seasonally in flow from several hundred gallons per minute (gpm) at peak in late winter and spring to zero flow at some sites during the dry season in late summer and fall. Seasonal variation in flow of the mine drainage is related to variations in both precipitation and evapotranspiration. In the discharges from unflooded mines, the storage of water in the abandoned coal mines is small and short-term. A conceptual model for an unflooded mine and the associated discharge in this syncline would be a bucket with a small hole at the bottom, filling and draining with variation in recharge. It could also be conceptualized as an underground watershed, with a contributing drainage area discharging as a small stream at the lowest elevation.

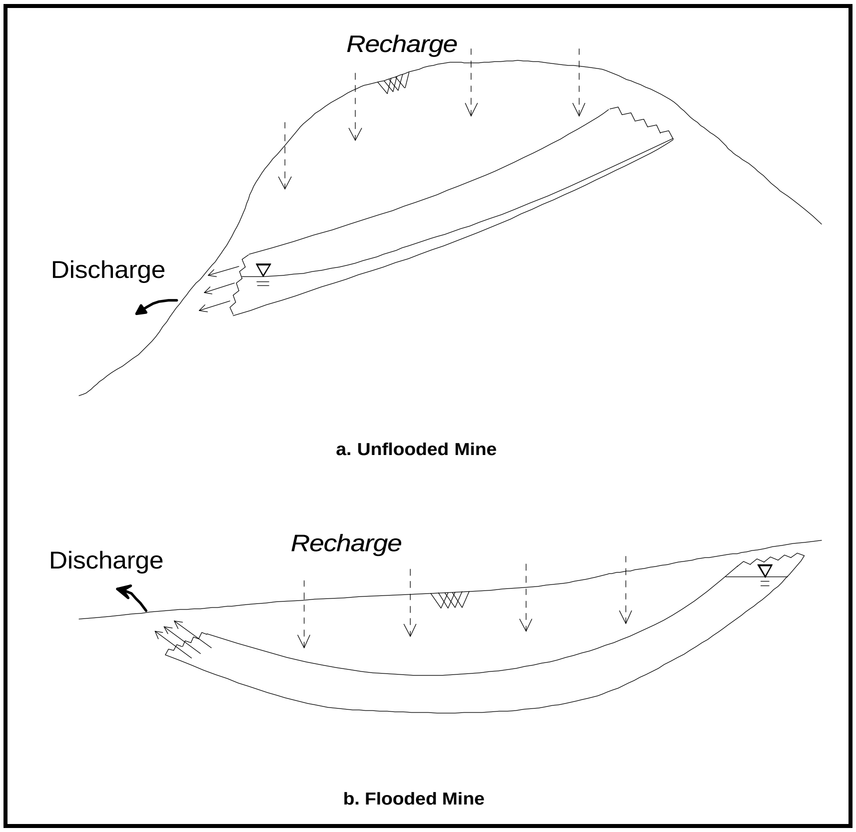

Figure 2. Schematic sketches of the mine configurations.

<u>Flooded Mines</u>

Discharges on the south side of the Youghiogheny River (South Yough) originate from an interconnected deep mine pool system. The mines have up to 600 ft. of overburden and a geometry that allows water to pool in the abandoned mines before discharging at the surface (see Figure 2b). The South Yough discharges are in two primary locations where the outcrop is cut by streams, on the Youghiogheny River west of Connellsville and on Redstone Creek north of Uniontown, as seen in Figure 3. Flow from flooded mines in the Uniontown Syncline is more stable year-round, and only slight fluctuations occur over seasons. The flooded mines are best conceptualized as water spilling over the lip of a filled, somewhat oddly shaped bathtub.

The South Yough hydraulic system comprises three distinct mine pools (Figure 3). Static water levels in various wells located in mine pool indicate the existence of at least three sections in the South Yough mine complex. The elevation of the northern pool has been observed at 860 ft and the discharges flow into the Youghiogheny River. The central pool stands at approximately 970 ft, draining primarily into Redstone Creek, though some central pool water may drain into the northern pool. The southern pool has been observed at 1010 ft and the majority of the water drains into the central pool, although some release may occur through small seeps at the far south end.

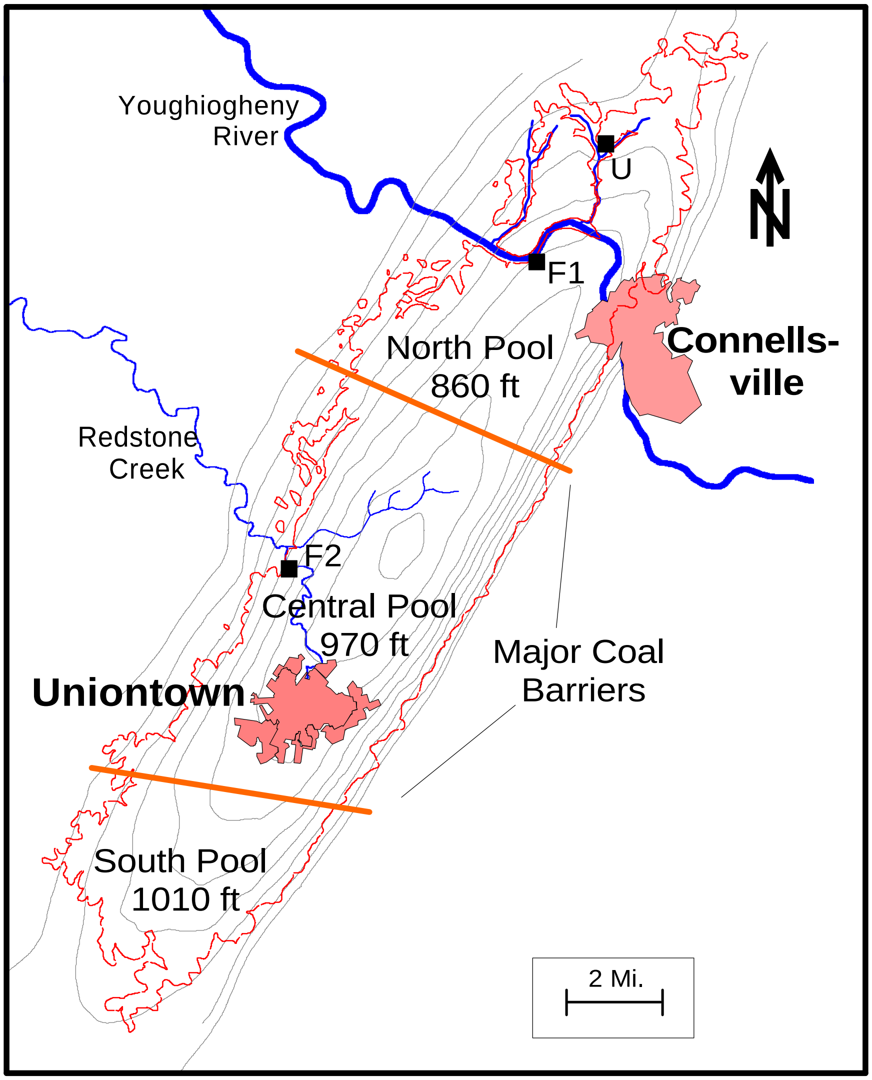

Figure 3. Discharge Site Locations and Mine Pool Elevations in the Uniontown Syncline. Elevation contours of the Pittsburgh Coal seam are also shown.

Summary of Water Quality Data

Monthly water quality monitoring in the Uniontown Syncline began in the summer of 1998. The representative data summarized here are for four sites that appear to correspond exactly in location to discharge sites monitored during Scarlift in 1974-75. Flow data have also been included as well as an estimate of the residence time for water in the mine behind each discharge. The sites are designated by their state of flooding, F for flooded and U for unflooded.

Alkalinity and CO_2 Acidity

Samples taken from the field are analyzed for CO_2 acidity and alkalinity in the laboratory. Table 1 summarizes the alkalinity and CO_2 acidity characteristics of the three sites during Scarlift and the current study. A description of each site is included in Table 1 along with their current Carnegie Mellon project ID names and the corresponding Scarlift site ID names.

Table 1. Selected AMD Discharges in the Uniontown Syncline and their Acidic/Alkaline Status

Site ID	Description	1974-75	1998-99	CMU ID	Scarlift ID
F1	Deep Mine Discharge	Alkaline	Alkaline	A0	M19
F2	Deep Mine Discharge	Acidic	Alkaline	P0	P1
U	Gravity Drained Discharge	Acidic	Acidic	M59	M59

pH

The field measurements of the mine drainage discharges from the Uniontown Syncline include pH measurements. These measurements give an indication of changes in CO_2 acidity/alkalinity in the sites between1974-75 and the recent monitoring. The median pH values for the selected sites are found in Figure 4.

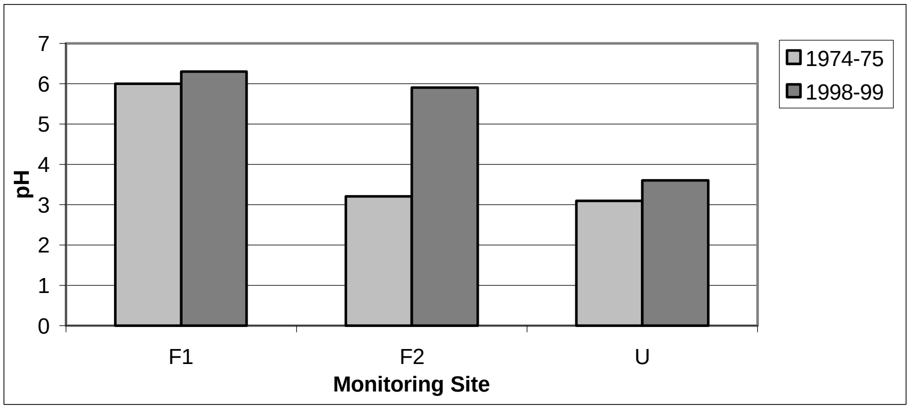

Figure 4. Median pH values for selected AMD sites in the Uniontown Syncline.

Total Iron and Sulfate

Total iron and sulfate were measured both in the current study and during Scarlift. Total iron measurements are more reproducible than the ferrous iron measurements. Total iron and sulfate concentrations from both studies are presented in Figures 5 and 6.

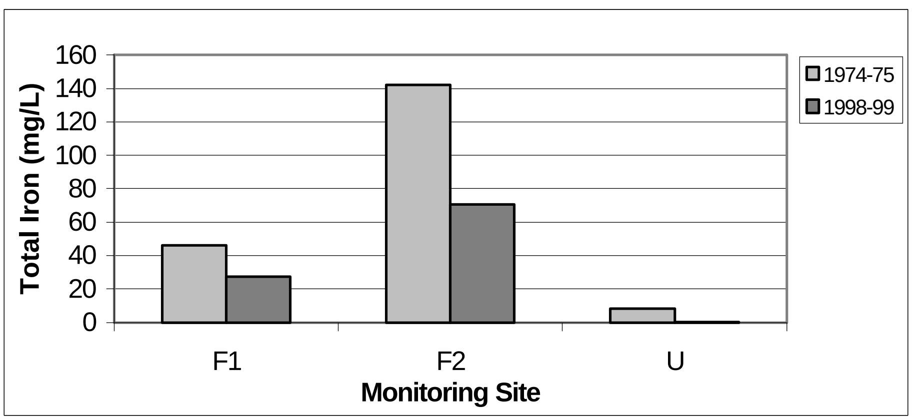

Figure 5. Median Total Iron concentrations for selected AMD sites in the Uniontown Syncline.

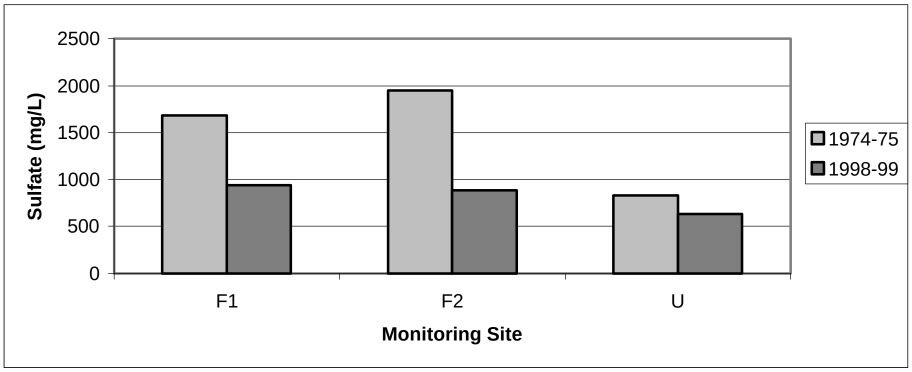

Figure 6. Median sulfate concentrations for selected AMD sites in the Uniontown Syncline.

Flow Data

Flow data for the selected sites are provided in Table 2. Estimated volumes of the respective mine pools are included as are residence times calculated from the average annual flow. For the flooded mine sites, F1 and F2, residence time estimates are based on approximate mined area behind the mine pool and heights observed in wells. The volume for U is an estimate based on the total volume of the mine with 70% or the coal removed, assuming it is only 3% flooded.

Table 2. Flow data for selected Uniontown Syncline AMD discharges in 1998-99.

Site ID	F1	F2	U
Average Flow (gpm)	3200	4800	240
Approximate Volume (gal)	6.3×10^9	28×10^9	1.2×10^7
Residence Time (years)	3.7	11	0.1

Preliminary interpretations

Significant water quality improvements have been observed in discharges from abandoned coal mines in Western Pennsylvania, both from mines that have naturally flooded because of geometry (e.g. EPA, 1975), and where flooding was induced via mine sealing (e.g. Forman, 1972). Inundation of abandoned mine voids brings about improvements because generation of AMD is inhibited when the oxygen supply for pyrite oxidation is exhausted (Watzlaf, 1992). The Uniontown syncline includes AMD discharges from mines with various degrees of flooding, and discharges that are unaffected by water quality control measures (e.g., alkalinity addition, passive treatment) for long term mine water quality improvement. The extent of change in mine drainage quality with time corresponds well with the extent of flooding in the contributing mined-out areas. Differences in the rate of change between flooded mines may be accounted for by their relative residence times. Changes also occur in unflooded mines and may be an indication that pyrite exhaustion occurs over time in AMD. These interpretations are explained below, and in more detail in Lambert (2000).

pH and Alkalinity Increase

All sites exhibited an increase, at the 95% significance level, in median pH and median alkalinity between the 1974-75 and 1998-99 data sets. The most dramatic increase was at site F2, a discharge from a flooded mine that was acidic in the 1970s but is now alkaline. Site F1 was alkaline in 1974-75, though it was likely acidic when it first started discharging in the 1960s.

Median alkalinity at site F1 did increase significantly from the 1974-75 to 1998-99 data sets, from 170 to 336 mg/L as $CaCO_3$. The unflooded site examined in this paper remains acidic, as it had been in the 1970s and likely was when it began discharging prior to 1930. These data indicate that flooding is a necessary condition for a significant change in alkalinity to occur in mine discharges.

Site U is a discharge from an unflooded mine and there is slight increase in median pH between the 1974-75 and the 1998-99 data sets, but the drainage is still significantly lower in pH than the discharges from flooded mines, and is still net acidic. The persistence of CO_2 acidity is likely due to the abundance of oxygen available for the oxidation of pyrite in this low cover, unflooded environment.

Both F1 and F2 are both in the completely flooded category. Therefore, the mine water quality is expected to be similar. The fact that F1 was already neutral in the 1970s suggests that F1 began discharging long before F2, and/or that F1 has a shorter residence time. According to information in Ackenheil and Associates (1977), F1 broke out after F2. Exact breakout dates cannot be confirmed, although pumping that kept water levels below the surface at both sites was ceased in the area around 1961 (Graziani, 1999). The marked difference in water quality between the sites approximately 14 years later (1975) suggests that the lag time in breakout dates is not the governing factor in the difference in water quality. The shorter residence time of water in the contributing pool for F1 compared to F2 (Table 2) is likely responsible for a faster rate of improvement in F1 water quality. Other factors that might govern the difference in water quality between F1 and F2 in 1974-75 could include overburden content and thickness, which we are still evaluating.

Changes in Iron and Sulfate Concentrations

All sites exhibited a decrease in total iron and sulfate concentrations between the 1974-75 data sets and the 1998-99 data sets. As normalization to flow rate and a decrease in mass loadings demonstrate (Lambert, 2000), these decreases are not due to dilution. Substantial decreases occurred in the discharges from flooded mines. The large decrease in concentrations of iron and sulfate in the flooded mine is likely due to the exhaustion of available oxygen for pyrite oxidation. Other factors may also play a role in this long-term change.

Small decreases in iron and sulfate occurred in the discharge from the unflooded mine as well. Apparently, changes in long-term water quality have occurred at this site despite the unflooded condition. Among these factors may be a decrease in available surface area of pyrite for oxidation. This is being investigated.

Concentrations of iron and sulfate in the unflooded mines were lower than might have been expected in both the current and the Scarlift data sets. This is another indication that a decrease in iron and sulfate occurs even in unflooded mines, even if they are persistently acidic and low in pH. Again, this may be due to the exhaustion of pyrite or some other factor.

Summary and Conclusions

In several areas of western Pennsylvania, deep mine discharges that were reliably described as highly acidic in the 1960s and 1970s have shown natural amelioration of mine water quality as measured by CO_2 acidity, iron, and sulfate concentrations. In the Uniontown Syncline in Fayette County, PA, an extensive study of mine pool discharges in this basin was conducted in 1974-75 in conjunction with Operation Scarlift. We are currently studying a subset of the same discharges to document the extent of natural amelioration in this area and to identify the hydrologic and geochemical factors responsible for changes in mine water quality.

Comparisons of mine water quality data collected in this study and in Scarlift indicate that flooding has an important role in the change of AMD from acid to alkaline. Discharges from flooded mines were either alkaline in the Scarlift study, or have become alkaline since Scarlift. A substantial decrease in iron and sulfate concentrations occurred between 1974-74 and 1998-99 in discharges originating from flooded mines.

The discharge from an unflooded mine presented in this paper was acidic in 1974-75 and remained acidic in 1998-99. However, small decreases in iron and sulfate concentrations occurred. The concentrations of iron and sulfate in the discharge from the unflooded mine are surprisingly low, and were low even in 1974-75. This indicates that another factor besides flooding, possibly exhaustion of pyrite, can bring about improvements in quality, even in AMD discharges originating from unflooded mines. Investigation of this factor along with the role of overburden in long-term mine water quality changes is continuing.

Acknowledgments

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