Comparison of Water Quality from Fifteen Underground Coal Mines in 1968 and 1999

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Abstract

Acid mine drainage (AMD) from both abandoned surface and underground mines is a serious problem. The flow of water and changes in quality over time from abandoned mines is important in determining remediation strategies. Acid mine drainage from surface mines is estimated to last for 10-20 years, while estimates of acid drainage from underground mines vary from 10-100s of years. Fifteen underground mine discharges in West Virginia were studied to compare water quality changes between 1968 and 1999 to see if our data are consistent with other studies. Each of the discharges were categorized into one of three groups: undisturbed since 1968, affected by surface mining since 1968, and reclaimed. Comparing water quality between 1968 and 1999, the discharges in the undisturbed category showed a 35 to 95% improvement in acid concentration and a 40 to 99% reduction in iron concentration. The discharges affected by surface mining showed the most dramatic improvement. For acidity, iron, and aluminum, the percent improvements were all above 44%, and in most cases in the 70 to 99% range. In the reclaimed category, one of the four discharges declined in water quality. Discharge 82 showed a 76% increase in acidity, and iron and aluminum concentrations worsened by 58 and 96%. However, discharges 15 and 74 improved in water quality with a 94% acid load improvement and a 95% iron load improvement at both sites.

Introduction

Coal was first mined in the United States near Richmond, VA in 1750. Coal mining was performed by small operators using only picks and shovels on surface coal outcrops where little soil cover occurred. During the 1800s the demand for coal increased forcing the development of underground mines. The U.S. Soil Conservation Service estimated that about 600,000 acres of land had been disturbed by surface mining in 1975. No estimate has been made of the miles of underground passages and areal extent where coal has been removed by deep mining. One of the environmental consequences of surface and underground mining is the generation of acid mine drainage (AMD). According to the Environmental Protection Agency (1995), approximately 10,000 km of streams have been affected by acid mine drainage in the northeastern U.S. (Pennsylvania, Maryland, Ohio, and West Virginia). Mines abandoned prior to 1977 generate more than 90% of AMD in streams and rivers in this region and most of this acid drainage stems from underground mines. Acid drainage from abandoned deep mines is problematic and hard to correct because the mines are often partially caved and flooded, thereby restricting access, and reliable mine maps are often not available for study.

Acid mine drainage forms when sulfide minerals are exposed to oxidizing conditions. Upon exposure, sulfide minerals oxidize in the presence of water and oxygen to form highly acidic, sulfate-rich drainage. Acid mine drainage is characterized by high sulfate concentrations, high levels of dissolved metals (Fe, Al, Mn, etc.) and pH <4.5. Drainage quality from underground mines depends on the proportions of acid (pyrite) and alkaline (carbonate material) minerals in the coal and surrounding rock. If these factors (pyrite, oxygen, water) are expended, generation of AMD will slow or cease.

Surface mining increases porosity and hydraulic conductivity of rock left in the backfilled area, thereby introducing oxygen and additional water. Underground mines, on the other hand, can fill with water after abandonment and eventually limit the amount of air and water into the mine. On both surface and underground mines, the quality of discharges depends on the rock types encountered within the flow paths and not the total overburden chemistry (Ziemkiewicz and Skousen 1992).

The potential for AMD formation is widespread, so measures should be taken during mining to preclude or reduce the problem. Treating the acid-producing rock directly and stopping or retarding acid production is a practice that has been implemented on many surface mine sites. The most common preventative measure is through the use of alkaline amendments (Brady et al. 1990, Perry and Brady 1995, Rich and Hutchinson 1990, Rose et al. 1995).

With underground mines, opportunities for alkaline amendment are limited. Rock dust and other lime products may be layered on underground mine walls, floors, and ceilings, but this technique has limited success in high pyrite underground mines. Another technique being used after mining involves injection of alkaline materials on 8- to 16-m centers to fill mine voids with non-permeable materials. This technique removes both the water and oxygen necessary for AMD formation. Mixtures of class F fly ash and 3 to 5% portland cement have been used successfully to fill voids (Burnett et al. 1995).

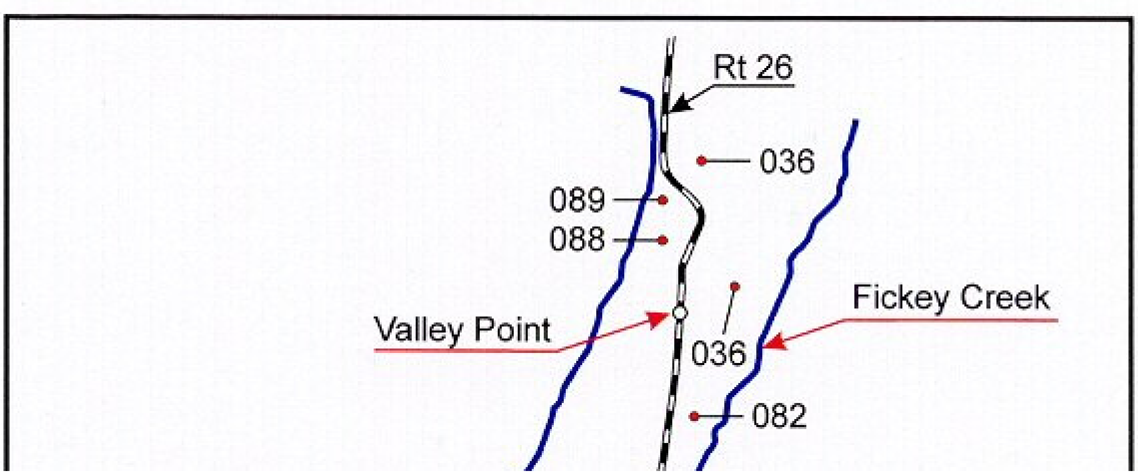
Another important technique to improve water quality from abandoned areas is remining. Remining or "daylighting" returns to an area that has already been mined for further coal removal. It has been shown that remining reduces acid drainage by: decreasing infiltration, covering the exposed acid-producing material, and removing the coal which is the major source of pyrite. Hawkins (1994) studied 57 discharges from 24 remined sites in Pennsylvania and found contaminant loadings were either reduced or unchanged after remining. Reduction in loads came primarily from a decreased flow rather than large reductions in concentrations. Remining has many advantages. It reduces environmental hazards, improves aesthetics, enhances land use quality, and decreases pre-existing pollutional discharges.

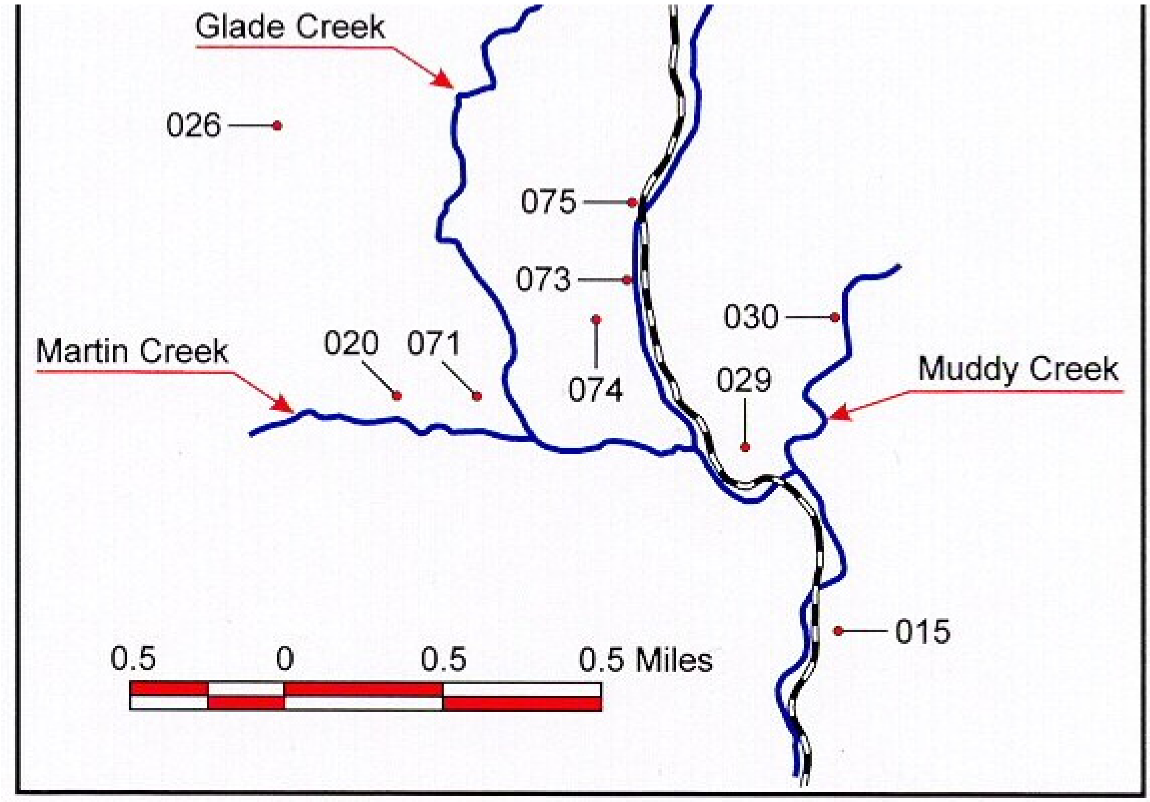
Determining the long-term behavior of acid-producing materials is critical in predicting longevity of the acid discharge. Researchers have stated that AMD from surface mines has a defined life of 10-20 years, after which improvement in drainage quality occurs as acid salts are leached from rocks by natural precipitation (Meek 1996).

Acid discharge longevity from U.S. underground mines is less understood because it is difficult finding reliable data and tracing historical information of a mined area. Acid discharges of underground mines in the U.K were given an exponential rate of decay in pollutant strength, based on volume of mine voids (Glover 1983). Younger (1995) indicated that acid in discharges from underground mines can be separated into two types. The first type of acid comes from leaching of stored acid salts (vestigal), while the second type is the creation of new acidity from water table fluctuations (juvenile). Younger (1995) suggested that AMD longevity at any given site depends on flushing of stored salts (interconnectness of mine voids, hydraulic conductivity, and recharge rates) and the generation of new acidity. Younger (1997) concluded that underground mine discharges can improve within 10 years as stored salts are leached, but may not improve for 100 years or more if new acidity is continually being generated and leached.

This study evaluated the discharge quantity and quality from 15 abandoned underground mines at two time periods. Data from a 1968 study were used to locate AMD discharges in 1999. After locating and sampling the water quality, we compared the 1968 data to our data collected in 1999.

Map - Location of underground mines sampled for this study. All occur between Albright and Valley Point, Preston County, West Virginia.





Materials and Methods

Fifteen underground mine discharges were chosen for comparison. All sites were located in Preston County, WV, were all within 16 km of each other, and were all sampled in 1968. The discharges were all draining drift mines to various streams within the Muddy Creek Watershed from the Upper Freeport coal seam (Table 1). The drift mining method was generally used in hilly areas where coal seams outcrop along the contour and where the seam is nearly flat or slightly dipping. The Upper Freeport coal seam was the most extensively mined in our research area by this method. It is the topmost strata of the Allegheny Formation of the Pennsylvanian System. Freeport coal is uniformly low in sulfur (<1.5% S) and has a comparatively low ash content (8 to 12%). It is a multiple-bedded coal seam that is divided into a top coal and bottom coal, separated by a shale interlayer, all of which average a total of six feet thick (Hennen and Reger 1914). The Allegheny Formation is capped by the Upper Freeport coal and overlying strata in the Conemaugh Group contain several massive sandstones and some shales. Limestone or alkaline-bearing rock units are not generally found within 50 m above the Upper Freeport coal in this area, so very little overlying geologic material was available for acid neutralization.

Table 1: Description of the 15 underground mines and their discharges sampled in 1968 and 1999.

Discharge #	Mining Method[1]	Disturbance Type	Receiving Stream
06	I-strip & drift	Affected by surface mining	Bull Run
15	I-drift	Reclamation has occurred	Muddy Creek
20	I-strip & drift	Undisturbed	Martin Creek & Glade Run
26	I-strip & drift	Affected by surface mining	Glade Run
29	I-drift	Affected by surface mining	Fickey Run
30	A-drift	Reclamation has occurred	Muddy Creek

36	I-drift	Undisturbed	Fickey Run
60	I-strip & drift	Affected by surface mining	Glade Run
71	I-drift	Affected by surface mining	Martin Creek
73	I-drift	Undisturbed	Fickey Run
74	I-drift	Reclamation has occurred	Fickey Run
75	I-drift	Affected by surface mining	Fickey Run
82	A-drift	Reclamation has occurred	Fickey Run
88	I-drift	Undisturbed	Glade Run
89	I-drift	Undisturbed	Glade Run

[1] I = inactive mine at time of sampling in 1968; A = active mine at time of sampling in 1968.

1968 Sampling Techniques

Field crews were sent out to identify all coal mines within the Monongahela River Basin and to sample AMD discharges. Each crew worked from a 7.5 minute USGS topographic map on which they outlined mine boundaries and indicated mine openings. Field sheets were also completed at each site with location information as well as the stratigraphic section of rocks. If a discharge of water from a mine site was found, the flow was measured and the water was sampled. Field measurements of water pH (electrometric pH meter) and temperature (thermometer) were taken and recorded.

Two water samples were taken from each discharge: 1) unfiltered water was put into a plastic liter bottle and put on ice to analyze later in the laboratory for acidity, alkalinity, and pH; and 2) filtered water was put into a 100-mL glass bottle and treated with acid for metals analysis (total iron, manganese, aluminum). Water samples were analyzed by a certified laboratory using standard methods. The flow was measured wherever possible using a bucket and stop watch. For larger flows, the crew would install a V-notch weir and measure flow rate.

1999 Sampling Techniques

Point discharges were located based on the USGS topographic map marked by the 1968 crew. Discharges were sampled as close to the mine portal as possible. Flows were calculated using a measured cross-sectional area and flow velocity or an estimate was made. Two water samples were taken at each sample point: a 250-mL unfiltered sample was taken for general water chemistry (pH, conductance, acidity, and alkalinity), and a 25-mL, filtered sample was acidified to pH <2 with .5 mL concentrated sulfuric acid. The acidified water sample was preserved for metal analysis.

Water pH, alkalinity, and acidity were determined by a Metrohm pH Stat Titrino Titration System (Brinkman Instruments, Westbury, NY). Conductivity was measured using an Orion Conductivity Meter Model 115 (Beverly, MA). The metal analysis was performed using an Inductively Coupled Spectrophotometer, Plasma 400 (Perkin Elmer, Norwalk, CT). Loadings were calculated from laboratory data and comparisons between 1968 and 1999 data were made.

In comparing 1968 and 1999 data, we made several assumptions. We assumed that the water samples were taken in similar areas and in a similar manner between studies and that the techniques for analyses were also equivalent. Changes in flow conditions were also a concern, since 1999 was a very dry year. Additional samples will be taken during the spring of 2000 to evaluate flows and concentrations during a high flow period. We also will check climatic data prior to the 1968 sample collection dates and compare it to climatic data in 1999.

Results and Discussion

The discharge data were organized into three categories: **undisturbed** since the original sampling in 1968 (Table 2), **affected by surface mining** since the original sampling (Table 3), or **reclaimed** (Table 4). Each discharge point was classified based on observations made during sampling in 1999 and also from reviewing the field notes made by the collector in 1968.

Undisturbed

Sample 36 (Table 2) showed an improvement in water chemistry, but a large increase in flow from 6 to 113 L/min. The discharge flows from caved portals, and mixes with other seeps surrounding the portals. The draining area contains much iron hydroxide floc. All AMD parameters have dramatically decreased in concentration: acidity from 3270 to 154 mg/L and iron from 672 to 7 mg/L. The increase in flow may be caused by the underground works intercepting water from adjacent mines with better water quality, thereby causing a dilution of the AMD, or the flow may have been increased due to surface recharge through cracks into the mine. The pollutant loadings at this site decreased even though the flow increased. The acid load was reduced from 28 to 25 kg/day, and the iron load decreased from 6 to 1 kg/day.

Discharge 88 showed improvement in water chemistry for the parameters that we measured. Houses have been built in the area around the caved mine opening. The flow remained constant at this site, and acidity decreased from 675 to 412 mg/L in the past 30 years.

Discharge 89 showed concentration decreases over time, except for an increase in aluminum from 29 to 40 mg/L. A small amount of white precipitate is visible in the stream bottom, which is probably aluminum hydroxide precipitate. The flow remained about the same. Water pH increased from 3.6 to 4.6 and iron decreased from 53 to 17 mg/L.

Discharge 20 increased in alkalinity from 0 to 79 mg/L. The 1968 field notes of this site say that the area was roughly reclaimed and the discharge flowed through spoil. The water appears to flow through the same spoil even now. The flow also increased at this site from 6 to 56 L/min, and the increased flow gives an increase in iron load from 1 to 5 kg/day.

Discharge 73 exhibited an improvement in water chemistry, but flow increased from 3 to 57 L/min. The 1968 notes stated that this discharge was sampled near wet auger holes. This increased flow may be a result of pressure build-up in the mine causing it to flow out of the hillside through old spoil. The pH increased from 2.2 to 4.4, and the acidity decreased from 1670 to 1087 mg/L. Due to the increase in flow, however, the acid load actually increased from 7 to 89 kg/day.

Table 2: Comparison of water quality and quantity from underground mines that have remained undisturbed since the original sampling in 1968.

Discharge #	Flow L/min	pH	Acidity mg/L	Acid load kg/day	Alkalinity mg/L	Iron mg/L	Iron load kg/day	Aluminum mg/L
36								
1968	6	3.0	3270	28	0	672	6	180
1999	113	3.9	154	25	0	7	1	14
88								
1968	11	2.8	675	11	0	---	---	---
1999	11	4.1	412	6	0	37	1	53
89								
1968	4	3.6	390	2	0	53	1	29

1999	19	4.6	179	5	2	17	1	40
20								
1968	6	3.0	490	4	0	105	1	17
1999	56	6.4	253	20	79	69	5	1
73								
1968	3	2.8	1670	7	0	237	1	157
1999	57	4.4	1087	89	0	19	2	78

Affected by Surface Mining

Discharge 60 (Table 3) showed a dramatic improvement, indicating that remining greatly improved water chemistry. Little floc is visible due to the small amount of iron present in the water now, which decreased from 228 to 7 mg/L. Even though the chemistry improved, the pH remained nearly the same. Excavation has occurred in the area and the surrounding area has been surface mined.

Discharge 26 also improved in water chemistry. The area above and surrounding the discharge has been surface mined and the discharge itself flows through old spoil. The iron decreased from 158 to 4 mg/L between 1968 and 1999, and the acidity decreased from 1765 to 283 mg/L. The improvement may have occurred either because of the remining or because the acid salts were leached from the spoil.

Discharge 06 showed water chemistry improvements, but the drainage from the underground mine has caused a large area to become swampy with dead vegetation and iron floc throughout. This deep mine appears to have been remined and largely drained, resulting in the swampy area. The acid load decreased from 194 to 45 kg/day and the iron load decreased from 51 to 2 kg/day.

Discharge 29 runs off a hillside from a surface mined area where the portals of the underground mine were daylighted and a gob pile was removed. The acidity decreased from 790 to 250 mg/L and the iron decreased from 105 to 70 mg/L. The flows increased, but the loads are greatly reduced due to the improvement in acid and iron concentrations.

Discharge 71 shows a tremendous improvement in water chemistry. The discharge flows out of caved portals, then through a gob pile. The area surrounding the portal has been surface mined. The water then flows through a valley bottom creating a swampy area devoid of vegetation. The flow has remained about the same and the acid load has decreased from 190 to 7 kg/day. The pH increased from 2.7 to 3.8. Metal concentrations are greatly reduced from 640 to 10 mg/L for iron, and 161 to 5 mg/L for aluminum.

Discharge 75 flows down a ditch from an area that has been mined. It flows through two caved portals and then through a gob pile. The acidity has decreased from 1300 to 119 mg/L and the pH has increased from 2.4 to 4.9 in the past 30 years.

Table 3: Comparison of water quality and quantity from underground mines that have been affected by surface mining since the original sampling in 1968.

Discharge #	Flow L/min	pH	Acidity mg/L	Acid load kg/day	Alkalinity mg/L	Iron mg/L	Iron load kg/day	Aluminum mg/L
60								
1968	15	3.7	1705	37	0	228	5	146

1999	4	3.7	152	1	0	7	1	14
26								
1968	NA**	NA	1765	NA	0	158	NA	151
1999	8	3.9	283	3	0	4	1	33
06								
1968	57	2.9	1370	194	0	624	51	67
1999	94	3.7	336	45	0	15	2	36
29								
1968	6	3.0	790	7	0	105	1	89
1999	57	6.4	250	21	80	70	6	42
71								
1968	57	2.7	2315	190	0	640	53	161
1999	38	3.8	135	7	0	10	1	5
75								
1968	4	2.4	1300	8	0	288	2	112
1999	11	4.9	119	2	1	13	1	1

**NA—data not available

Reclamation has Occurred

Discharge 82 (Table 4) showed a large degradation in water chemistry. The metals and acidity increased greatly, but the pH improved slightly. The acidity increased from 420 to 1694 mg/L and the iron increased from 82 to 194 mg/L. The flow also increased nearly ten fold. The area surrounding this site has been surface mined and culverts were put in to divert the water. The water is deep purple and an interesting reddish-orange floc has precipitated in concentric rings on the rocks.

Discharge 15 exhibited an improvement in water chemistry. The area was reclaimed and the discharges are collected into two pipes. The flow decreased from 1134 to 246 L/min and the acid load decreased from 3495 to 195 kg/day. The metals decreased from 576 to 102 mg/L for iron, and aluminum was reduced from 108 to 29 mg/L.

Discharge 30 showed an improvement in water chemistry. The area was surface mined and a rock-lined ditch was placed to channel the flow. The acidity decreased from 2515 to1788 mg/L and the iron decreased from 422 to 215 mg/L.

Discharge 74 showed an improvement in water chemistry and the flow decreased from 49 to 11 L/min. In 1968, the discharge came from one air shaft, two portals, and went through a gob pile. In 1999, the gob pile has been reclaimed and no visible portals or airshafts can be found. The discharge is now located at the edge of the reclaimed area and is captured in a pond. The acidity decreased from 1505 to 390 mg/L and the iron has been almost completely removed from levels of 20 kg/day in 1968 to <1 kg/day in 1999.

Table 4: Comparison of water quality and quantity from underground mines where reclamation has occurred since 1968.

Discharge #	Flow L/min	pH	Acidity mg/L	Acid load kg/day	Alkalinity mg/L	Iron mg/L	Iron load kg/day	Aluminum mg/L
82								
1968	21	2.9	420	13	0	82	2	7
1999	189	3.8	1694	461	0	194	53	168
15								
1968	1134	2.6	2140	3495	0	576	941	108
1999	246	3.8	550	195	0	102	36	29
30								
1968	102	2.9	2515	369	0	422	62	301
1999	170	2.9	1788	438	0	215	53	200
74								
1968	49	3.0	1505	106	0	288	20	84
1999	11	3.9	390	6	0	17	1	34

**NA—data not available

Percent Changes in Water Chemistry

Percent changes in each parameter were calculated to observe trends (Table 5). It is apparent that water quality improvements occurred for undisturbed discharges, but four of the five sites had increased water flow. As a result, acid loads increased from 60 to 92% on three of these sites. The undisturbed discharges showed acidity concentration improvements ranging from 35 to 95%. Surface mining (remining) accelerated improvement in water quality from deep mines. Average improvements were much greater than undisturbed deep mine sites and no surface mined sites had worse water. For acidity, iron and aluminum, the percent improvements were above 44% and in most cases in the 70 to 99% range. These results confirm that remining, even in adjoining areas, can greatly improve the quality and quantity of underground mine discharges. The reclaimed areas showed variation among the four sites. Site 82 declined in water quality and showed an increase in flow. The result was that the acid load increased by 97% and iron load increased by 96%. This increase may be due to recent "daylighting" of the mine and intercepting water that may have been discharging elsewhere. Reclamation on sites 15 and 74 greatly improved the water chemistry, with 94% acid load improvement.

Table 5: Percent changes in water chemistry and load between 1968 and 1999. Positive values represent percent improvement in the parameter and negative values (in bold) represent percent degradation in the parameter.

	Acidity	Acid Load	Iron	Iron Load	Aluminum

Undisturbed					
36	95	11	99	87	92
88	39	46	NA**	NA	NA
89	54	**-60**	68	0	**-28**
20	48	**-80**	40	**-80**	94
73	35	**-92**	92	**-50**	50
Affected by Surface Mining					
60	91	97	97	80	91
26	84	NA	97	NA	78
06	86	77	97	96	46
29	68	**-66**	44	-84	52
71	94	96	98	98	97
75	91	75	95	50	99
Reclaimed					
82	**-76**	**-97**	**-58**	**-96**	**-96**
15	74	94	82	96	73
30	29	**-16**	49	15	34
74	74	94	94	95	60

**NA—data not available

Conclusions

Acid mine drainage from underground mines showed water chemistry improvements at 14 of the 15 discharge sites. Acidity and iron concentrations were better after 30 years at 14 sites, while aluminum concentrations were improved at 13 sites. The undisturbed discharges all showed improved water chemistry, however the acid loadings worsened on three of the five sites due to increased flow. This may be caused by additional water from adjacent mines flowing into the underground mines or other changes in the mine void causing a redirection of water to the observed outlets. The discharges affected by surface mines exhibited the most dramatic improvement in water quality. The improvement was much greater at these sites due to further removal of high sulfur coal, burial of toxic materials, and revegetation. The flows remained relatively similar between 1968 and 1999 data, except for discharge 29.

One of the four reclaimed sites declined in water quality and also experienced a 10-fold increase in flow. Reclamation at sites 82 and 30 occurred recently to our 1999 sampling date. These discharges may be experiencing the release of newly-generated acid due to recent disturbance or to the creation of new flow paths in the spoil, also resulting in a release of stored acid salts. With time, these discharges will likely improve in quality. It would be interesting to return to these discharge sites to determine if the increases in acid and metals are temporary due to the recent disturbance and exposure of pyritic materials. The other two discharges showed an improvement in water quality.

The study shows that if underground mines are left undisturbed for a long period of time, the water quality will improve, which supports previous studies on acid release from underground mines. Remining accelerates improvement in water quality. If surface reclamation occurs, mixed results may happen, but a greater percentage of our discharges on these sites showed decreased flow and improved water chemistry. Further historical research into the area surrounding underground mine discharges will be important in determining causes of water quality changes and give a better understanding of how changes occur over time.

This paper is the preliminary work of a larger study that focuses on determining acid discharge longevity from acid-producing underground mines in northern West Virginia. Further research will expand the sampling area, develop a model to predict longevity based on several factors (e.g., overburden chemistry, pyrite content, mine area and void space, and water hydraulics) and extend the results to other watersheds.

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Picture 1 - Site 89: This is an undisturbed site. The seep emerges from the portal and discharges into a pond.

Picture 2 - Site 88: This is an undisturbed site. The seep emerges from the collapsed portal, creating a large area of Fe-floc.

Undist089.jpg (80678 bytes)

Picture 3 - Site 60: This is a surface affected site. The seep emerges in the grassy area near the wooded stake.

Picture 4 - Site 15: This is a reclaimed site. The cemented water-way courses the discharge down the hill to Muddy Creek.

Picture 5 - Site 15: This is a reclaimed site. The pipes go back into the mine and help control outflow from the wet/dry (?) seals.

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