The Long-Term Evaluation of Mine Seals Constructed in Randolph County, WV in 1967

By

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ABSTRACT

In 1967, the Federal Water Quality Administration (FWQA) installed mine seals in abandoned mine portals in Randolph County, WV in a project known as Elkins Mine Drainage Pollution Control Demonstration Project. The seals were designed to prevent the entry of air into the portals while allowing water to exit. By keeping the air from reaching reactive materials such as pyrite, it was believed the formation of acid mine drainage (AMD) could be reduced.

Water discharges from the seals were monitored several years after construction to observe any immediate results on water quality. In 1980, the Bureau of Mines conducted a study to determine if the seals had been effective in reducing pollutants from the mines and determined the quality of water from several portals had improved.

A 1990 reconnaissance was performed in order to evaluate the long-term effectiveness of the seals. The physical condition of each seal was observed and water quality analyses were compared to previous studies. Many seals had deteriorated over time and discharge quality had improved for the most part since earlier studies, but pollutant levels are still not at acceptable levels.

INTRODUCTION

Acid mine drainage (AMD) has been a major problem for eastern coal mining region of the United States. Inactive underground mines are responsible for 52 percent of acidic pollution of surface water in Appalachia.(1) Early underground mining practices typically relied on gravity for water drainage instead of pumping. Consequently, high volumes of AMD continue to be discharged from abandoned mines. The pollution of surface and ground water reserves plague the state and federal agencies responsible for abandoned mine lands. These agencies do not have sufficient resources to construct or maintain effective water treatment systems and long-term, cost-effective solutions are needed. Mine sealing was one of the first methods of AMD abatement that appeared to be both effective and affordable.

AMD forms when pyrite, an integral part of most coals and their adjacent strata, oxidizes and releases iron and sulfate and produces acidity. Oxygen must be available in order for oxidation to occur, and water serves as a reactant and carrier of AMD. Mine sealing is done in order to keep air from entering the mines and reacting with the pyrite. Wet seals are constructed to do so while allowing water to escape.

The purpose of this study was to evaluate the long-term effectiveness of fourteen wet mine seals constructed in 1967 to ameliorate mine water quality problems in Randolph County, West Virginia. A comparison of data compiled before sealing (1966), shortly following sealing (1971), and about a decade later (1980) with data collected in September 1990, was made to determine the influence each seal has had on effluent water quality.

BACKGROUND

Legislation

In 1962, the Committee on Public Works of the House of Representatives requested the Department of Health, Education, and Welfare (DHEW) to begin an extensive study of water pollution caused by AMD. The committee made recommendations for abatement and concluded that the most promising method was sealing.(2) The program was the responsibility of the Division of Water Supply and Pollution Control (DWSPC) which is now part of the U.S. EPA. The U.S. Bureau of Mines was among several agencies to be involved in this study.

Demonstration Site

In March, 1964, the Roaring Creek watershed near Elkins, West Virginia was selected for the demonstration project. (See Figure 1.) It covers 72 square kilometers and drains into the Tygart Valley River in the upper Monongahela and Ohio Basins. The area is mountainous and has average temperatures of 0.3^{0}C (32.5^{0}F) in January and 21.1^{0}C (70^{0}F) in July with an annual average of 10.4^{0}C (51^{0}F). The average annual precipitation in Elkins is 45.8 inches. Table 1 presents selected quarterly precipitation data for the study area. Large storms and snow melt frequently cause basin-wide flooding in early spring, and this may cause flushing of pollutants from mines in winter and spring.

TABLE 1. Quarterly rainfall (in inches) in the Elkins, WV area for selected years

Year	Quarter 1st	2nd	3rd	4th	Total
1965	11.5	10.6	6.9	6.1	35.1
1966	8.0	10.3	15.6	8.9	42.8
1971	8.7	6.7	15.5	5.5	36.4
1980	9.5	14.2	22.1	7.8	53.6
1989	13.1	16.1	15.5	10.4	55.1
1990	8.7	14.8	11.4	11.1	46.0

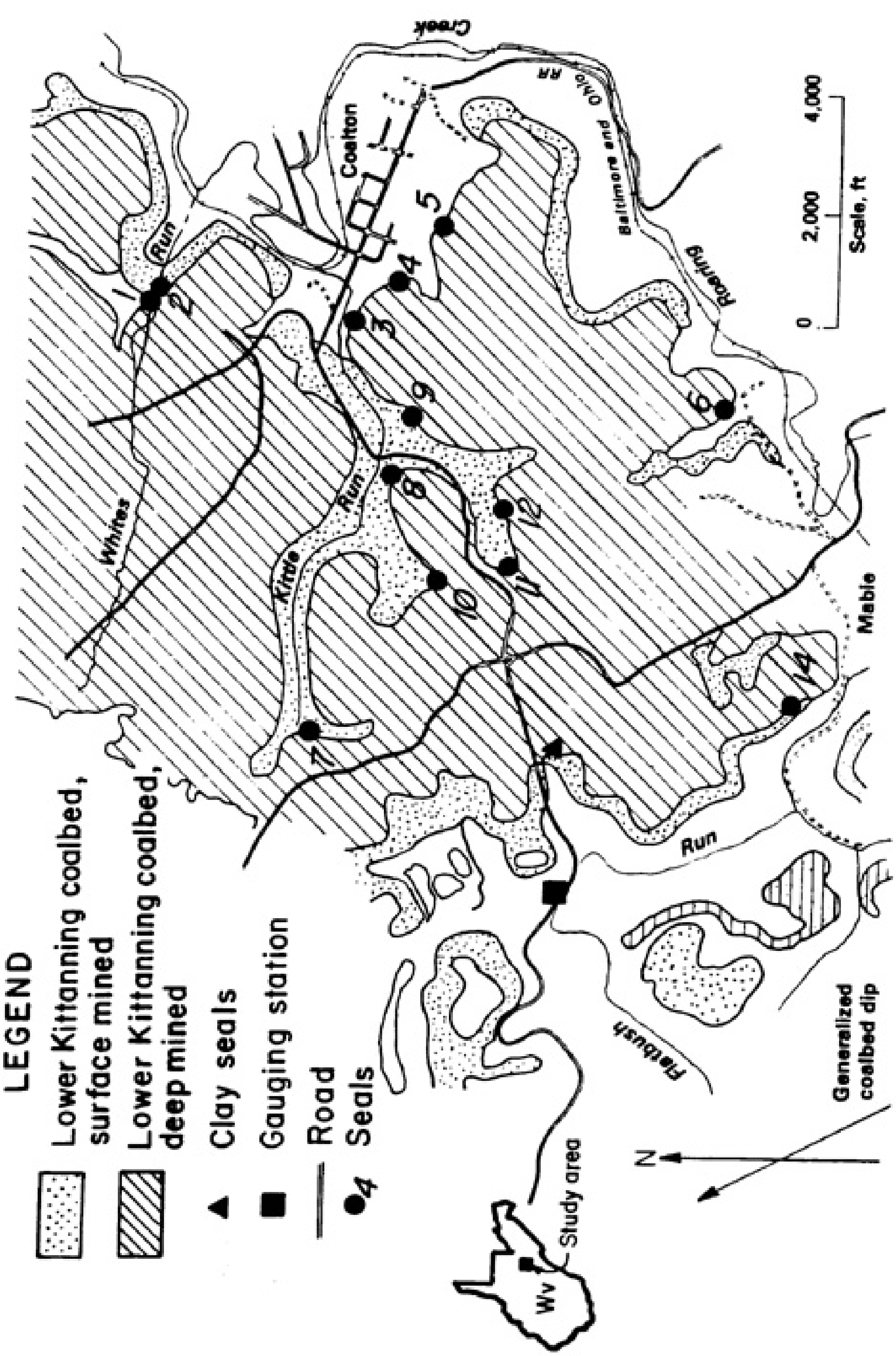

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FIGURE 1. Locations of mine seals in Elkins study area (6).

The Roaring Creek Watershed is located in east central West Virginia near the eastern edge of the Appalachian Plateau. It is underlain by conglomerate, sandstone, shale, coal, and underclay of the Pennsylvanian-age Allegheny Formation and the undivided Kanawha/New River Formations.(1) The Kittanning Coalbed of the middle Allegheny Formation has been extensively surface- and underground-mined in the western half of the watershed. All of the mine seals comprising the Elkins Project were installed in 12,000 hectare pillared, drift mine and a smaller underground mine in the Kittanning Coalbed. Historically, these mines have been the source of large quantities of contaminated water. Before sealing, these mines were discharging over 11,000 kg of acidity (as $CaCO_3$ equivalent) per day into the Tygart River. (5)

The average sulfur content of the Kittanning Coalbed is low ranging from 0.6 to 0.8 percent. However, core logs of the overburden in the area show material with pyrite content up to 9.96 percent.(4) Therefore, the overburden has more potential for producing AMD than the coal itself and probably is the main source of pollutants.

Mine Seals

In an attempt to keep air from entering the underground mine, a plan for sealing part of the mining complex was developed by the agencies involved in the Elkins Mine Drainage Pollution Control Demonstration Project. The plan included the use of dry, wet, and clay seals. Dry sealing included filling areas of subsidence and blocking other openings. Wet seals, which allow water to exit the mine but prevent air from entering, were to be constructed at openings where water discharged. Clay was used to seal badly fractured areas.(4)

The dry and wet seals consisted of two courses of fly ash blocks which were covered with urethane foam to prevent deterioration by the acidic waters. Dry seals had one wall and wet seals were made of two or three walls. Two blocks were removed from the bottoms of the wet seals to allow water to pass. A typical block wet seal is shown in Figure 2. Clay seals consisted of compacting the clay against the openings.(4)

Sealing of the south section of the mined area started in July 1966 and ended September 1967. Dry seals were constructed at exposed headings and on the updip side of the mine. Water was redirected so it flowed toward the wet seals at the openings, and this resulted in increased flows at most openings.(6) Thirteen wet seals and forty-three dry seals were constructed in the 1,200 hectare mine and one additional wet seal (13) was installed in a small, isolated mine. In addition to wet mine seals, a badly fractured highwall area where strip mining intersected underground mine workings was sealed with clay.(5)

It is important to note that reclamation project in the Roaring Creek-Grassy Run watershed was not completed. The number of seals actually installed was only a fraction of what had been planned.

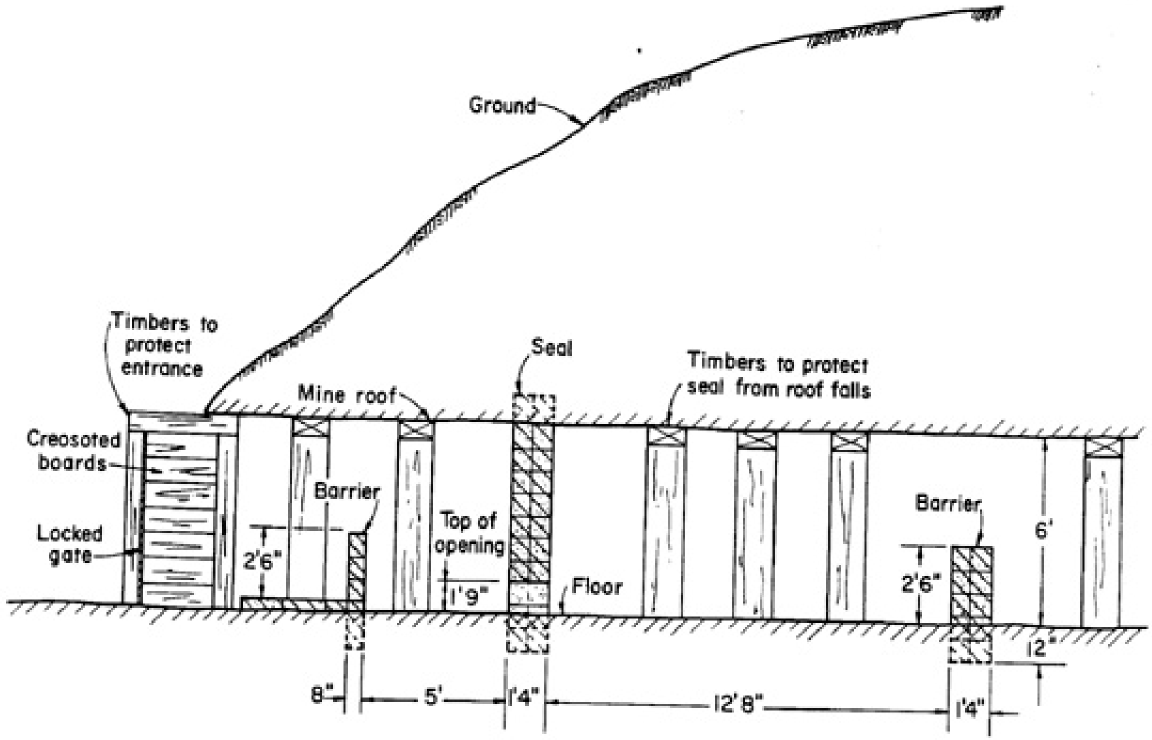

FIGURE 2. Cross section of a block wet seal (6).

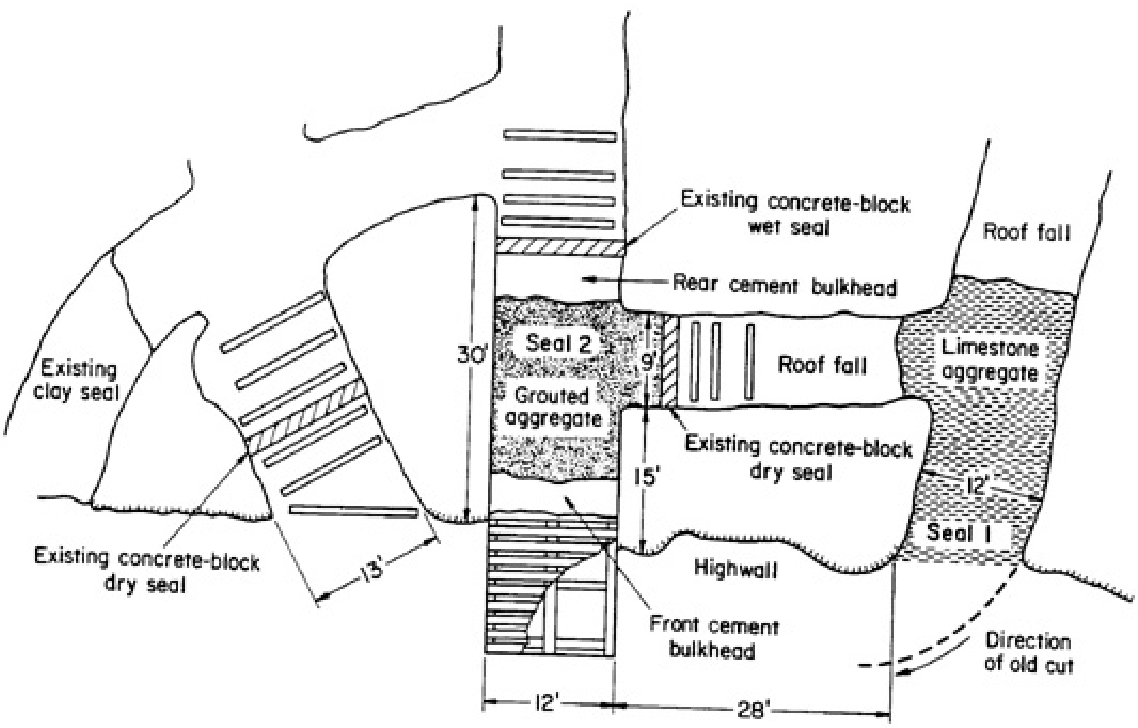

FIGURE 3. Cross section of seal 1, a permeable limestone seal, and seal 2, a double bulkhead hydraulic seal (6).

Data Collection

Data was collected quarterly between 1966 and 1971 and in most cases only the averages were reported.(4) The 1980 study included data gathered for the first three quarters of the year.(6) The 1990 study took place in the third quarter. All data is presented in Table 2.

CURRENT EVALUATION

The 1990 evaluation included flow measurements, chemical analyses and physical observations for each seal and its vicinity. Flow was taken at the weir when possible or immediately outside the seal if the mine could not be entered. All substantial flow in the near vicinity was also recorded. Comparisons of flow permit a quantitative assessment of water diversion through mine passages over time. Water samples collected at flow points in 1990 were analyzed for pH, acidity (as $CaCO_3$ equivalent), total iron, and manganese, and loads were calculated. The seal, the weir, and the internal and external construction were examined, and the response of these parts to weathering was also noted. The comparisons of these factors allows for a long-term evaluation of the each seal's ability to decrease pollutant loads as well as the physical soundness of the seal. This study includes pre-seal and post-seal data in an effort to determine each seal's effectiveness and durability over twenty-three years.

RESULTS AND DISCUSSION

The following is a description of the physical status, AMD flow, and water quality of each seal. Figure 1 is a map of the study area and locations of the seals. Table 2 contains complete water flow and quality data.

Seals 1 and 2 are located in adjacent entries. A block wet seal had been installed in entry 2 in 1967. (See Figure 3.) Two years later a double bulkhead seal was constructed in front of the existing wet seal. Subsequently, a seep developed in the adjacent opening (#1) due to pressure behind the seal. This entry was sealed with graded limestone. The purpose of this design was to force all exiting water through the limestone, and the resulting precipitates were intended to plug the seal.(4)

Seal 1 was covered by a highwall slide by the time of the 1980 report and the interior was not inspected for this 1990 study. There were two distinct seeps outside seal 1. About ninety-five percent of the flow occurred in the left seep. A smaller seep on the right contained yellowboy. Seal 2 appeared to be in a good structural condition in 1980 (6) and also in 1990. Flow from the opening was low. Iron precipitates appeared two to four meters in front of the seal. Flow for seal 2 has been recorded for each study year. In 1980, flow was recorded for both seals with 75% of flow exiting seal 2.(6) However, in 1990, the majority of water and pollutants exited seal 1. In order to compare with pre-seal data, results for 1980 and 1990 were flow weighted and the following data is presented for both seals. There was a decrease in total flow over time but the concentrations did not increase accordingly. The highest concentrations occurred in 1966 with the highest flows. Acidity went from 837 mg/L in 1966 to 305 mg/L in 1980 and 601 mg/L in 1990. Acidity load went from 291.7 kg/day in 1966 to 35.1 kg/day in 1990. Iron load decreased by 91 percent during this time with the majority of the decrease occurring by 1980. Manganese and pH were recorded only for 1980 and 1990 studies. Manganese concentration rose while load declined over ten years from 1.28 mg/L (0.2 kg/day) to 2.16 mg/L (0.1 kg/day) while the pH fell from 3.0 to 2.9.

TABLE 2. Water Quality Data for Selected Years for Each Mine Seal.

SEAL #	DATE*	FLOW (L/min)	pH	ACIDITY (mg/L)	Fe (mg/L)	Mn (mg/L)
1	1980-1	41.6	2.9	86.0	53.0	1.6
	1980-2	30.3	2.8	395.0	59.0	1.4
	1980-3	30.3	2.7	342.0	48.0	1.4
	1980-A	34.1	2.8	274.3	53.3	1.5
	1990-3	42.3	2.9	644.0	128.0	2.1
2	1966-A	242.0	NA	837.0	228.1	NA
	1980-1	125.0	3.2	341.0	62.0	1.2
	1980-2	136.0	3.0	304.0	46.0	1.1
	1980-3	87.1	2.7	297.0	44.0	1.4
	1980-A	116.0	3.0	314.0	50.7	1.2
	1990-3	5.2	2.9	251.0	23.8	2.7
3	1966-A	183.0	NA	217.0	9.4	NA
	1971-A	274.0	NA	164.0	2.7	NA
	1980-1	515.0	4.7	39.0	3.3	1.1
	1980-2	174.0	3.5	80.0	0.8	1.2
	1980-3	102.0	3.5	90.0	0.4	1.6
	1980-A	197.8	3.9	69.7	1.5	1.3
	1990-3	90.8	3.8	34.3	0.5	0.9
4	1966-A	204.4	2.9	219.0	7.6	NA
	1980-1	519.0	3.2	116.0	3.4	1.3
	1980-2	167.0	3.2	179.0	3.0	1.5
	1980-3	37.9	3.1	182.0	3.2	1.8
	1980-A	241.3	3.2	159.0	3.2	1.5
	1990-3	59.6	3.3	133.0	2.4	1.5
5	1966-A	32.3	2.6	712.0	80.0	NA
	1971-A	75.3	NA	388.0	NA	NA
	1980-1	98.4	3.2	225.0	16.7	2.4
	1980-2	56.8	2.9	388.0	21.0	2.7
	1980-3	8.7	2.8	371.0	24.0	3.3
	1980-A	54.6	3.0	328.0	20.6	2.8
	1990-3	2.2	2.9	300.0	15.7	2.5
6	1966-A	143.8	3.5	37.0	1.0	NA
	1980-1	238.0	5.5	11.7	0.1	0.1
	1980-2	140.0	5.7	4.6	0.1	0.2
	1980-3	64.3	5.6	3.8	0.1	0.1
	1980-A	147.4	5.6	6.7	0.1	0.1
	1990-3	93.5	6.5	31.2	0.1	0.1
7	1966-A	231.0	2.5	1942.0	434.5	NA
	1971-A	360.0	2.6	1060.0	291.3	NA
	1980-1	670.0	2.9	564.0	112.0	3.8
	1980-2	167.0	2.7	606.0	120.0	4.6
	1980-3	159.0	2.6	692.0	137.0	6.6
	1980-A	332.0	2.7	620.7	123.0	5.0
	1990-3	39.0	2.7	893.0	161.0	12.5
8	1980-1	189.0	3.2	341.0	48.0	1.4
	1980-2	28.4	2.8	550.0	67.0	1.8
	1980-3	9.5	2.7	688.0	105.0	2.4
	1980-A	75.6	2.9	526.3	73.3	1.9
	1990-3	0.8	2.8	409.0	49.0	1.7
9	1966-A	1501.0	NA	307.0	25.3	NA
	1971-A	1533.0	NA	186.0	10.1	NA
	1980-1	2456.0	3.4	82.0	3.5	0.7
	1980-2	1283.0	3.2	122.0	3.3	0.8
	1980-3	515.0	3.0	142.0	4.2	1.1
	1980-A	1418.0	3.2	115.3	3.7	0.9
	1990-3	673.4	3.3	66.6	2.0	0.7
10	1966-A	53.8	2.3	1958.0	465.0	NA
	1971-A	360.0	2.6	1117.0	343.7	NA
	1980-1	640.0	2.8	652.0	126.0	3.2
	1980-2	291.0	2.7	707.0	130.0	2.9
	1980-3	185.0	2.6	723.0	140.0	2.9
	1980-A	372.0	2.7	694.0	132.0	3.0
	1990-3	72.7	2.7	708.0	128.0	2.4
11	1966-A	221.0	NA	977.0	117.2	NA
	1971-A	360.0	NA	601.0	NA	NA
	1980-1	151.0	2.9	561.0	117.0	1.6
	1980-2	159.0	2.7	764.0	154.0	1.8
	1980-3	49.2	2.6	1298.0	282.0	2.8
	1980-A	119.7	2.7	874.3	184.3	2.1
	1990-3	26.1	2.7	781.0	165.0	1.5
12	1966-A	124.0	NA	264.0	NA	NA
	1971-A	53.8	NA	2222.0	NA	NA
	1980-1	75.7	2.9	1724.0	439.0	2.4
	1980-2	56.8	2.5	2523.0	639.0	3.6
	1980-3	15.1	2.3	5036.0	1253.0	6.2
	1980-A	49.2	2.6	3094.3	777.0	4.1
	1990-3	96.9	2.7	973.0	231.0	1.9
13	1966-A	48.4	2.8	591.0	NA	NA
	1971-A	91.5	3.1	275.0	58.0	NA
	1980-1	117.0	3.8	94.0	18.5	7.6
	1980-2	64.3	3.6	139.0	10.2	7.9
	1980-3	34.1	3.1	116.0	13.2	8.5
	1980-A	71.8	3.5	116.3	14.0	8.0
	1990-3	45.4	3.3	73.3	15.2	5.7
14	1966-A	98.4	NA	245.0	22.0	NA
	1980-1	235.0	4.0	31.0	0.4	0.5
	1980-2	117.0	3.8	55.0	0.6	0.6
	1980-3	45.4	3.8	80.0	0.9	0.6
	1980-A	132.5	3.9	55.3	0.6	0.6
	1990-3	51.6	5.9	28.5	0.2	0.1
Gauging Station	1966-1	4247.0	3.3	155.0	4.0	NA
	1966-2	3785.0	3.2	146.0	3.0	NA
	1966-3	901.0	3.0	228.0	6.0	NA
	1966-4	3278.0	3.3	146.0	6.0	NA
	1966-A	3052.8	3.2	168.8	4.8	NA
	1971-1	5129.0	3.8	44.0	3.0	NA
	1971-2	2055.0	3.5	70.0	2.7	NA
	1971-3	5284.0	3.5	103.0	1.5	NA
	1971-4	2752.0	3.6	111.0	12.0	NA
	1971-A	3805.0	3.6	82.0	4.8	NA
	1980-1	1570.0	3.7	31.0	0.6	3.1
	1980-2	980.0	3.3	49.0	0.9	3.3
	1980-3	348.0	3.2	38.0	0.9	4.2
	1980-A	966.0	3.4	39.3	0.8	3.5
	1990-3	1393.0	6.4	31.1	1.9	3.1

* DATE KEY. 1966: A = Average of quarterly sampling. (4)
1971: A = Average of quarterly sampling. (4)
1980: A = Average of three samples. (6)
1 = Sampled March 27 - April 23.
2 = Sampled July 16-17.
3 = Sampled October 15-16.
1990: 3 = Sampled September 24-27.

Seal 3 is a block wet seal and is in good physical condition as of the 1990 survey. The interior had some material spalling from the right rib. A room to the left of the entrance contained the weir which was in good condition with no noticeable AMD precipitates. The water level in the mine was one meter high behind the wooden barricade, and water exiting did not shows signs of yellowboy. Four years after sealing, the flow increased and pollutant concentrations decreased. By 1980, flow returned to its pre-seal value while the concentrations of contaminants had decreased. Both parameters had decreased again by 1990. Acidity concentration and load dropped from 217 mg/L and 57.2 kg/day in 1966 to 69.7 mg/L and 20.7 kg/day in 1980. These further decreased to 34.3 mg/L and 4.5 kg/day in 1990. Iron loads also decreased with values of 2.48 kg/day, 0.9 kg/day, and 0.1 kg/day for 1966, 1980, and 1990 respectively. Manganese decreased from 1.3 mg/L (0.5 kg/day) in 1980 to 0.9 mg/L (0.1 kg/day) in 1990. The pH stayed in the 3.8-3.9 range in 1980 and 1990.

Seal 4 was built in a heavily subsided area known as the Coalton School Strip where spoil was buried. Four 4-inch plastic drainpipes were placed in a hole above the seal's opening to control head pressure behind the seal. A wooden shelter was constructed to protect the pipes.(4) The shelter is still standing as well as the pipes but only one pipe was open to flow, which was very low. The majority of the flow was seeping to the left of the wooden structure, probably from the seal. A smaller seep (<4 L/min) was located about twenty yards down the hill from the pipes. Recent flow from the major seep was lower than any previous measurements. Acidity concentration gradually decreased from 219 mg/L in 1966 to 159 mg/L in 1980 and 133 mg/L in 1990. The acidity load also dropped with values of 64.5 kg/day, 46.5 kg/day, and 11.4 kg/day for the respective years. Iron concentrations and loads decreased over time from highs of 7.6 mg/L (2.2 kg/day) in 1966 to 3.2 mg/L (1.1 kg/day) in 1980 and 2.4 mg/L (0.2 kg/day) in 1990. Manganese concentration remained at 1.5 mg/L from 1980 to 1990 with a decreased flow. The pH changed slightly from 2.9 in 1966 to 3.2 in 1980 and 3.3 in 1990.

Seal 5 is a wet seal. The portal area has experienced several falls and was not entered. There was no mention of falls in 1980 report so these must have occurred in the past decade. Flow increased 40 percent after sealing to 54.6 L/min then showed a sharp decrease in the 1990 sample period with a value of 2.2 L/min (Figure 4). Acidity dropped off from 712 mg/L to 328 mg/L in 1980 and remained about the same in 1990 with a concentration of 300 mg/L. Iron concentration showed the same trend with a pre-seal value of 80 mg/L which decreased to 20.6 mg/L and 15.7 mg/L in 1980 and 1990. Manganese concentrations of 2-3 mg/L have not changed in the past decade. The pH increased from 2.6 in 1966 to 3.0 in 1980 and was 2.9 in 1990.

Due to lack of space, Seal 6 was built differently than the other wet seals. Only one wall was built and two 20-ft lengths of 4-inch plastic pipe were placed through the wall. A 90 degree elbow with a short standpipe was situated on the outside end of each pipe to serve as air locks.(4)These pipes had broken off by the time of the 1980 report but the water had pooled high enough to keep air out.(6) This seal was not entered during our study but the water was still pooled inside the seal. The interior structure of the seal appeared to be in good condition. Flow remained relatively constant between 1966 and 1980 with a reading of about 150 L/min. The flow was measured in 1990 at 93.5 L/min. The acidity concentration in 1966 was only 37 mg/L then dropped to 6.7 mg/L in 1980 and was measured as 31.2 mg/L in 1990. Acidity loads were 7.7 kg/day, 1.8 kg/day, and 4.2 kg/day for the respective years. Iron concentrations remained low over time with a 1.0 mg/L value in 1966 which dropped to 0.1 mg/L in 1980 and 1990. The pH showed a drastic increase from 3.5 in 1966 to 5.6 in 1980 and 6.5 in 1990.

Seal 7 is located at the end of Kittle Run. The mine opening was in poor condition as it was partially caved. Inside, the right coal rib and roof were caved to the extent that daylight could be seen. The weir may have been leaking but appeared to be in good shape except for some white precipitate buildup. The two openings at the base of the seal were blocked or partially blocked by precipitate or rocks, limiting flow. Flow increased from a 1966 reading of 231 L/min to 360 L/min in 1971 and then decreased to 332 L/min in 1980 and 39 L/min in 1990 (Figure 5). Acidity fell from 1942 mg/L (646 kg/day) in 1966 to 1060 mg/L (550 kg/day) in 1971 and 620.7 mg/L (283 kg/day) in 1980. The 1990 acidity values were 893 mg/L (50.2 kg/day). Iron also had an overall decrease from 434.5 mg/L (145 kg/day) in 1966 to a 1990 value of 161 mg/L (9.0kg/day). Manganese was recorded only in the last two studies as 5.0 mg/L (2.1 kg/day) in 1980 and 12.5 mg/L (0.7 kg/day) in 1990. The pH increased from a 1966 value of 2.5 to 2.7 in 1980 and 1990.

Seal 8 was in good exterior shape as the cover boards were difficult to remove and timbers were very sturdy. There were two small leaks or streams near the bottom of the weir wall and no flow over the weir. A white precipitate was observed on the roof. Flow decreased since the 1980 average of 75.6 L/min to less than 1 L/min in 1990. Acidity dropped from 526 mg/L (41.6 kg/day) to 409 mg/L (0.5 kg/day) from 1980 to 1990. Iron fell to a 1990 value of 49.0 mg/L (.06 kg/day) from 73.3 mg/L (5.7 kg/day) in 1980. Manganese held steady at an average 1.8 mg/L for both studies while the pH remained about 2.9.

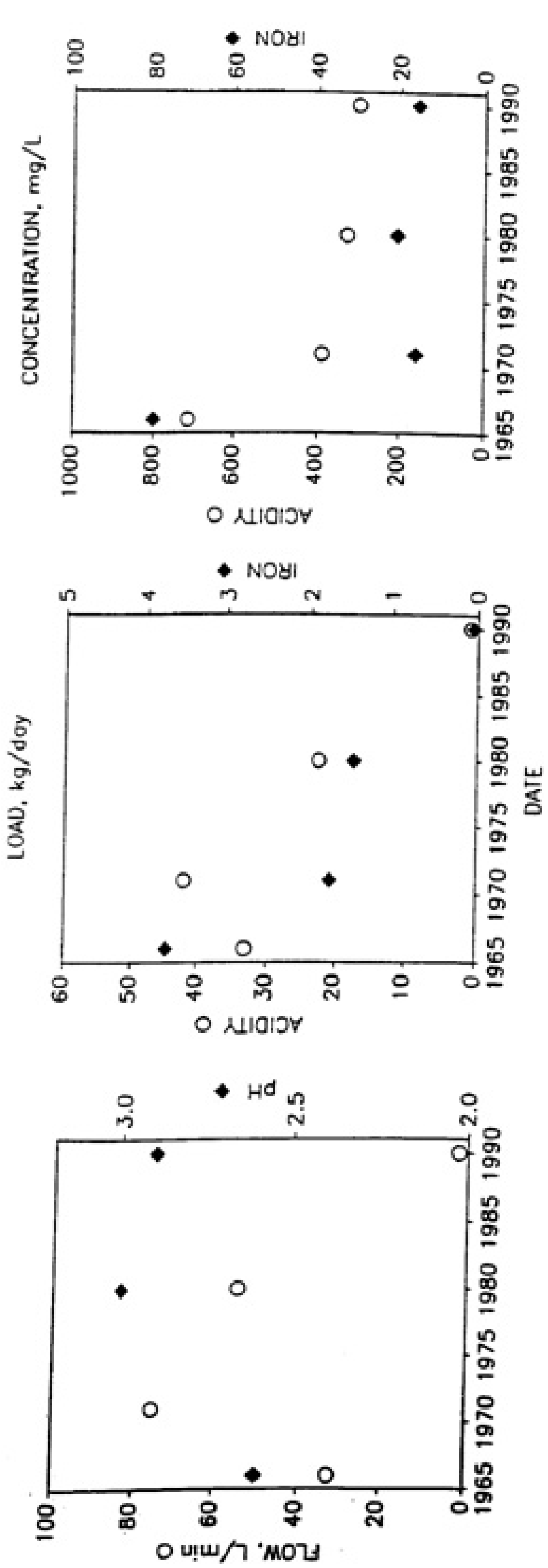

FIGURE 4. Flow, pH, acidity and iron concentrations and loads for seal 5 in 1966, 1971, 1980, and 1990.

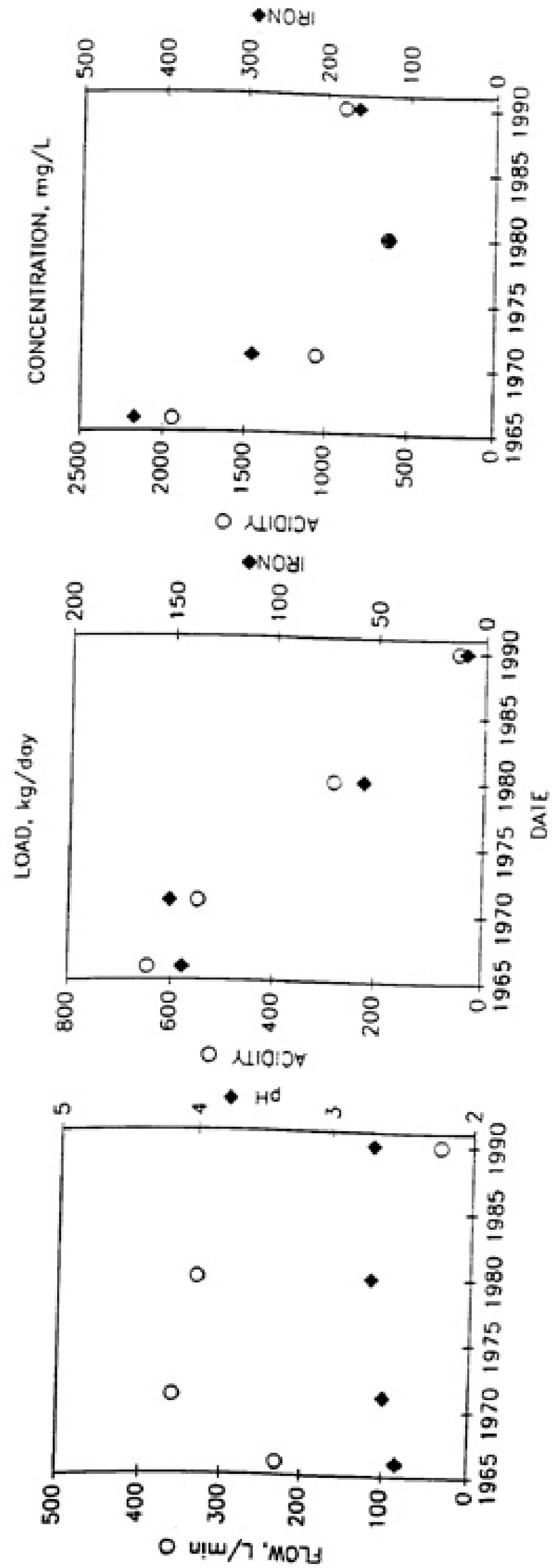

FIGURE 5. Flow, pH, acidity and iron concentrations and loads for seal 7 in 1966, 1971, 1980, and 1990.

Seal 9 had an extensively boarded opening and was not entered. The exterior timbers were beginning to show deterioration and may require replacement in 5-10 years. The square notch weir was intact **and had** white precipitate buildup. The flow was approximately 1500 L/min for 1966 and 1971 and dropped to 1418 L/min in 1980 and 673.4 L/min in 1990. Acidity dropped from 307 mg/L (664 kg/day) before sealing to 186 mg/L (411 kg/day) in 1971. In 1980, the acidity concentration had fallen to 115.3 mg/L (207 kg/day) and then to 66.6 mg/L (64.6 kg/day) in 1990. Iron was reduced by 60 percent between 1966 and 1971 from 25.3

mg/L (54.7 kg/day) to 10.1 mg/L (22.4 kg/day). Iron continued to drop to 3.7 mg/L in 1980 and 2.0 mg/L in 1990 with loads of 7.2 kg/day and 1.9 kg/day respectively. Manganese has remained at 0.8 mg/L since 1980. The pH has not significantly changed (3.2-3.3) between 1980 and 1990.

Seal 10 was installed at the head of a hollow and access was difficult. There were no boards over the opening. Timbers inside indicated a cave-in and no weir was observed. Flow was measured at the entrance and also at a location approximately 100 yards northeast of the seal. The discharge there appeared to be intermittent. Flow increased from 53.8 L/min before sealing to 360-375 L/min in 1971 and 1980 then returned to near the pre-seal level in 1990 with a reading of 72.7 L/min. As acidity levels decreased, acidity loads greatly increased, due to larger flows, from a 1966 value of 152 kg/day to 579 kg/day in 1971 and 363 kg/day in 1980. The 1990 acidity value was comparable to the 1980 value (700 mg/L), but with the decreased flow a smaller load of 74 kg/day was produced. Iron concentrations in 1980 and 1990 were also similar (130 mg/L) and show considerable decreases from values of 465 mg/L in 1966 and 343.7 mg/L in 1971. Iron load followed the same trend as the acid load with an increase from 36 kg/day before sealing to 98 kg/day in 1971 and 69 kg/day in 1980. In 1990, the load was 13.4 kg/day. The manganese level in 1980 was 3.0 mg/L and decreased to 2.4 mg/L in 1990. The pH showed a small increase from 2.3 to 2.7 from 1966 to 1990.

The interior of seal 11 was not investigated because of a large number of cave-ins. This seal was located at the head of a stream. The flow had increased from 221 L/min in 1966 to 360 L/min in 1971 and then decreased to 119.7 L/min in 1980 and 26.1 L/min in 1990. The acidity load significantly diminished to 29 kg/day in 1990. Pre-seal and 1971 loads were about 160 kg/day and the 1980 load was 130 kg/day. Acidity concentrations fluctuated from 977 mg/L in 1966 to 601 mg/L in 1971 and then increased to 874 mg/L before decreasing to 708 mg/L in 1990. Iron concentrations ranged from 100-200 mg/L. Before sealing, the iron load was 37 kg/day and decreased to 27 kg/day in 1980 and has since dropped to 6.2 kg/day in 1990. Manganese dropped from 2.1 mg/L to 1.5 mg/L and the pH remained at 2.7 since 1980.

Seal 12 was in good shape overall. Timbers and roof supports seemed to be in excellent shape as did the shale roof. The floor was very muddy and consisted of clay, iron precipitate, and manure since cows use the opening f or shelter. The weir needed some cleaning but was in good shape. The holes at the base of the seal were not blocked and water ponded between the seal and weir. Investigation of the area led to the discovery of several large sinkholes which could allow air into the mine. The flow has been below the pre-seal value of 124 L/min since 1971 and remained at about 50 L/min until the increase to 96.9 L/min in 1990. The acidity value and load drastically increased from 264 mg/L and 47.1 kg/day in 1966 to 2222 mg/L and 172 kg/day in 1971. The acidity continued to increase to 3094 mg/L (168 kg/day) in 1980 before decreasing to 973 mg/L (135.8 kg/day) in the 1990 study. Iron concentration and load, which were reported only for 1980 and 1990 studies, followed the same trend and were reduced from 77 mg/L and 43 kg/day in 1980 to 231 mg/L and 32 kg/day. Manganese load was reported as 0.25 kg/day for 1980 and 1990. The pH decreased from a pre-seal 2.9 to 2.7 in 1990.

Seal 13 was built in the entrance of a small, isolated mine. An attempt was made to seal all openings. This was not entered due to the iron precipitate which filled the opening half way to the roof. The weir could not be seen and the only structure visible was the back wall. The exterior was in good condition. Flow was measured by a drainage pipe about 100 feet downstream. Flow increased after sealing to 91.5 L/min in 1971 and 71.8 L/min in 1980 but returned to the 1966 value of about 45 L/min in 1990 (Figure 6). Although pre-seal (1966) and 1990 flows were similar, acidity values fell from 591 mg/L to 73.3 mg/L and acidity load from 41.2 kg/day to 4.8 kg/day. The iron concentration was 58 mg/L in 1971 but has decreased to 14-15 mg/L for 1980 and 1990. Iron load went from 7.6 kg/day to 1.6 in 1980 and 1.0 in 1990. Manganese was reduced from 8.0 mg/L (0.8 kg/day) in 1980 to 5.7 mg/L (0.4 kg/day) in 1990. The pH increased from a 1966 value of 2.8 to 3.3 in 1990.

The interior wooden beams and weir of seal 14 were in good condition. The water openings in the back wall were clear of debris. The exterior was also in good shape. The flow increased from 98.4 L/min in 1966 to 132.5 L/min in 1980 and was 51.6 L/min for the 1990 reading. Acidity experienced a large drop from 245 mg/L (34.7 kg/day) before sealing to 55.3 mg/L (8.3 kg/day) and 28.5 mg/L (2.1 kg/day) for 1980 and 1990 respectively. Iron also showed a considerable decrease from 22 mg/L (3.1 kg/day) in 1966 to acceptable levels of 0.6 mg/L (0.1 kg/day) in 1980 and 0.2 mg/L (0.01 kg/day) in 1990. Manganese concentration dropped from 0.6 mg/L in 1980 to 0.1 mg/L ten years later. The pH was recorded for the last two studies only and had risen from 3.9 in 1980 to 5.9 in 1990.

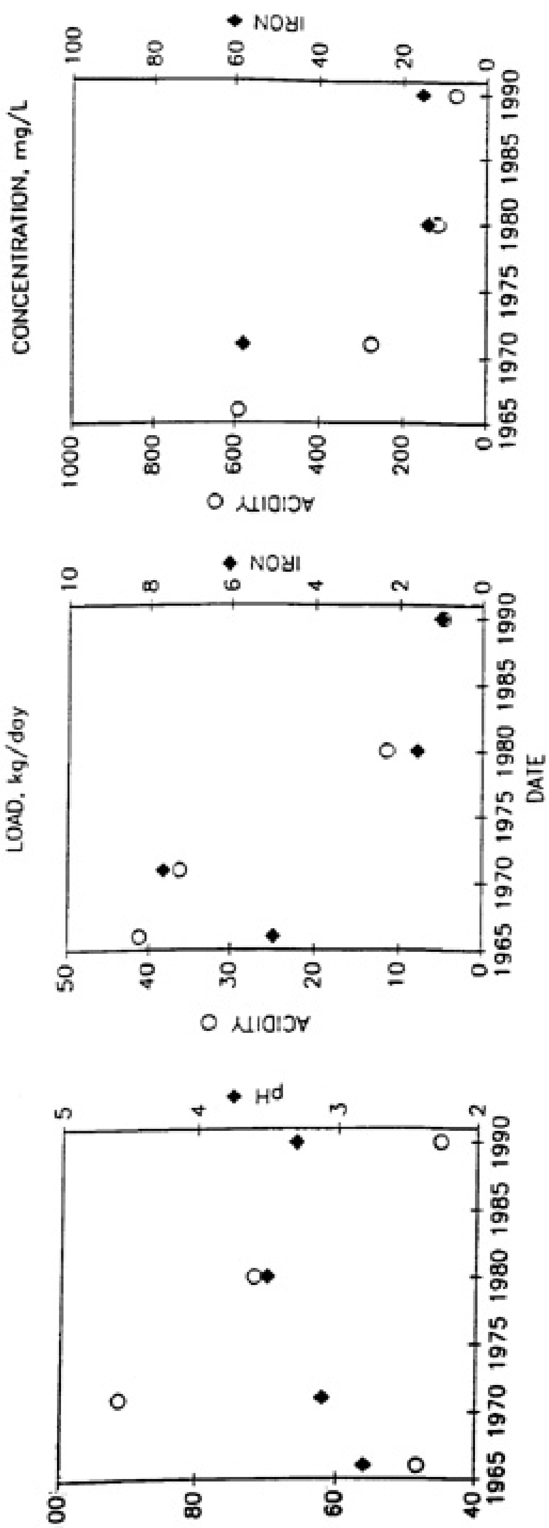

FIGURE 6. Flow, pH, acidity and iron concentrations and loads for seal 13 in 1966, 1971, 1980, and 1990.

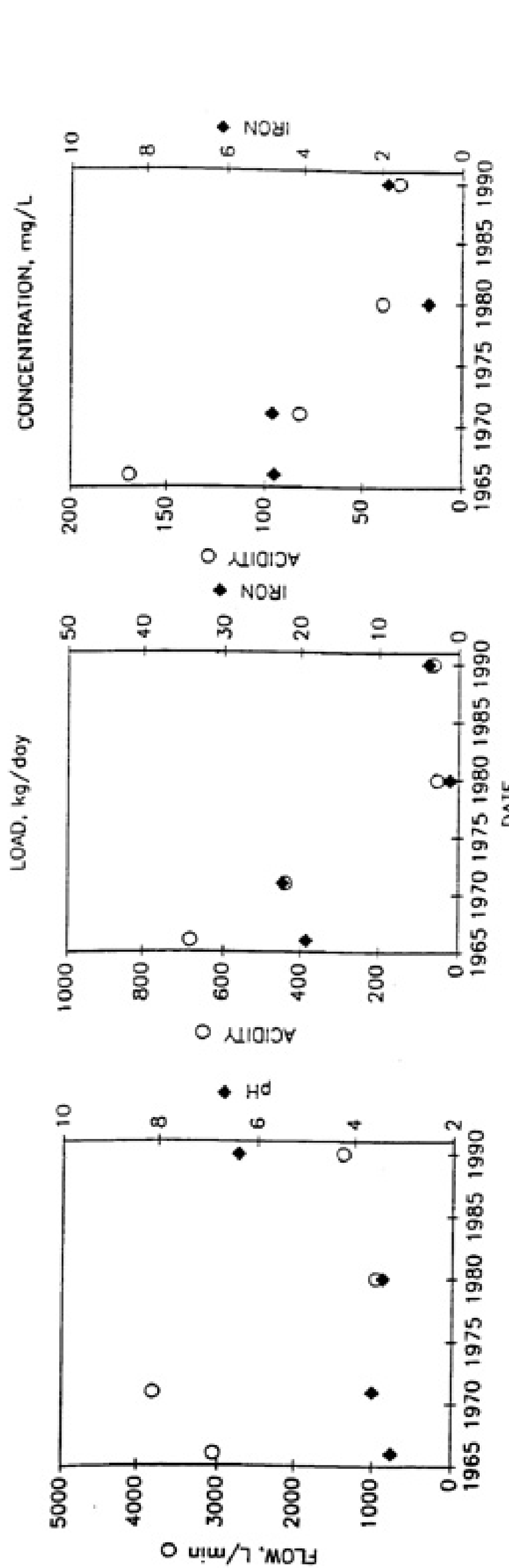

FIGURE 7. Flow, pH, acidity and iron concentrations and loads for the gauging station in 1966, 1971, 1980, and 1990.

Erosion control measures were taken in 1968 in the clay seal area at which time seepages were found at the base of the seal area. The area affected by the seepage was several acres

(6) and has not significantly increased since. The clay seals are still leaking. A small pond is located downstream of the clay seals and is inhabited by plants. The pH of the seep was 2.6 in 1980 and 3.1 in 1990. The pond effluent also increased pH from 2.7 to 3.3 between 1980 and 1990.(6)

The gauging station is located on the northern branch of Flat Bush Run, a major tributary of Roaring Creek. The effluent from seal 13 f lows into the stream on which the station is located. One quarter of the Flat Bush watershed land had been surf ace mined, and all mined land was reclaimed and revegetated.(6) Flow at this point has always been high with annual averages between 3800-4300 L/min during 1966-71 (Figure 7). The reading in 1990 was 1393 L/min, an increase of 30 percent from the 1980 value of 966 L/min. Acidity has gradually decreased over time with 169 mg/L (682 kg/day) in 1966, 82 mg/L (439 kg/day) in 1971, 39.3 mg/L (52.7 kg/day) in 1980, and 31.1 mg/L (62.4 kg/day) in 1990. Iron concentration went from highs in 1966 and 1971 of about 4.8 mg/L to 0.8 mg/L in 1980 and 1.9 mg/L in 1990. Manganese concentrations were 3.5 mg/L in 1980 and 3.1 mg/L in 1990 with a 26 percent increase in load. This location had the highest pH for all field samples with a 1990 measurement of 6.4, compared to a reading of 3.3 for pre-sealing and 3.4 in 1980.

Although most seals experienced decreased flows over time, as well as decreased concentrations and loads,, several other trends were observed. Figures 4 through 7 show flow, pH, and acidity and iron concentrations and loads for 1966-1990 for seals 5, 7, 13 and the gauging station. Figure 4 shows flow decreased for seal 5 but acidity and iron concentration remained steady from 1971 to 1990. Figure 5 reflects decreasing flow for seal 7 since 1971, with decreasing acidity and iron concentrations, except for 1990 when slight increases were recorded. Loads have steadily declined since sealing. Flows for seal 13 in 1966 and 1990 were comparable as Figure 6 shows. However, pH had increased in 1990 and acidity concentration and load and iron load had greatly decreased. Gauging station results are shown in Figure 7. Flow and iron concentration display a variable pattern. Acidity, however, has slowly declined over time, regardless of the flow. The seals have had different effects on the discharge at each location with unpredictable results in most cases.

SUMMARY

The majority of the wet seals' exteriors were in good shape. Timbers were sturdy and showed signs of normal weathering. Most portals had vegetation immediately outside the opening and downstream. Four seals experienced internal cave-ins and some had minor slides. Timbers inside seals were generally in good condition. As for the actual seal, cement walls showed no sign of failure or major leakage. Holes at the base of a few seal walls were blocked causing reduced f low. The weirs held up well and only a few small leaks from weir walls could be noted. A moderate amount of precipitate build-up was found in several weirs but could easily **be cleaned and did not affect** the flow. Ponding of water for several feet between the weir and exit was normal as was the iron precipitate in the ponded water, which ranged from several inches to a few feet deep. In general, plumbing did not fare well as pipes had broken off or had become clogged and no longer served their original purposes. Overall, the seals were constructed well but can not be expected to escape cave-ins or slides. They held up well to typical weathering.

The highest flows occurred immediately after sealing in 1971 although rainfall was below normal for this year. Water was originally diverted so as to exit through the seals but the decreases in flow since 1971 show these diversions have not been effective over time. Flow from all seals decreased between 1971 and 1980 and was drastically reduced at several seals by 1990. Therefore, water must be currently diverted through other underground passageways or fractures. Concentrations and loads in 1971 were comparable to those in 1966, and then they tended to decrease by 1980 and 1990. A few 1990 flows are comparable to 1966 values with lower concentrations in 1990. In only a few cases has any load increased since the 1971 report. The majority of pollutants may have been flushed out with high flows in the early years as even similar flows in recent years have not produced loads comparable to those in 1966 or 1971.

Most pH values increased slightly over time and three locations showed significant pH increases. of these, seals 6 and 14 showed decreases in acidity and flow, but the gauging station had increased flow since 1980 as well as increased acidity, sulfate, and iron loads. There was also a significant amount of calcium in the gauging station water. There may be alkaline water mixing with the AMD because dilution alone can not explain the 3 unit change in pH.

CONCLUSIONS

At first glance, it seems the seals have effectively lowered the amount of acid and iron exiting the mines since they were sealed. However, the data that has been presented in Table 2 can only be considered a glance into the actual lifetime of the seals and the water. Unknown factors such as the paths of water flow through the underground workings and the existence of unsealed areas where air may enter or water escape prevent an accurate appraisal of water quality results based solely on the seals. Additionally, decreases in concentrations and loads can not necessarily be attributed to the seals since no monitoring was performed on unsealed mines as a control. The reductions may be a natural phenomenon. Although many pollutant concentrations and loads have been lowered, the majority are still substantially above acceptable water quality levels of 7.0 mg/L for total iron, 4. 0 mg/L f or manganese, and a pH between 6. 0 and 9. 0. (7) The sealed portals generally had shallow cover and areas of subsidence are very common. This condition could allow air to enter the mine and defeats the purpose of the seal. Therefore, wet seals are not recommended for mines with shallow workings and overburden. The continued expulsion of pollutants could be due to the flushing of salts formed sometime ago, or pyrite oxidation may be currently occurring to some degree and may be responsible for all or part of the AMD quality. If the lone determining factor of the seals' effectiveness was the exclusion of air to prevent the formation of pollutants, it would be concluded the seals have not been successful. However, over time, pollutant levels have been reduced. Thus, the effect seals have had on water quality is inconclusive.

REFERENCES

1. Stream Pollution by Coal Mine Drainage in Appalachia. Federal Water Pollution Control Administration. Cincinnati, Ohio. Revised 1969.
2. Committee of Public Works, U. S. House of Representatives. "Acid Mine Drainage," 1962. House Committee Print No. 18, 87th Congress, Second Session. U. S. Government Printing Office: Washington, D.C.

3. Englund, K. J. Geologic Map of the Roaring Creek Area Randolph County, West Virginia. Investigations Map 1-577, 1969. USGS Miscellaneous Geologic
4. Industrial Environmental Research Laboratory, Resource Extraction and Handling Division. Elkins Mine Drainage Pollution Control Demonstration Project (U. S. EPA contract 68021321), ed. by PEDCO Environmental, Inc. EPA, Cincinnati, OH, EPA-600/7-77-090, Aug. 1977, 292 pp.
5. Scott, R. B., R. D. Hill, and R. C. Wilmoth. Cost of Reclamation and Mine Drainage Abatement- Elkins Demonstration Project. Pres. at Soc. Min. Eng. AIME Meeting, St. Louis, MO, Oct. 21-23, 1970, Soc. Min. Eng. AIME preprint 70-AG-349, pp. 3-20.
6. Adams, L. M., and J. R. Lipscomb. Evaluation of Mine Seals Constructed in 1967 at Elkins, Randolph County, WV. Bureau of Mines, RI-8852, 1984, 30 pp.
7. U.S. Code of Federal Regulations. Title 40 - Protection of the Environment; Chapter l -- Environmental Protection Agency; part 434--Coal Mining Point Source Category; Subpart E-Post-Mining Area; July 1, 1985.