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Evaluation of Mine Seals Constructed in 1967 at Elkins, Randolph County, WV

By Lester M. Adams and Jennings R. Lipscomb

UNITED STATES DEPARTMENT OF THE INTERIOR

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT AND SELECTED CONVERSION FACTORS

°C	degree Celsius	mg/L	milligram per liter
°F	degree Fahrenheit	mi^2	square mile
ft	foot	µmho/cm	micromho per centimeter
ft/mi	foot per mile	pct	percent
gal/min	gallon per minute	pH	hydrogen ion concentration
in	inch	yr	year
lb/d	pound per day		

To convert acres to hectares, multiply by 0.4047.

To convert feet to meters, multiply by 0.3048.

EVALUATION OF MINE SEALS CONSTRUCTED IN 1967 AT ELKINS, RANDOLPH COUNTY, WV

By Lester M. Adams[1] and Jennings R. Lipscomb[2]

ABSTRACT

In 1980, the Bureau of Mines surveyed a group of mine seals in Randolph County, WV, to evaluate their effectiveness for reducing toxic pollutants in mine water discharges. The survey focused on 11 block wet mine seals, but mine seals of several other types were also examined. The seals were installed in 1966 and 1967 in abandoned drift portals by the Federal Water Quality Administration (FWQA), a predecessor of the Environmental Protection Agency (EPA), in cooperation with the Bureau of Mines and other Federal and State agencies, in a project known as Elkins Mine Drainage Pollution Control Demonstration Project. The seals were designed to prevent air from entering the mine portals while allowing mine water to flow out. It was believed that by preventing air from entering inactive or abandoned mines, the formation of toxic pollutants and acid mine drainage (AMD) could be reduced.

Evaluation of the seals was based on water flow measurements, water analyses, and visual observations. The Bureau's 1980 data were compared with past data collected by the EPA. Several leaks and failures were observed in the clay seals, as evidenced by apparent blowouts and the absence of vegetation where the mine water surfaced. Analyses of the 1980 data indicated some improvement in the quality of water discharged from many of the wet air seals.

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INTRODUCTION

THE PROBLEM OF ACID MINE DRAINAGE

The coal mining operations which began in the Appalachian region many decades ago relied on hand labor. As a result, most of the entries into the coal seam were made on the downdip side of a hill, with mining progressing in an updip direction. Because of the upward slope of the workings, there was no need to pump water from the mine; water flowed from the work areas by gravity. Furthermore, coal haulage to the pit mouth and tipple was downgrade and therefore relatively easy. Underground mining from the drainage side of the coal seam and surface mining along the outcrop was widespread and produced great volumes of mine water from a large number of abandoned workings throughout the region.

Binders in a coal seam and accompanying rock strata contain iron sulfides which, when in contact with air and underground water, form acidic solutions that dissolve additional minerals and are then discharged as AMD. The water in the mine acts as a carrier and discharges the AMD into the receiving stream.

The pollutants from inactive and abandoned underground mines adversely affect the potential use of nearby streams and impoundments. AMD deteriorates receiving streams by increasing acidity, hardness, and dissolved and suspended solids contents. The dissolved ions in AMD are often found in such concentrations as to be harmful or even toxic to aquatic life (5).[3] A suggested method of eliminating or attempting to control the introduction of toxic pollutants into the mine discharge is to build airtight barriers or seals. The seals would prevent air (oxygen) from coming in contact with pyrite and other sources of toxic materials found in the remaining coal and adjacent rock strata after mining is completed.

[3]Underlined numbers in parentheses refer to items in the list of references preceding the appendixes.

In a demonstration of this method, the FWQA (now EPA) installed several types of air seals at abandoned coal mine workings near Elkins, WV. Based on studies and evaluation by the Bureau of Mines, this report updates the available data on the Elkins project and compares the Bureau's findings with the earlier EPA findings.

THE ELKINS PROJECT

By the late 1950's and early 1960's, AMD had become a major concern among persons interested in pollution abatement. In 1962, Congress requested that the Department of Health, Education, and Welfare (DHEW, now Department of Health and Human Services) undertake a study of water pollution caused by AMD. The study report analyzed the nature and scope of the AMD problem and recommended procedures for reducing it. Congress subsequently authorized a demonstration program of AMD control and delegated overall responsibility for the program to DHEW's Division of Water Supply and Pollution Control (DWSPC). By 1971, DWSPC evolved into the EPA. Among other groups participating in the program was the Bureau of Mines, whose responsibility was to investigate mine conditions, prepare surface maps, design control measures, plan for reclamation, and work with the EPA in awarding the construction contract.

Sealing of the mines and concurrent reclamation near Elkins was begun in July 1966 and terminated in September 1967. Disturbed areas were revegetated in the spring of 1968. Evaluation of the effectiveness of the mine sealing and reclamation measures is continuing, but all regular sampling at the project site was concluded in January 1972. As a follow-up to its previous involvement in the Elkins project, the Bureau surveyed the project area in 1980 to determine the condition of the seals and reclamation and to sample and analyze water discharged through the seals. The EPA-measured average reductions in acidity, iron, and sulfate after sealing were 51, 30, and 43 pct, respectively. The Bureau's 1980 findings showed further reductions: 80 pct (acidity), 85 pct (iron), and 69 pct (sulfate).

PURPOSE AND METHODOLOGY

The purpose of this study was to evaluate recent water flow and water quality data for 11 block wet air seals and 1 double bulkhead seal that now functions as an air seal and to compare these data with data previously collected and evaluated by the EPA (1, 4). Except for the double bulkhead seal, the seals had been in place for more than 12 yr at the time the Bureau collected its data.

The seal locations were visited during 1980 in early April, during "high flow"; mid-July, during "medium flow"; and mid-October, during "low flow." Samples and data taken at each site included a water sample for laboratory analyses and measurements of flow rate, pH, dissolved oxygen, conductivity, and temperature. Laboratory analyses included determinations of acidity, aluminum, calcium, ferrous iron, manganese, sulfate (SO_4) and total solids.

The available water quality data in the EPA final report (4) were limited mainly to flow, acidity, iron and sulfate concentrations, and in some cases pH. However, for two seals, additional measurements included specific conductance and calcium and aluminum concentrations.

INSTALLATION OF THE MINE SEALS

The mine seals evaluated in this study had previously been installed at a site located in the Norton-Coalton-Mabie area (Roaring Creek watershed) near Elkins, Randolph County, WV. The seals were constructed through a cooperative effort of the State of West Virginia, Bureau of Mines, U.S. Geological Survey, U.S. Fish and Wildlife Service, and the EPA (then DWSPC; later known as FWQA) as part of the Elkins Mine Drainage Pollution Control Demonstration Project. The Elkins project entailed construction of about 101 seals of various types, but only selected seals--primarily block wet air seals--were studied as part of the evaluation reported here. Block wet air seals were installed in a large mine complex and one was installed in a small mine complex. A gauging station had been established on a major tributary of Roaring Creek in the project area.

The air seals were designed to prevent air from making contact with the underground acid-producing materials in the remaining coal and adjacent strata. The air sealing was expected to prevent or reduce the oxidation of pyrite and prevent the formation of sulfuric acid and iron sulfate. When fully effective, an air seal prevents the inflow of air but permits the outflow of water (6). A discussion of the various methods of mine sealing is presented in appendix B.

In 1967, 11 wet seals were constructed in mine openings of a 2,965-acre underground mine complex and 1 wet seal was constructed in the opening of a small isolated underground mine. Not all openings of the large mine complex were sealed; the portals on the south section of the complex were sealed, but several on the north section were left open (4). (Over a period of time, roof collapse may have effectively sealed the north section openings, thereby at least reducing air movement in the mine.) Much of the south area was also backfilled, graded, and revegetated with forage crops and trees. A number of clay seals and block dry seals were installed where old headings had been exposed by contour stripping operations. Several dry seals (some block and some clay) were constructed on the updip side of the mine. Backfilling, grading, and clay sealing had stopped the seeps at the bases of the highwalls and at the tops of the outslopes and directed the waterflow to the controlled-flow openings at the wet seals located at the abandoned mine mouth. As a result of this redirection of waterflow, the flow rates at the seals were higher than they were prior to the seal installations. (Another reason higher flow rates were recorded after sealing was that the post-sealing measurements were more accurate than those taken before the seals were installed.)

The openings at the time of the construction were sufficiently sound and devoid of caving to permit construction of the seals. The locations of the seals are plotted on the Geological Survey topographic quadrangles (7.5' series) of Ellamore and Junior, WV, in figure 1.[4] Figure 2 shows the seal locations relative to the mined coalbeds in the area.

ANALYSIS OF COAL MINED IN THE AREA

The Upper, Middle, and Lower Kittanning Coalbeds are located in the Elkins project area. Since the coal rises to the south and east, the Upper and Middle Kittanning Coalbeds eventually pinch out in the upper reaches of the Roaring Creek watershed. All the seals surveyed for this study are located in the Lower Kittanning Coalbed.

Kittanning coal is ranked as high volatile A-bituminous with variable sulfur and ash content. Results of sampling of the Lower Kittanning coal profile at two locations in the Norton No. 2 Mine are presented in table D-1 (appendix D). The total thickness of the sampled bed sections ranged from 84 to 98 in. The floor consisted of clay, and the roof was

[4]The numbering system used by EPA to identify the seals was changed for this report; see cross-reference table in appendix E.

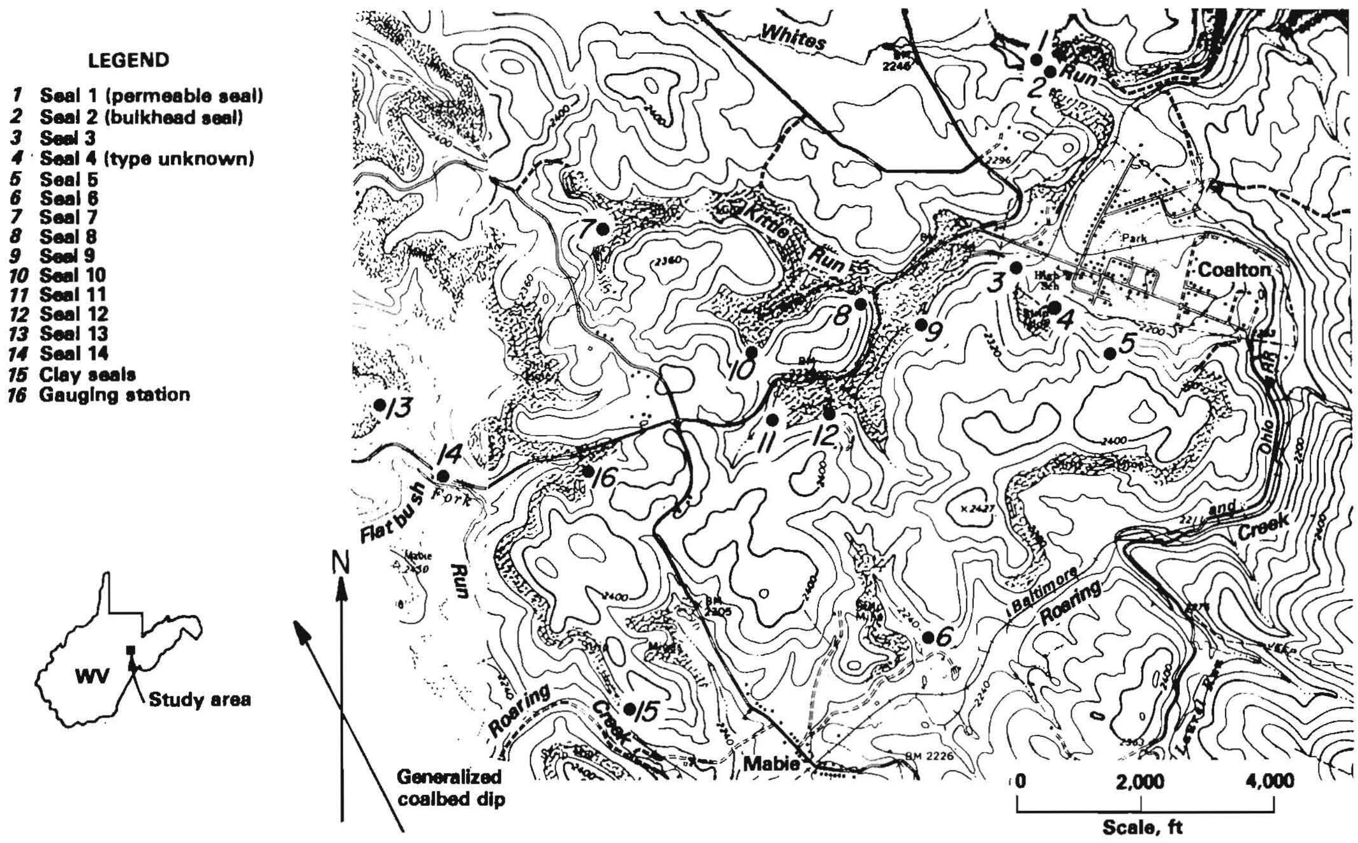

FIGURE 1. - Locations of selected Elkins area mine seals. (Except as noted in legend, all seals shown are block wet seals.)

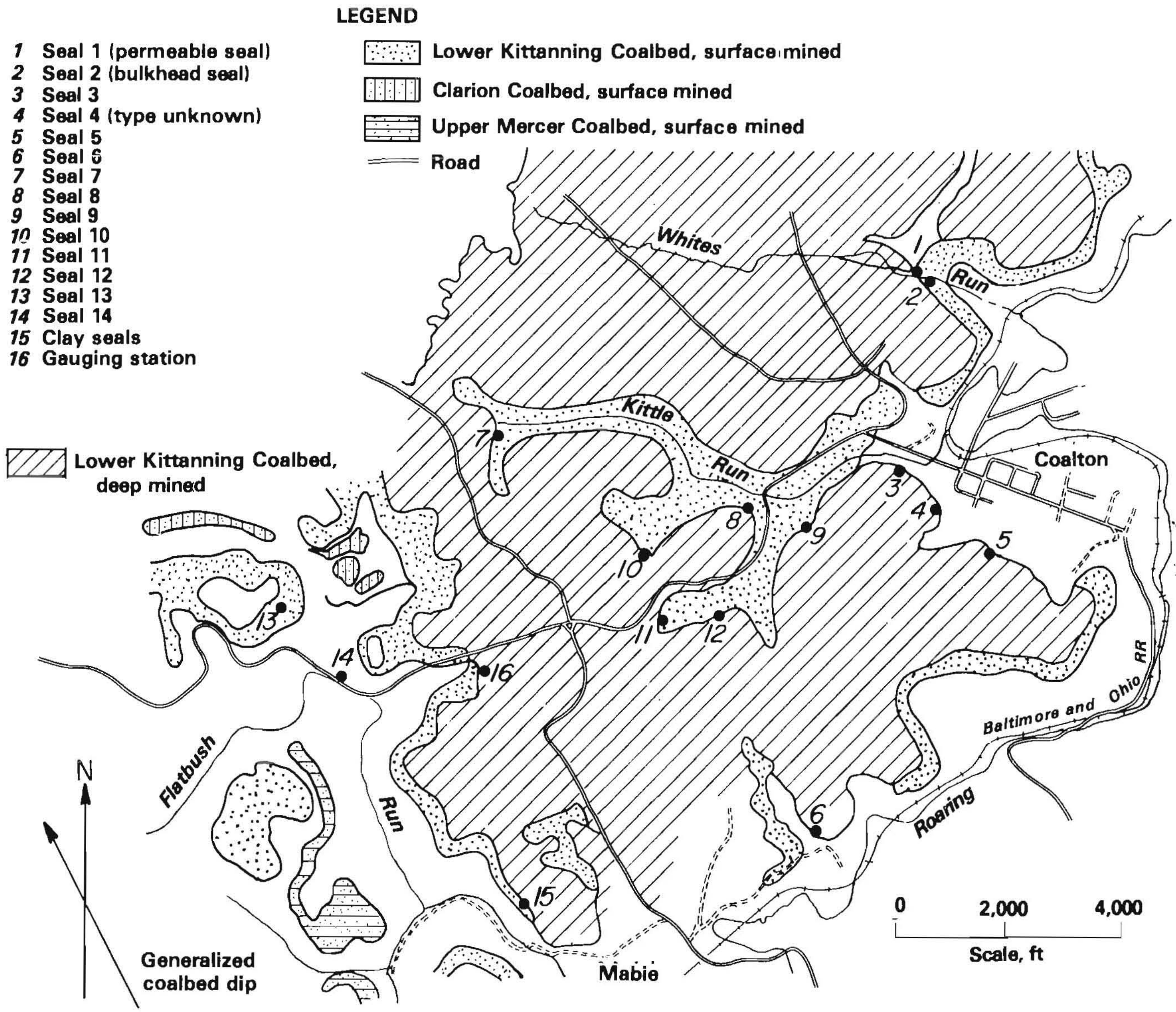

FIGURE 2. - Locations of selected Elkins area mine seals relative to mined coal seams. (Except as noted in legend, all seals shown are block wet seals.)

shale. The coal ash residue ranged from 9.4 to 11.7 pct, and the sulfur content ranged from 0.6 to 0.8 pct. Five supplemental samples were collected by the Bureau from various work areas (Upper, Middle, and Lower Kittanning) in early 1965. The analyses of these samples are presented in table D-2.

A general discussion of the hydrology, topography, and geology of the project site is included in appendix A.

COMPARISON OF DATA COLLECTED BEFORE AND AFTER SEALING

The results of the Bureau's laboratory analyses of the water samples collected in 1980, together with flow measurement and other field test data, are tabulated in table C-5. Bar graphs that show acidity and sulfate loading in pounds per day, based on average load, were plotted for all but two of the wet seals (figure C-1, appendix C). These graphs also show available data, based on EPA quarterly averages, for the years 1966 and 1968-71. When the Bureau collected its data in

1980, each of the seals had been in place approximately 12 yr.

The mine seals are discussed individually in the sections that follow, and for each seal (except the clay seals) a summary of the data collected before and after sealing is presented. For seals 7 and 10, the EPA reported water sample analyses (tables C-1 and C-2) which included more than the flow, acidity, and sulfate data summarized in figure C-1. Discussion of these additional data is included in the sections on seals 7 and 10. For seal 13, (the seal constructed at a small isolated mine) the EPA measured mine atmosphere oxygen content before and after sealing (table C-3); and these data are discussed in the section on seal 13. For the clay seals, which began to fail shortly after their installation, only observations of a general nature are presented. All but one of the wet seals, on which the highwall had collapsed, appeared to be in good condition in 1980.

The gauging station on the North Fork of Flatbush Run was reestablished by the Bureau. The flow and water quality of Flatbush Run were assumed to reflect not only the effect of the sealing on this portion of the watershed but also the effect of surface restoration which had been undertaken.

SEALS 1 AND 2

The location where seals 1 and 2 were installed was mined periodically from 1904 to 1950. It was first sealed with a block wet air seal in 1967. This seal was replaced 2 yr later by a double bulkhead (seal 2), which was constructed as follows: A rear barrier wall of quick-setting cement was placed in the opening; then 10 to 15 linear feet of limestone aggregate was put in front of the rear wall. Grout pipes were strategically placed in the aggregate and out through the front barrier wall of quick-setting cement, which was installed against the limestone aggregate. The aggregate section of the seal was then grouted through the grout pipes to fill voids in the stone and produce an impervious seal as shown in figure 3. However, as the head of water behind the seal increased, the pressure caused a seep nearby. Upon investigation, an adjacent opening was located which was found to be connected to the sealed opening by a short crosscut. A permeable limestone seal (seal 1) was constructed in this second opening by pneumatically placing graded limestone and fines into the opening and grouting the void area between the roof and limestone (4, p. 138).

When the Norton Field Office of the EPA was closed in 1971, the drain pipes under both seals were opened and left to drain freely. This prevented the buildup of a sizable hydrostatic head, which could have developed if the permeable seal had become clogged (1, p. 76). Both seals now function as air seals. Seal 2 appeared to be in good structural condition; seal 1 had been covered by a highwall slide and therefore could not be inspected.

Before sealing, the effluent from the seal 2 location showed concentrations of 837 mg/L[5] acidity, 105 mg/L iron, and 1,147 mg/L sulfate at a discharge flow rate of 64 gal/min (4, p. 110). In 1980, the flow from this seal was 31 gal/min, and chemical analyses indicated 314 mg/L acidity, 51 mg/L iron, and 475 mg/L sulfate in the effluent. These data indicate a 63-pct reduction in acidity, a 51-pct reduction in total iron, and a 58-pct reduction in sulfate during the more than 12 yr period (since installation of the original seal). For seal 1, the 1980 discharge flow rate was 9 gal/min, and the effluent contained 274 mg/L acid, 53 mg/L total iron, and 582 mg/L sulfate.

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[5]All data in the sections that discuss individual mine seals are arithmetic means derived from actual measurements. For more detailed data, see appendix C.

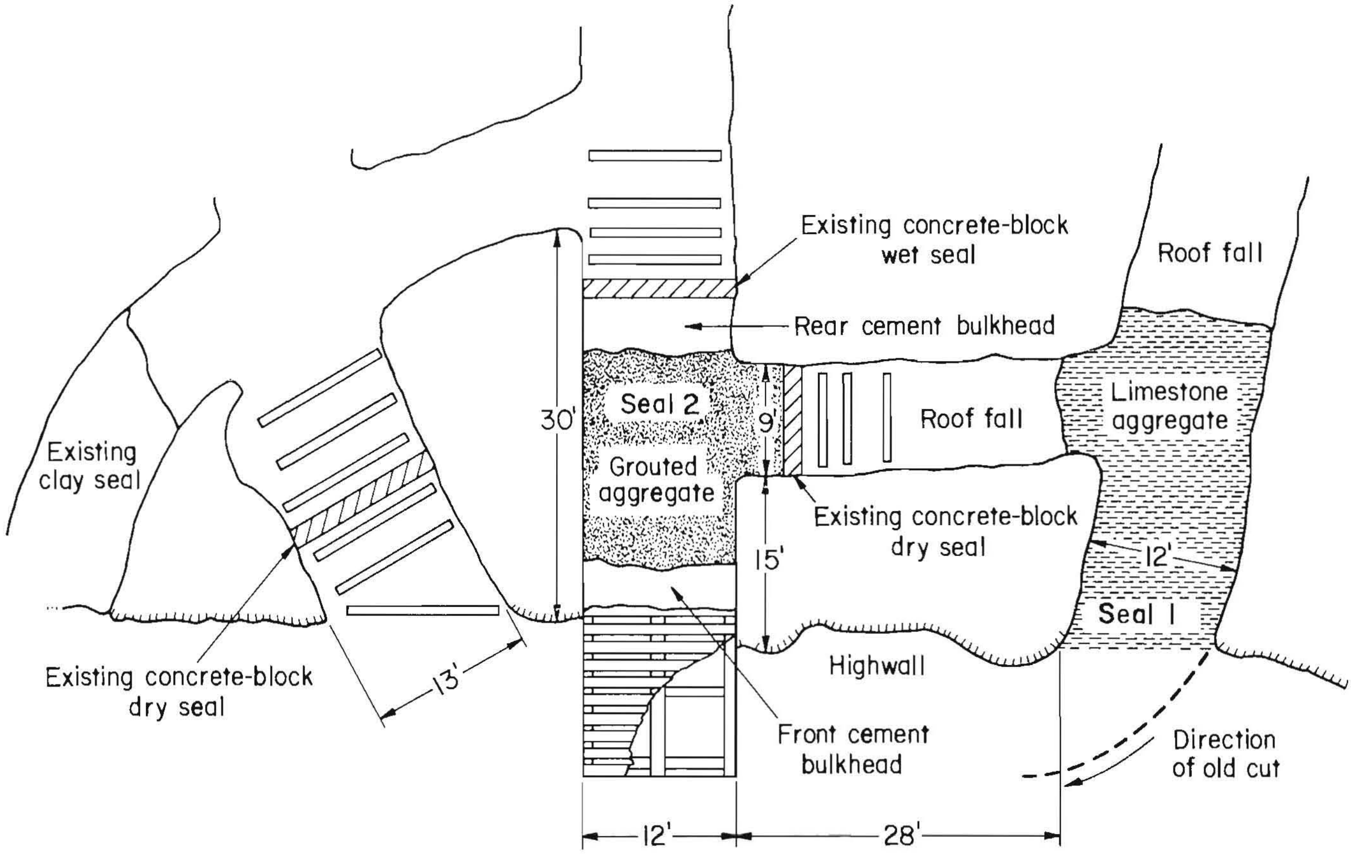

FIGURE 3. - Cross section of seal 1, permeable limestone seal, and seal 2, double bulkhead hydraulic seal (2, p. 140).

SEAL 5

Like most wet seals, this seal permits the outflow of water but prevents the passage of air into the old workings. Before sealing, the abandoned portal had discharge flow rate of 14 gal/min. The effluent contained 658 mg/L acidity, 80 mg/L iron, and 574 mg/L sulfate and had a pH of 2.6 (4, p. A77). In 1980, the discharge flow rate was 14 gal/min. However, the effluent contained 328 mg/L acidity, 20 mg/L iron, and 440 mg/L sulfate and had a pH of 2.9. Thus, it appears that during the 12-yr period there was a 50-pct reduction in acidity, a 75-pct reduction in iron, and a 23-pct reduction in sulfate.

SEAL 4

Seal 4 is located in a heavily subsided 7.5-acre mined area designated as the Coalton School Strip which had been strewn with large boulders and rocks in the outcrop and spoil areas. The objectionable material was buried and covered with unconsolidated spoil, and a contour backfill was constructed by reducing a portion of the highwall. During construction, an old drainway (the site of seal 4) was intercepted, causing a temporary flood in the vicinity of the Coalton High School below. Reportedly, a wet seal was constructed by placing four 4-in plastic drainpipes in the hole and burying them, and a wooden shelter was built over the discharge end (4, p. A112). However, during the 1980 data-gathering visits, it could not be determined what type of seal had been constructed at this site.

Before sealing, this opening had a discharge flow rate of 54 gal/min. The effluent contained 219 mg/L acidity and 7.6 mg/L iron and had a pH of 2.9 (4, p. A108). In 1980, the discharge flow was 64 gal/min. There was a decrease of about 27 pct in acidity, to 159 mg/L, and a decrease of about 58 pct in iron, to 3.2 mg/L; pH increased to 3.2.

SEAL 3

Seal 3--and each of the seals discussed in the following nine sections--was constructed as a block wet seal. The initial flow rate at the seal 3 location was 48 gal/min, and the discharge contained 217 mg/L acidity, 9.5 mg/L iron, and 427 mg/L sulfate (4, p. 110). In 1980, the discharge flow rate was 70 gal/min, and the discharge contained 71 mg/L acidity, 1.5 mg/L iron, and 246 mg/L sulfate. Thus, there had been a 67-pct reduction in acidity, an 85-pct reduction in total iron, and a 43-pct reduction in sulfate.

SEAL 9

The discharge flow rate from this seal appeared to be the highest in the Roaring Creek watershed. Before sealing, the flow rate at the portal was 397 gal/min; the discharge contained 307 mg/L acidity, 26 mg/L iron, and 486 mg/L sulfate (4, p. A110). Twelve years after sealing, the discharge flow rate was 375 gal/min, and the discharge contained 116 mg/L acidity, 3.6 mg/L iron, and 313 mg/L sulfate. Apparently, acidity was reduced by about 62 pct, iron by about 88 pct, and sulfate by about 36 pct.

SEAL 12

The data collected at this location previous to sealing showed lower concentrations of acidity and sulfate and a higher flow volume over the sampling period than after sealing because the surface runoff was sampled and measured along with the mine discharge (4, p. 110). The flow from this seal 1 yr after it was constructed was at 11.4 gal/min, and contained 2,193 mg/L acidity and 2,022 mg/L sulfate (4, p. 110); iron concentration was not reported. In 1980, the discharge flow rate was 13 gal/min. The effluent contained 3,094 mg/L acidity and 3,640 mg/L sulfate. These data show that after 12 yr there was a 41-pct increase in acidity and an 80-pct increase in sulfate.

SEAL 10

Before sealing, the flow at the portal where seal 10 was constructed was at a rate of 14 gal/min; it contained 1,958 mg/L acidity, 470 mg/L iron, and 2,740 mg/L sulfate. One year after sealing, the flow rate had increased to 78 gal/min and contained 1,615 mg/L acidity, 412 mg/L iron, and 1,494 mg/L sulfate (4, p. 110). Twelve years after sealing, the average flow rate was 98 gal/min, and the discharge contained 694 mg/L acidity, 132 mg/L iron, and 1,098 mg/L sulfate. During the period before and immediately after seal 10 was constructed, measured acidity and concentrations of iron, aluminum, calcium, and sulfate decreased; after 12 yr, there were further reductions in these values. These reductions are apparent from the data in table C-1, which summarizes the quarterly data for seal 10.

SEAL 11

Before sealing, the discharge at the seal 11 site flowed at the rate of 58 gal/min and contained 977 mg/L acidity and 1,002 mg/L sulfate (4, p. 110). In 1980, flow rate was 32 gal/min, and the discharge contained 874 mg/L acidity (a reduction of about 11 pct) and 1,037 mg/L sulfate (a slight increase).

SEAL 7

The flow rate at the seal 7 location was 71 gal/min. The flow, at pH 2.5, contained 1,887 mg/L acidity, 435 mg/L iron, and 2,096 mg/L sulfate (4, pp. A99-A100). The 1980 flow had slowed slightly, to 68 gal/min (pH 2.7) and contained 620 mg/L acidity, 123 mg/L iron, and 965 mg/L sulfate. These data indicate an apparent 67-pct reduction in acidity, 72-pct reduction in iron, and a 46-pct reduction in sulfate. Apparently there was a marked improvement in the quality of the water discharging from this location.

A summary of the quarterly data for seal 7 is shown in table C-2.

SEAL 8

This seal was constructed in the portal of an abandoned mine located at the mouth of the upper Kittle Run subwatershed (4, p. 101). Both the heavy timber protective canopy at the entrance to the seal and the seal itself appeared to be in good condition. The data collected in 1980 are included in table C-5. An evaluation of this seal similar to those of the other seals could not be accomplished because of a lack of data available for the years prior to 1980.

SEAL 6

Seal 6 was constructed somewhat differently than the others. There was not sufficient linear space to install the 2.5-ft-high barrier wall outside the double-block wall main seal. In order to create a water seal, two 20-ft lengths of 4-in plastic pipe were placed through the wall, and 90° ells with short standpipes were installed in a vertical position on the outside end to serve as air locks (4, p. A85).

During the 1980 inspections, it was observed that the vertical pipes were broken off; however, the pipes produced a horizontal flow that pooled over their discharge ends and permitted them to continue serving as air locks. Before sealing, the discharge flow rate was 38 gal/min. The flow, at pH 3.5, contained 37 mg/L acidity, 1.0 mg/L iron, and 219 mg/L sulfate (4, p. A-85). In 1980, the flow rate was 39 gal/min; the discharge (pH 5.6) contained 7.0 mg/L acidity, 1.0 mg/L iron, and 153 mg/L sulfate. These data appear to show an increase in pH, an 81-pct decrease in acidity, no change for iron, and a 30-pct decrease in sulfate.

SEAL 14

Before sealing, the discharge at this abandoned portal flowed at 26 gal/min; its pH was 2.8; and it contained 245 mg/L acidity, 22 mg/L iron, and 558 mg/L sulfate (4, p. A-73). The 1980 flow rate was 35 gal/min, at pH 3.9, and the effluent contained 55 mg/L acidity, 0.64 mg/L iron, and 253 mg/L sulfate. These data show an increase in pH and an apparent 78-pct decrease in acidity, a 97-pct decrease in iron, and a 55-pct decrease in sulfate. The increase in flow was believed to be directly related to backfilling and grading against the highwall; this activity covered numerous seeps and caused all the cumulative water to exit at the sealed portal (4, p. A-66).

SEAL 13

The portal where seal 13 was constructed formerly served as the entry for a small isolated mine of only a few acres in size. An attempt was made to seal all the air entrances into the mine. (This was not attempted in the larger mine complex, where the other seals were constructed.) The oxygen content in the mine fell from a presealing level of 21 pct to below 11 pct within the first 2 yr after sealing (table C-3). But during the fourth quarter of 1969, the oxygen content increased to about 15 pct, and it remained near that level throughout the monitoring period. An extensive investigation of the seal and the associated mined area revealed no apparent cracks or openings into the mine. Thus, there was no explanation formulated for the increase in oxygen content (4, p. A-41). The effect of sealing on the mine atmosphere could not be determined during the 1980 study because accessibility to the air sampling device installed in the seal was considered dangerous.

Before sealing, the discharge flow rate from the portal was 13 gal/min, at pH 2.8; the discharge contained 591 mg/L acidity, 93 mg/L iron, and 1,035 mg/L sulfate (4, p. 110). The flow in 1980 was at 19 gal/min, pH 3.4, and contained 116 mg/L acidity, 14 mg/L iron, and 325 mg/L sulfate. After more than 12 yr, it appears there was an 80-pct reduction in acidity, an 85-pct reduction in iron, and a 69-pct reduction in sulfate.

CLAY SEALS

Exposed openings in the Roaring Creek watershed where the highwall had been badly fractured and later strip mining operations had intercepted the deep mine workings were sealed by compacting clay against the highwall with a vibrating sheeps-foot roller. The clay was compacted against the highwall to a height well above the underground mine workings (4, p. 100; 8, p. 7).

After regrading, two problems became apparent in one of the (Elkins) demonstration project work areas. First, the long (600 ft) steep slopes were conducive to erosion. The erosion could have been reduced by cutting a diversion ditch at the top of the slope and building several terraces. However, in 1968, a road was cut across the slope to facilitate hydroseeding and this did help control the erosion. Second, in early 1968, a large seepage area developed below the project work area. The seals and/or compacted backfill did not hold water in the underground mine (4, p. A-52). A portion of the area as it appeared in 1980 is shown in figure 4.

Initially, the seepage area covered about 5 acres and would not support vegetation. The area affected by the seepage was found to be only slightly enlarged during the 1980 visits to the study area. Encrustation of the unvegetated area with precipitated iron deposits was found at points where the seep water had reached the surface and spread some distance downslope from the seep. The water from the major seep had a pH of 2.6, the unvegetated soil over which the seeps spread had a pH of 2.9, and the effluent from a sediment pond below the seep area had a pH of 2.7.

The adjacent vegetated soil, part of which also drained into the pond, showed a soil pH of 5.2. The vegetation was quite dense and consisted of legumes and grasses and pine and deciduous trees.

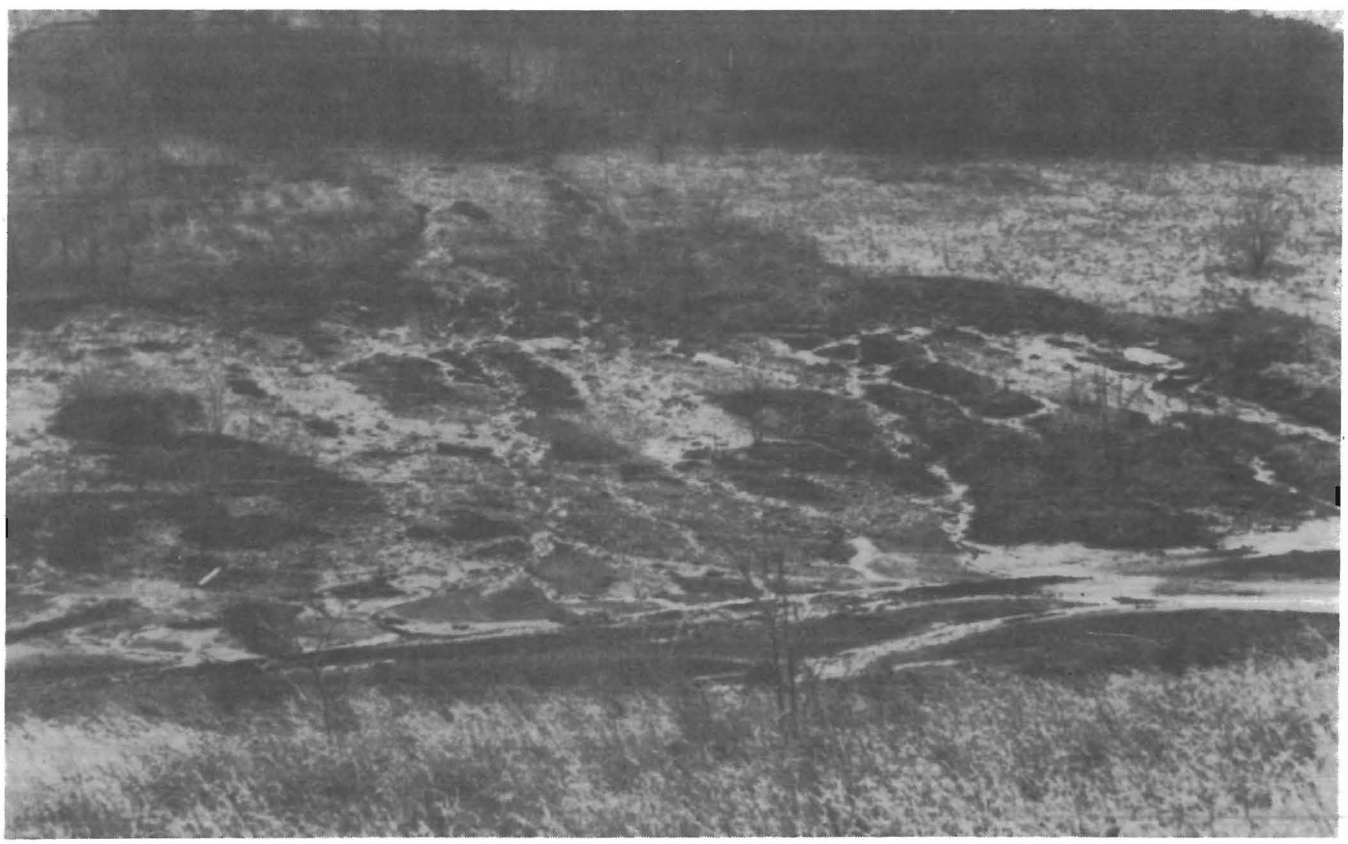

FIGURE 4. - View of surface area affected by leaking clay seals.

The vegetation generally appeared healthy except near the seep areas. The invasion of native volunteer plants over the vegetated area was extensive.

GAUGING STATION

The gauging station was located about 2,000 ft downstream from seal 13, near the mouth of the North Branch of Flatbush Run. There are about 692 acres in this watershed, of which 160 acres (or about 23 pct of the land area) had been surface mined (3, p. 13). The entire surface-mined area had been reclaimed. Except for a few isolated areas, an adequate to excellent ground cover of grasses and legumes had been established. It was observed in 1980 that a great number of native species of herbaceous plants and trees had invaded the area. There were also some spots of severe erosion.

Reclamation activities in the Flatbush Run subwatershed and the apparently improved condition of the effluent from seal 13 contributed to better water quality flowing by the gauging station site in 1980, as can be seen from table C-4. (However, there was a large buildup of precipitated iron on the underground weir, the channel between the weir and the outside, and over an area outside the portal near seal 13, the principal water source for the stream on which the gauging station was located.) The data in table C-4 indicate a general improvement in water quality at the gauging station site from 1965 to 1980. The pH was fairly constant, but acidity, specific conductivity, and sulfate decreased. The Bureau's field and laboratory data pertaining to this station are detailed (for each of the 1980 sample-collection visits) at the end of table C-5.

DATA INTERPRETATION AND PERTINENT VARIABLES

The results of the Elkins mine sealing project are summarized in table 1, which shows the change in acidity and in iron and sulfate concentrations at each of the seal locations from 1966 (the year before the seals were installed) to 1980. These data indicate overall improvement in the quality of water discharged from the mines after installation of the wet air seals. However, caution is required in this interpretation since a comparison is being made between the earlier EPA data sets (for which the numbers of samples studied and sample variation are unknown) and only three sets of data from the Bureau's 1980 study. In addition, certain variables can be expected to influence water quality data such as those examined in this study, yet their effect may be difficult to accurately determine. Three such variables--flooding, flow rate variation, and subsidence--are discussed below.

The methods of wet seal construction shown in figure B-1 would result in flooding of a portion of the deep mine at each seal location. However, because no detailed mine map showing coal elevations was located for this study, the percentage of the mine that was flooded is unknown. In any event, the degree of flooding would vary at each seal location.

TABLE 1. - Change in acidity and iron and sulfate concentrations in mine seal discharges from 1966 to 1980, percent

Seal[1]	Acidity	Iron	Sulfate	Seal[1]	Acidity	Iron	Sulfate
2	-63	-51	-58	9	-62	-88	-36
3	-67	-85	-43	10	-57	-68	-26
4	-27	-58	NDR	11	-11	NDR	+3.4
5	-50	-75	-23	12	+41	NDR	+80
6	-81	NDR	-30	13	-80	-85	-69
7	-67	-72	-46	14	-78	-97	-55

NDR No data reported by EPA. [1]EPA reported no data for seals 1 and 8.

Variations in flow from the seals would be anticipated according to the seal design. The flow rate from the sealed mine complex would increase or decrease rapidly in response to precipitation events. Therefore, interpretation of flow changes as a result of mine sealing should be made with caution. The possible dependence of concentration and load on flow rate--which could not be assessed from available data--makes interpretation of water quality changes difficult.

Subsidence events in the abandoned mine could also alter flow patterns and changes in flow rate at the air seals. Flow patterns and/or rates might therefore vary independently of precipitation events or might not be comparable with previous flow data.

POSSIBLE PROBLEMS IN THE USE OF AIR SEALS

The construction of block wet air seals should not be considered a universal solution to the problem of sealing of abandoned underground mines for the following reasons:

1. The use of an air seal under shallow cover (less than 150 ft) could be ineffective if surface subsidence occurs. This is the reported depth range of many sinkholes (2, p. 34). The mine atmosphere would be equilibrated with the surface atmosphere in a short period of time if subsidence did occur over the air-sealed mine, and conceivably barometric pressure changes could cause atmospheric "breathing" through the shallow overburden.

2. The construction of a wet seal (as shown in figures 2-3) should cause the development of a mine pool behind the low wall of the seal. The flooding of a local area of a mine may decrease the formation of AMD to a slight degree, depending on the extent of the shallow pool. However, damage to the low wall due to roof falls is possible. This could then result in the loss of the shallow mine pool, with the flow of mine water directed to the main block seal. Inspection and maintenance of the low wall dam would be expensive and dangerous, because a portion of the main seal would have to be removed for inspection purposes.

3. It is possible that an opening at the main seal could become plugged either by solution or mineral deposits. During periods of low- or no-flow conditions, mineral deposits (particularly of hydrous iron oxides) could solidify and clog or plug the opening. Should this situation occur, a large head behind the main seal could build up which could overcome the structural design capability of the main block wall.

Most of the difficulties listed above can be overcome if an active inspection and maintenance program continues long after construction of the wet air seals. Observation of surface subsidence over a large mine complex may be impossible. If the seals are constructed to include boreholes to the surface so that the oxygen level in the mine can be monitored, an increase in the oxygen level may indicate that surface subsidence has occurred over the sealed mine.

The construction of air seals to reduce the oxygen level in a mine also implies that no further mining or development of the mine property around the outcrop will occur. This may be impossible to accomplish, since the sale and development of land is often beyond control of those responsible for mine sealing.

Since air seals may not be effective in or even capable of reducing the oxygen level in a mine enough to prevent the formation of AMD, the value of an air seal may be in the reduction of the iron and sulfate concentrations of the mine effluent discharge. Accurate determination of iron and sulfate reduction would probably require at least monthly sampling over a long period of time or continuous sampling over a shorter period. Implementation of such a program would require a high expenditure of funds. Enhancement of wet seal effectiveness may be possible when the mechanics of AMD control in underground mines are more fully understood and when the effects of creating small pools by low wall barriers are further investigated.

CONCLUSIONS

The 1980 data indicate overall reductions in acidity, sulfate, and iron concentrations relative to the data collected 12 yr earlier by the EPA. These results are tentatively interpreted as evidence of decreased production of AMD after air sealing.

The small isolated mine seal (seal 13) showed the greatest decrease in the production of AMD. This may have been the result of a combination of the air seal installation and surface reclamation performed around the periphery of the small isolated mine complex.

Improved water quality was also noted at the gauging station.

RECOMMENDATIONS FOR FUTURE STUDY

Block wet air seals should be evaluated at about 5- to 10-yr intervals or until deterioration renders the seals totally ineffective. It would be useful to observe changes in the regraded and revegetated areas, particularly the areas affected by clay seals. Should the overall area be left intact without further surface mining, it would be important to determine if any further subsidence could be detected and traced to a deterioration of the underground pillars. Grouting behind clay seals and/or the installation of selectively placed grout seal curtains in the old workings may alleviate surface deterioration in the vicinity of seals.

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APPENDIX A.--HYDROLOGIC, TOPOGRAPHIC, AND GEOLOGIC DESCRIPTIONS OF STUDY AREA

HYDROLOGY

The climate of the study area is of the continental mountainous type, with relatively cold winters and mild summers. Long-term temperature averages at the Elkins airport, 1,975-ft elevation, range from a monthly normal of 25° in January to 70° F in July.

Precipitation received by the Upper Monongahela Basin is derived from moisture-laden air from three main sources: (1) the southwesterly flow of air from the Gulf of Mexico, (2) the easterly flow from storms traveling up the Atlantic Coast, and (3) the northwesterly flow of air, which picks up moisture over the Hudson Bay-Great Lakes region and generates frequent snow showers during the winter. Although intense thunderstorms cause local flooding during the summer, basin-wide flooding occurs more frequently in early spring as a result of general large-scale storms. Surface runoff from these storms is sometimes intensified by snow melt. The Elkins long-term annual precipitation average is 45.8 in (4). Table A-1 shows quarterly[1] precipitation data for 2 yr previous to construction of the seals, the period of seal construction (1966-67), several years immediately after sealing, and 1980, the year this evaluation was conducted.

TABLE A-1. - Quarterly precipitation data at Elkins, WV, airport, inches

Year	1st	2d	3d	4th	Total
1965..	11.45	10.56	6.90	6.11	35.02
1966..	8.03	10.28	15.56	8.93	42.80
1967..	11.98	15.33	14.44	11.08	52.83
1968..	6.33	11.95	10.05	18.85	47.18
1969..	6.79	8.99	16.92	7.99	40.69
1970..	5.65	10.05	14.31	10.70	40.71
1971..	8.66	6.65	15.45	5.47	36.23
1980..	9.45	14.16	22.05	7.83	53.59

[1]January-March, April-June, July-September, October-December.

TOPOGRAPHY

The Roaring Creek watershed is situated near the east edge of the Appalachian Plateaus and is physiographically divisible into two areas (Kanawha and Allegheny Mountain sections), each closely related to the weathering characteristics and structure of the underlying rocks. The Kanawha section comprises the western two-thirds of the area. This section has gently dipping beds of relatively nonresistant shale, siltstone, sandstone, coal and underclay and exhibits maturely dissected topography and dendritic drainage patterns. Most of the streams occupy narrow V-shaped valleys that lie between broad flat uplands supported by moderately resistant sandstone beds. Topography in the eastern third of the area, from the base to the crest of Rich Mountain, is typical of the Allegheny Mountain section of the Appalachian Plateaus. On the west slope of the mountain, tributaries of Roaring Creek downdip between cliffs and flatiron-like ridges carved from moderately dipping sandstone and conglomeritic sandstone (4, p. 21).

A general section of the lower Allegheny Mountain and upper Kanawha sections is described in table A-2. This section is a composite section based on field measurements in Barbour, Upshur, and western Randolph Counties (7, p. 242, 264-5).

GEOLOGY

The Roaring Creek watershed covers about 28 mi^2 and lies in the broad Belington syncline, which is centrally located in the Appalachian geosyncline between relatively flat-lying rocks to the west and more intensely folded rocks to the east. The trough line of the syncline strikes irregularly northward across the study area and plunges about 100 ft/mi in that direction (4, p. 21).

TABLE A-2. - General composite section of lower Allegheny Formation and upper Kanawha Formation in western Randolph County, WV (7)

Material	Thickness, ft
Sandstone, massive, gray; East Lynn........................	35
Coal, Middle Kittanning........	4
Sandstone, gray (often represented by sandy shale)........	10
Coal, Lower Kittanning[1]........	8
Fire clay, Lower Kittanning....	5
Shale, sandy..................	13
Sandstone, flaggy; Clarion.....	0-30
Coal, Clarion[1]................	0- 2
Shale, sandy..................	20
Sandstone, Homewood; massive, gray, often pebbly; prominent along Tygart Valley River, on Roaring Creek, and along headwaters of the Little Kanawha River........................	25-60
Coal, Upper Mercer; lenticular, often splinty[1]................	0-10
Shale, sandy and dark, with lenticular sandstone..........	25-60
Kanawha Black Flint (probably Mercer Limestone of Pennsylvania), dark with slate and occasional marine fossils.......	0- 5
Coal, Lower Mercer.............	0- 5
Sandstone, Upper Connoquenessing; massive, grayish-white with quartz pebbles; prominent along Tygart Valley and Middle Fork Rivers..................	30-65

[1]Coals in study area.

Sedimentary rocks of Late Mississippian to Late Pennsylvanian Age, occurring in beds totaling about 2,200 ft thick, crop out in the Roaring Creek area. The basal 820 to 875 ft of the beds is mostly marine rocks assigned to the Greenbrier and Mauch Chunk Formations of Late Mississippian Age. Outcrops of these formations are limited to a few localities on the east edge of the area. The remainder of the stratigraphic sections consist largely of continental coal-bearing rocks of the New River, Kanawha, Allegheny, and Conemaugh Formations of Early to Late Pennsylvanian Age. These formations are at the surface in nearly all of the study area but are locally covered by deposits of the Quaternary Age.

The Allegheny Formation of Middle and Late Pennsylvanian Age is a coal-bearing sequence of sandstone, siltstone, and shale that lies between the Kanawha and Conemaugh Formations in West Virginia. In the Roaring Creek area, it ranges from 265 to 300 ft thick. This formation includes a persistent clay bed at its base; two economically important coalbeds, the Clarion and Kittanning; and a mapped sandstone member near its top. The Allegheny Formation outcrops in nearly all of the area west of the foot of Rich Mountain.

The Kittanning Coalbed, the most widely mined coal in the Roaring Creek area, has been nearly depleted by extensive underground and strip mining. The bed has a maximum thickness of about 116 in, excluding partings, near Coalton in the trough of the Belington syncline. Westward, on the limb of the syncline, the bed is split into three benches by underclay and carbonaceous shale partings up to 21 in thick. Only black carbonaceous shale and underclay were found at the geologic position of the Kittanning Coalbed in the ridge that fringes the southwest edge of the area. The coalbed is composed mostly of bright attritus with minor amounts of vitrain and dull attritus. Lenses of pyrite and pyritic impure coal up to 3 in thick are common in the bed (4, p. 23).

The strata between the Kittanning Coalbed and a mapped sandstone member in the upper part of the Allegheny Formation range from 85 to 125 ft in thickness and consist mainly of medium-gray shale and silty shale. This part of the formation also includes lenticular beds of fine- to coarse-grained sandstone, siltstone, coal, underclay, and argillaceous limestone. A persistent bed of canneloid shale up to 18 in thick occurs about 21 to 33 in above the Kittanning coalbed (4, p. 24).

APPENDIX B.--SEAL TYPES

Several types of mine seals which varied in structure and function were constructed in the study area. (A total of about 101 seals were constructed.) The various types of seals are described below.

Dry Seals

A dry seal is constructed by placing suitable material such as cement blocks in mine openings to prevent the entrance of air and water into the mine. A dry seal is suitable for openings where there is little or no flow and little danger of a hydrostatic head developing.

Wet Seals

A wet seal prevents the entrance of air into a mine while allowing the mine discharge to flow through the seal. Seals of this type are constructed with a water trap similar to traps used in sinks and drains.

The wet seals (fig. B-1) were constructed of two courses of fly ash blocks which were coated on both sides with urethane foam for protection against acid attack. A low block wall barrier about 2.5 ft high was constructed outside the main seal to maintain an airtight pool of water. Where pooling of the water could not be maintained by this single barrier outside the seal, a similar barrier was constructed on the underground side of the seal as well. Two blocks were left out of the otherwise solid two-course block wall to allow water drainage through the seal. The seals were protected by heavy creosote-impregnated timber structures which were designed and installed to prevent roof falls (4, p. 78).

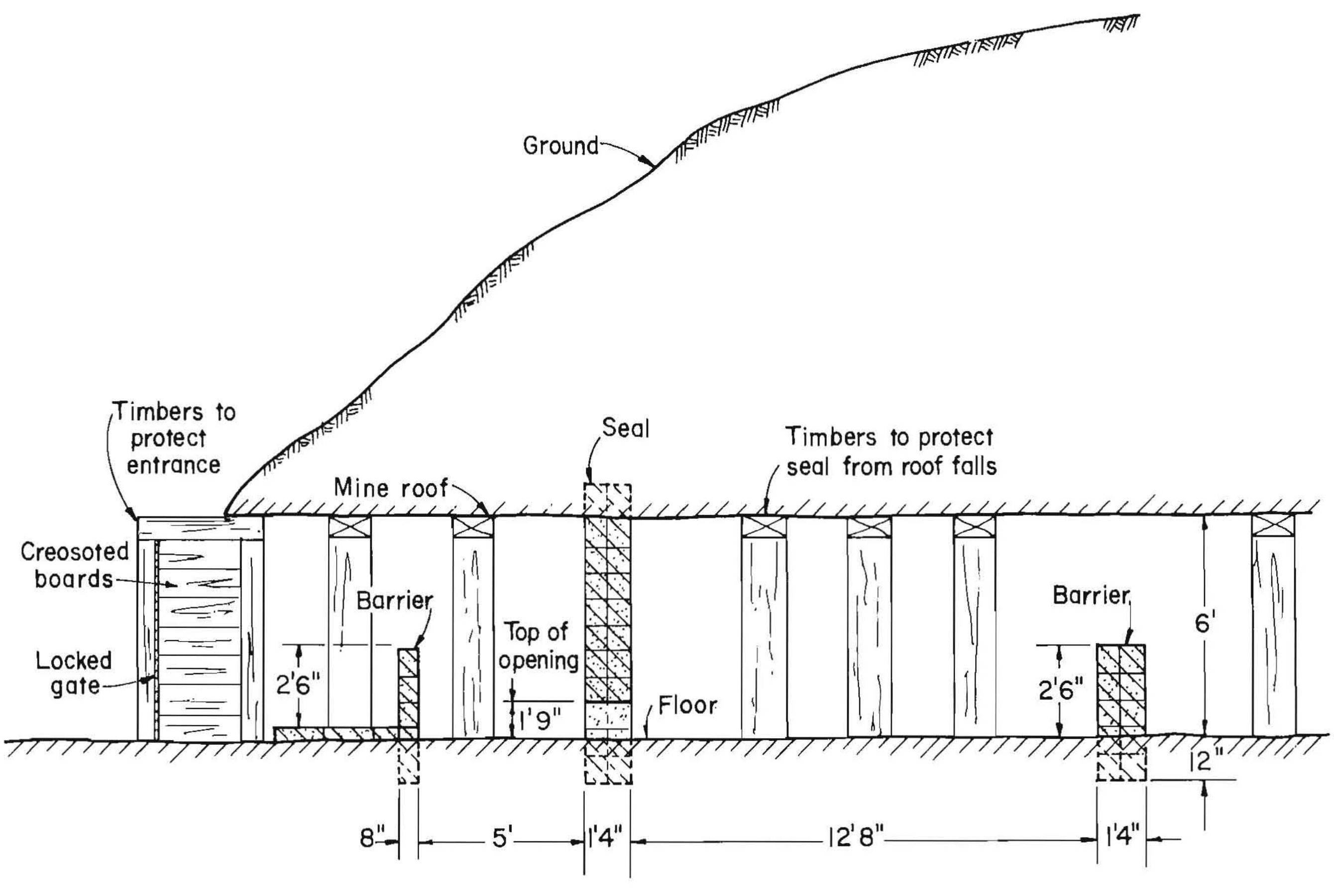

FIGURE B-1. - Cross section of typical block wet air seal.

Hydraulic Seals

Construction of a hydraulic seal involves placing a plug in a mine entrance that is discharging water. The plug stops the discharge, and the resultant flooding excludes air from the mine and retards the oxidation of sulfide minerals (4, p. 77).

Clay Seals

Clay may be placed in openings of underground mines to form a hydraulic seal or to control infiltrated water (fig. B-2). A good-quality plastic clay should be used to insure impermeability. The seal is constructed by first cleaning the mine opening; debris or any other material that would make the clay seal ineffective must be removed. The clay material is then deposited in layers and compacted to force it into cracks and voids along the walls and roof of the seal area. Earth should be backfilled over the seal to hold it in place and protect it from erosion. Under ideal conditions, a clay seal constructed in this manner can withstand up to 30 ft of hydrostatic head (4, p. 153).

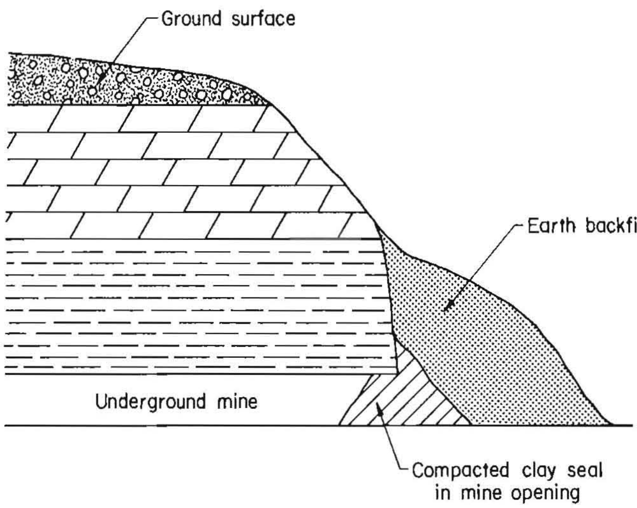

FIGURE B-2. - Cross section of typical clay seal.

Double Bulkhead Seal

This type of hydraulic seal (fig. 3, seal 2) is constructed by placing two spaced retaining bulkheads in a mine entry and filling the void between them with an impermeable material. The two bulkheads provide a form for the center seal. The center seal is formed by injecting concrete or grout through the front bulkhead, when it is accessible, or through vertical pipes from above the mine. Bulkheads have been constructed with quick-setting cement and grouted coarse aggregate. Grouting of the bulkheads and center seal may be required to prevent leakage along the top, bottom, and sides of the seal. Curtain grouting of adjacent strata is often done to increase strength and reduce permeability (5, p. 109). In the example of a double bulkhead seal shown in figure 3, (seal 2), the bulkheads were of cement construction and the center was made of grouted aggregate.

APPENDIX C.--FLOW, ACIDITY, AND SULPHATE LOADS BEFORE AND AFTER SEALING

Field data (on flow) and laboratory data (acidity and sulfate loads) gathered for this and previous studies are shown in bar-graph form in figure C-1, and these and other parameters are detailed in tables C-1 through C-5. Data dated 1965-66 were gathered (by the EPA) before installation of the seals. The seals were constructed in 1967, and this is why there are no data for that year in tables C-1 and C-2. The 1968-71 data (also collected by the EPA) were taken from reference 4. The 1980 data were collected by the Bureau of Mines.

A limiting factor encountered in this study was the collection of meaningful data. The available records pertaining to this study generally consisted of tables with yearly or quarterly arithmetic means. In tables C-1 through C-4, the Bureau's data, like the previously collected data, are shown as quarterly arithmetic means.

Figure C-1 shows the discharge flow rates, acidity, and sulfate loads for selected seals as a function of time. The period covered begins with 1966, the year before the seals were installed, and ends with 1980, approximately 12 yr after installation. The graphs in figure C-1 are based on yearly arithmetic means.

The data reported by the EPA for seals 7 and 10 were more complete than the data reported for the other seals, and these data are reported in tables C-1 and C-2. The only seal for which mine oxygen content was measured was seal 13 (the seal constructed in the small isolated mine); the oxygen content and discharge data for this seal are shown in table C-3. Table C-4 summarizes the quarterly data collected at the gauging station, and table C-5 details the data collected by the Bureau during three sampling visits in 1980.

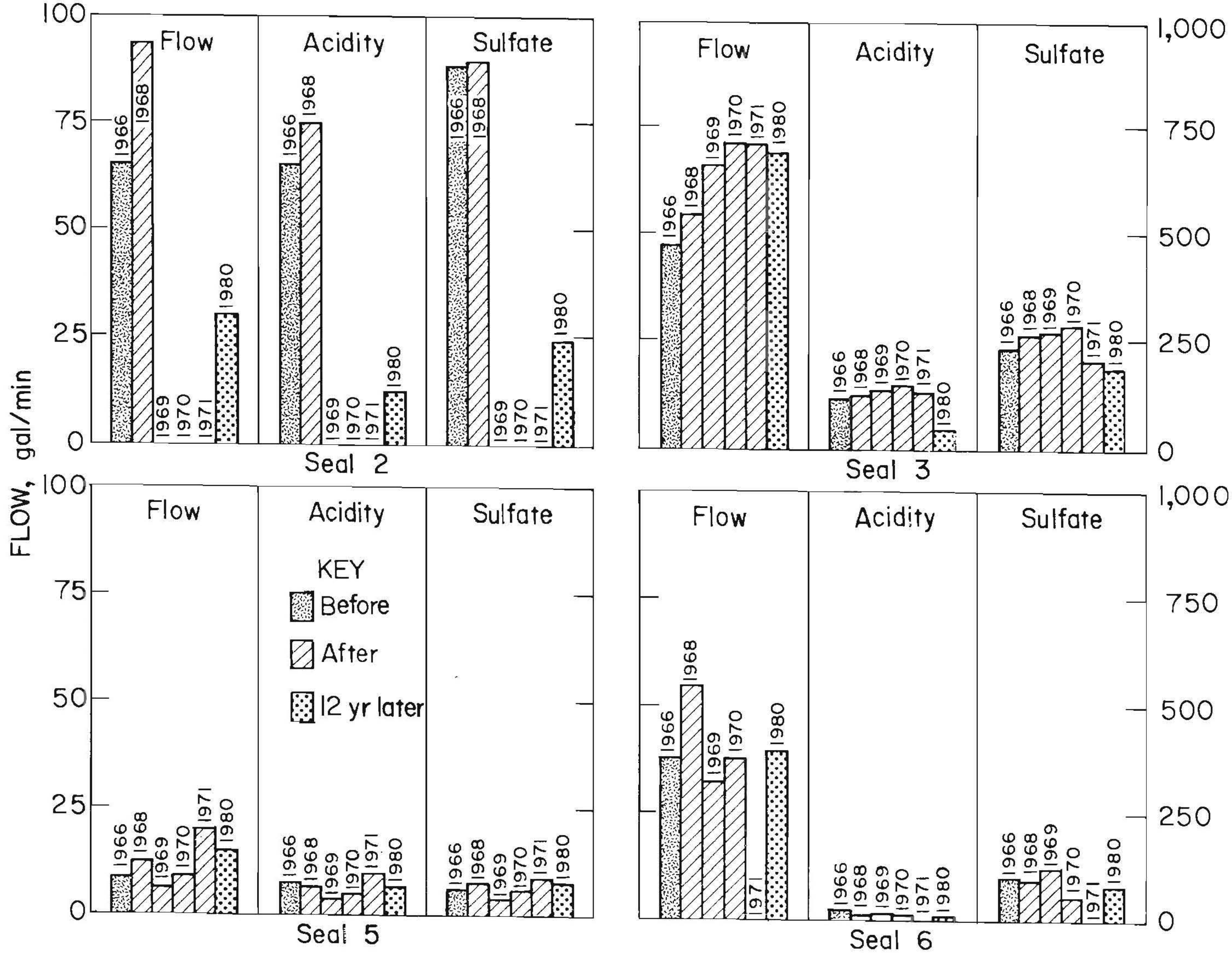

FIGURE C-1. - Flow rates, acidity, and sulfate loads before and 12 yr after sealing, for selected seal locations.

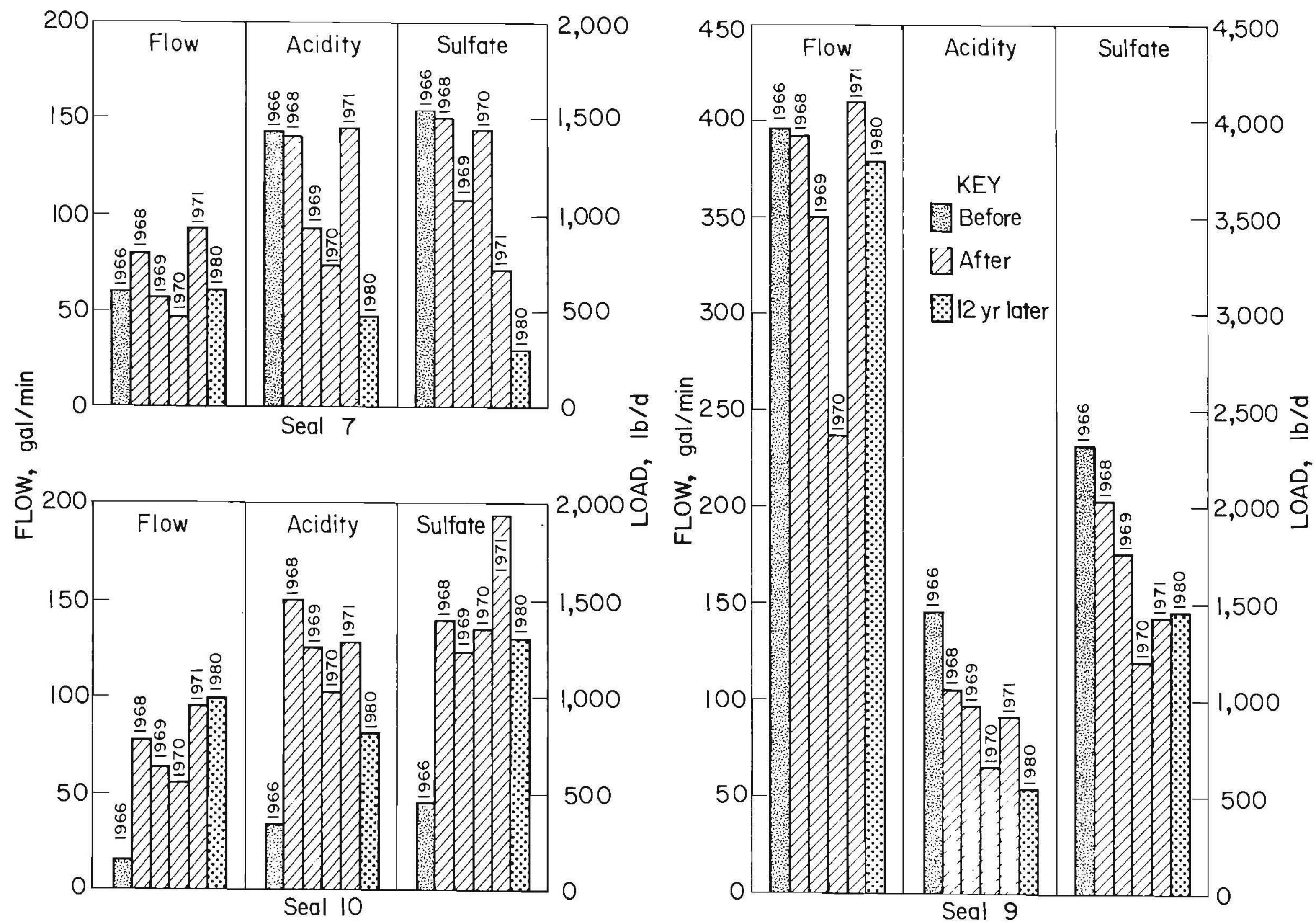

FIGURE C-1. - Flow rates, acidity, and sulfate loads before and 12 yr after sealing, for selected seal locations—Continued.

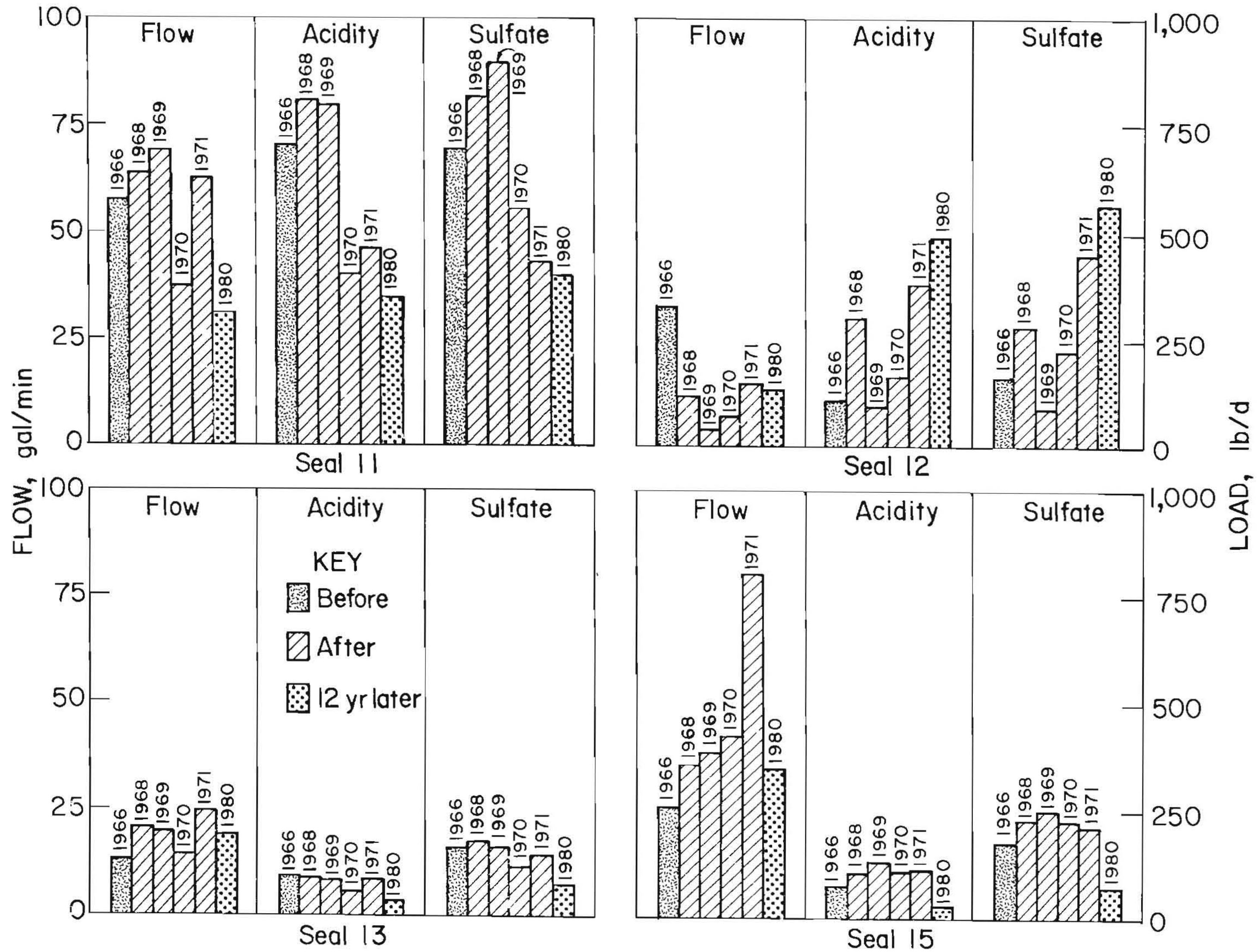

FIGURE C-1. - Flow rates, acidity, and sulfate loads before and 12 yr after sealing, for selected seal locations—Continued.

TABLE C-1. - Quarterly data for seal 10 discharge

Year	Flow, gal/min				pH				Specific conductance, µmho/cm			
	1st	2d	3d	4th	1st	2d	3d	4th	1st	2d	3d	4th
1965...........	NA	41	9	6	NA	2.4	2.4	NA	3,125	3,530	3,290	NA
1966...........	17	14	9	19	2.2	2.3	2.3	2.3	3,710	3,186	3,856	3,942
1968...........	148	17	21	51	2.6	2.6	2.6	2.5	2,166	2,243	2,683	2,553
1969...........	76	70	53	74	2.5	2.5	2.4	2.5	2,266	2,400	2,450	2,600
1970...........	100	73	25	26	2.4	2.5	2.5	2.5	2,533	2,116	2,550	2,300
1971...........	126	81	81	NA	2.6	2.6	2.6	NA	1,566	1,980	2,066	NA
1980...........	ND	169	78	48	ND	2.8	2.7	2.6	ND	1,450	1,100	1,250

Year	Load, tons				Concentration, mg/L			
	1st	2d	3d	4th	1st	2d	3d	4th
			ACIDITY					
1965...........	NA	37	9	7	NA	1,617	1,842	2,043
1966...........	20	14	10	21	2,133	1,773	2,125	1,960
1968...........	116	77	19	53	1,433	1,450	1,680	1,901
1969...........	67	56	50	70	1,610	1,465	1,700	1,715
1970...........	84	48	24	25	1,523	1,204	1,768	1,715
1971...........	76	52	45	NA	1,125	1,194	1,052	NA
1980...........	ND	60	30	19	ND	652	707	723
			TOTAL IRON					
	1st	2d	3d	4th	1st	2d	3d	4th
1965...........	NA	9	2	2	NA	402	452	517
1966...........	5	3	3	4	503	407	535	415
1968...........	33	16	5	15	413	302	402	532
1969...........	18	17	12	22	435	447	415	527
1970...........	20	12	8	8	363	310	565	586
1971...........	24	14	15	NA	355	330	346	NA
1980...........	ND	12	4	6	ND	126	130	140
			SULFATE					
1965...........	NA	41	11	8	NA	1,805	2,298	2,563
1966...........	27	25	12	29	2,890	3,237	2,445	2,265
1968...........	113	68	17	51	1,393	1,283	1,465	1,837
1969...........	71	57	45	78	1,697	1,497	1,535	1,920
1970...........	81	66	35	34	1,477	1,655	2,568	2,380
1971...........	106	98	52	NA	1,575	2,250	1,186	NA
1980...........	ND	110	46	27	ND	1,194	1,064	1,038
			CALCIUM					
1965...........	NA	5	1	1	NA	205	396	301
1966...........	2	2	1	NA	264	237	280	NA
1968...........	19	12	3	9	231	228	273	327
1969...........	14	14	9	13	330	367	305	313
1970...........	17	11	5	7	317	372	365	452
1971...........	21	14	12	NA	315	330	276	NA
1980...........	ND	7	4	2	ND	73	89	69
			ALUMINUM					
1965...........	NA	1	1	0.3	NA	110	119	99
1966...........	1	1	.3	1	79	66	57	92
1968...........	5	5	1	3	56	90	106	110
1969...........	4	4	3	5	85	101	90	113
1970...........	6	2	2	2	109	52	118	140
1971...........	5	3	6	NA	79	75	140	NA
1980...........	ND	3	2	1	ND	37	39	41

NA Not available. ND No data collected.

TABLE C-2. - Quarterly data for seal 7 discharge

Year	Flow, gal/min				pH				Specific conductance, µmho/cm			
	1st	2d	3d	4th	1st	2d	3d	4th	1st	2d	3d	4th
1965..........	NA	310	22	9	NA	2.5	2.5	2.5	NA	2,485	2,821	3,080
1966..........	72	54	18	144	2.4	2.5	2.5	2.5	3,218	2,583	3,125	2,490
1968..........	117	103	58	45	2.7	2.7	2.6	2.6	2,105	1,841	2,500	1,858
1969..........	72	76	49	76	2.6	2.5	2.4	2.6	1,866	2,216	2,191	2,070
1970..........	99	76	31	72	2.5	2.5	2.5	2.6	2,016	2,050	2,283	1,808
1971..........	99	72	112	NA	2.7	2.6	2.5	NA	1,233	1,840	2,566	NA
1980..........	ND	117	44	22	ND	2.9	2.7	2.6	ND	1,125	1,028	1,100

Year	Load, tons				Concentration, mg/L			
	1st	2d	3d	4th	1st	2d	3d	4th
ACIDITY								
1965..........	NA	276	22	4	NA	1,637	1,850	2,337
1966..........	90	50	18	112	2,275	1,783	2,065	1,428
1968..........	89	69	54	32	1,407	1,244	1,637	1,317
1969..........	50	53	33	63	1,281	1,255	1,186	1,450
1970..........	62	48	25	51	1,183	1,136	1,395	1,267
1971..........	48	48	77	NA	895	1,021	1,266	NA
1980..........	ND	36	15	8	ND	564	606	692
TOTAL IRON								
1965..........	NA	60	5	4	NA	357	453	610
1966..........	22	11	4	24	553	400	485	300
1968..........	24	19	11	18	375	343	350	359
1969..........	14	19	7	20	365	447	282	462
1970..........	13	12	7	19	255	298	428	458
1971..........	14	10	22	NA	260	258	356	NA
1980..........	ND	7	3	2	ND	112	120	137
SULFATE								
1965..........	NA	331	29	19	NA	1,967	2,503	3,210
1966..........	119	45	19	121	3,013	1,583	2,245	1,545
1968..........	104	73	51	37	1,653	1,313	1,550	1,552
1969..........	54	67	40	81	1,400	1,576	1,462	1,890
1970..........	62	73	38	75	1,185	1,818	2,100	1,851
1971..........	64	53	73	NA	1,195	1,354	1,200	NA
1980..........	ND	58	21	13	ND	900	869	1,125
CALCIUM								
1965..........	NA	40	5	3	NA	239	435	483
1966..........	14	8	3	NA	343	277	370	NA
1968..........	18	15	11	8	292	268	351	343
1969..........	13	18	10	15	335	427	352	252
1970..........	16	13	8	15	305	230	440	430
1971..........	14	11	21	NA	263	290	346	NA
1980..........	ND	4	2	1	ND	59	83	92
ALUMINUM								
1965..........	NA	9	1	1	NA	110	127	137
1966..........	3	2	1	6	81	65	95	74
1968..........	4	4	3	2	61	68	103	101
1969..........	3	3	2	5	69	86	76	113
1970..........	5	1	1	3	98	36	98	93
1971..........	3	2	7	NA	59	57	120	NA
1980..........	ND	2	8	5	ND	27	31	38

NA Not available. ND No data collected.

TABLE C-3. - Quarterly data for seal 13 discharge, and mine oxygen content

Year	1st	2d	3d	4th	1st	2d	3d	4th
	pH				Acidity, mg/L			
1967	SCP	SCP	SCP	3.2	SCP	SCP	SCP	359
1968	3.2	3.2	3.2	3.2	325	334	344	265
1969	3.2	3.2	3.2	3.2	350	339	376	327
1970	3.1	2.9	3.1	3.3	263	310	297	294
1971	3.2	3.2	3.0	2.9	249	248	276	326
1980	ND	3.8	3.6	3.1	ND	94	139	116
	Iron, mg/L				Sulfate, mg/L			
1967	SCP	SCP	SCP	85	SCP	SCP	SCP	797
1968	74	68	72	72	686	702	708	627
1969	63	91	62	71	645	656	717	678
1970	74	49	72	83	603	628	845	606
1971	56	47	56	73	488	508	406	535
1980	ND	18.5	10.2	13.2	ND	275	295	406

MINE ATMOSPHERE OXYGEN CONTENT,[1] pct

Year	1st	2d	3d	4th
1967	SCP	SCP	SCP	9.1
1968	8.3	10.8	7.0	7.4
1969	NA	NA	7.0	14.8
1970	15.0	12.0	NA	13.3
1971	15.0	15.3	14.0	NA

NA Not available. ND No data collected.

SCP Seal construction period; no data collected.

[1]Mine atmosphere was not sampled in 1980 because accessibility to air sampling tube in seal was considered dangerous.

NOTE.--Prior to sealing (Mar. 1964 to Aug. 1967), the following values were obtained: pH, 2.8 (mean) and 3.1 (max); acidity, 591 mg/L (mean) and 438 mg/L (min); iron, 93 mg/L (mean) and 48 mg/L (min); sulfate, 1,035 mg/L (mean) and 710 mg/L (min); and oxygen, 21 pct (mean).

TABLE C-4. - Quarterly gauging station data

Year	Flow,[1] gal/min				pH			
	1st	2d	3d	4th	1st	2d	3d	4th
1965	1,534	642	31	121	3.4	3.2	3.0	3.1
1966	1,122	1,000	238	866	3.3	3.2	3.0	3.3
1967	1,584	1,082	337	637	3.4	3.4	3.3	3.6
1968	1,315	1,266	220	821	3.6	3.8	3.4	3.6
1969	942	583	467	839	3.7	3.5	3.1	3.5
1970	866	664	211	767	3.7	3.3	3.4	3.7
1971	1,355	543	1,396	727	3.8	3.5	3.5	3 6
1980	ND	415	259	92	ND	3.75	3.3	3.2
	Precipitation,[2] in				Specific conductance, µmho/cm			
1965	[3]11.98	[3]11.05	[3]7.22	[3]6.40	602	680	1,045	890
1966	[3]8.40	[3]10.76	16.28	9.35	614	644	1,034	693
1967	12.55	16.23	15.11	11.59	564	543	738	383
1968	6.63	12.50	11.00	11.33	456	353	673	443
1969	7.11	9.41	17.70	8.36	446	550	526	463
1970	5.91	10.52	24.97	11.20	370	483	608	340
1971	9.06	6.96	16.17	5.73	350	414	403	417
1980	[3]9.88	[3]14.81	[3]23.06	[3]8.19	ND	215	250	250
	Load, tons				Concentration, mg/L			
	1st	2d	3d	4th	1st	2d	3d	4th
1965	122	53	5	15	141	151	271	224
1966	99	80	30	69	155	146	228	146
1967	87	48	27	24	101	88	146	69
1968	63	44	16	28	95	64	124	61
1969	39	37	26	41	76	118	101	90
1970	34	38	14	31	72	104	121	74
1971	32	21	77	44	44	70	103	111
1980	ND	7	6.9	1.9	ND	31	49	38
	TOTAL IRON							
1965	5	1	0.1	0.4	5	4	6	6
1966	3	2	2	3	4	3	6	6
1967	5	3	2	2	6	5	9	5
1968	4	2	.5	2	6	2	4	3
1969	3	1	3	2	5	6	11	4
1970	2	1	.5	1	3	7	4	5
1971	2	.8	1.1	5	3	2.7	1.5	12
1980	ND	.14	.13	.05	ND	.60	.94	.89
	SULFATE							
1965	234	102	9	24	270	292	493	370
1966	163	125	53	143	253	230	405	301
1967	212	117	66	64	246	213	359	183
1968	192	114	35	97	267	165	287	212
1969	91	81	45	90	176	252	177	196
1970	93	64	32	66	197	176	280	155
1971	81	40	51	56	111	136	68	143
1980	ND	21	17	7	ND	94	120	140
	CALCIUM							
1965	NA	40	3	9	NA	115	165	136
1966	51	45	17	48	79	82	134	101
1967	69	38	24	25	79	69	131	73
1968	65	36	16	38	90	52	131	83
1969	58	103	35	46	114	327	137	99
1970	33	30	15	34	71	82	125	79
1971	46	21	46	29	63	70	62	74
1980	ND	3.4	2.1	.8	ND	14.9	14.9	19.9
	ALUMINUM							
1965	NA	6	0.4	1.4	NA	16	25	22
1966	8	7	3	7	12	13	19	14
1967	8	4	3	3	10	7	14	8
1968	7	2	1	4	9	4	12	10
1969	5	4	3	3	9	11	11	7
1970	4	2	.8	4	10	7	9	9
1971	5	.9	NA	0	7	3	NA	NA
1980	ND	.45	.23	.12	ND	2.0	1.6	2.4

NA Not available. ND No data collected. [1]1969-71 data based on daily readings.
[2]Data from Kittle Run rain gauge 5.
[3]Data from Elkins, WV, airport, adjusted to correspond with Kittle Run gauge 5 data.

TABLE C-5. - 1980 Bureau of Mines field and laboratory data

Sampling location	Sampling visit[1]	Flow, gal/min	pH	Conductivity, µmho/cm	Temp, °C	Laboratory analyses, mg/L								
						Dissolved oxygen	Acidity	Aluminum	Calcium	Ferrous iron	Total iron	Manganese	Sulfate	Total solids
Seal:														
1.......	1st	11	2.9	1,200	12.5	4.2	86	19.8	50	12.9	53	1.6	548	1,076
	2d	8	2.8	1,150	13.0	2.4	395	22	64	27	59	1.4	750	1,304
	3d	8	2.7	1,055	11.0	2.0	342	12.8	55	33	48	1.4	450	1,020
2.......	1st	33	3.2	1,000	12.5	4.8	341	18.8	46	3.2	62	1.15	525	952
	2d	36	3.0	700	12.5	2.3	304	15.1	51	6.1	46	1.1	443	916
	3d	23	2.7	925	10.5	3.0	297	17.9	55	22	44	1.4	458	876
5.......	1st	26	3.2	900	12.5	9.8	225	20	2.6	.36	16.7	2.4	375	776
	2d	15	2.9	900	13.5	10.6	388	28	2.6	.69	21	2.7	470	998
	3d	2.3	2.8	875	11.5	8.0	371	35	23	.93	24	3.3	475	1,050
4.......	1st	137	3.2	690	12.0	10.2	116	11.1	43	.10	3.4	1.3	306	544
	2d	44	3.2	750	12.5	10.8	179	14.9	55	.23	3.0	1.5	410	800
	3d	10	3.1	750	11.5	8.9	182	18.0	63	.30	3.2	1.8	415	852
3.......	1st	136	4.7	395	12.0	10.4	39	5.2	38	.11	3.3	1.1	163	336
	2d	46	3.5	475	12.8	10.6	80	7.3	52	.20	.77	1.2	270	504
	3d	27	3.5	475	11.0	8.55	90	10.0	61	.15	.40	1.6	305	604
9.......	1st	649	3.4	650	12.0	9.6	82	5.8	51	.02	3.5	.74	250	500
	2d	339	3.2	650	16.0	9.4	122	7.2	47	.69	3.3	.79	330	604
	3d	136	3.0	700	13.5	8.25	143	10.9	61	.30	4.2	1.1	360	708
12.......	1st	20	2.9	1,675	12.0	5.9	1,724	94	63	17.9	439	2.4	2,288	3,456
	2d	15	2.5	1,900	13.0	4.8	2,523	133	88	57	639	3.6	2,332	5,236
	3d	4	2.3	2,650	11.5	3.8	5,036	279	100	181	1,253	6.2	6,300	9,456

10......	1st	169	2.8	1,450	13.0	9.2	652	37	73	2.5	126	3.2	1,194	1,624
	2d	77	2.7	1,100	14.5	6.1	707	39	89	22	130	2.9	1,064	2,020
	3d	49	2.6	1,250	13.0	4.9	723	41	69	28	140	2.9	1,038	1,896
11......	1st	40	2.9	1,175	12.5	5.9	561	32	50	3.1	117	1.6	806	1,404
	2d	42	2.7	1,100	14.0	4.6	764	40	55	4.0	154	1.8	956	1,928
	3d	13	2.6	1,400	12.5	1.9	12,981	72	65	65	282	2.8	1,350	2,632
7.......	1st	177	2.9	1,125	12.0	8.6	564	27	59	.56	112	3.8	900	1,252
	2d	44	2.7	1,028	17.0	8.4	606	31	83	2.0	120	4.6	869	1,760
	3d	42	2.6	1,100	13.3	6.7	692	38	92	4.6	137	6.6	1,125	1,732
8.......	1st	50	3.2	1,000	12.5	9.6	341	22	44	.44	48	1.4	580	1,028
	2d	7.5	2.8	950	14.5	8.2	550	34	71	1.5	67	1.8	780	1,496
	3d	2.5	2.7	1,125	11.0	8.35	688	49	22	3.4	105	2.4	813	1,764
6.......	1st	63	5.5	240	12.0	7.2	11.7	.60	33	.02	.05	.13	143	260
	2d	37	5.7	290	12.0	6.8	4.6	.80	35	.10	.10	.15	153	272
	3d	17	5.6	325	11.5	6.55	3.8	.70	34	.13	.13	.14	163	276
14......	1st	62	4.0	420	12.0	6.4	31	1.4	52	.19	.40	.53	213	452
	2d	31	3.8	425	12.0	6.4	55	1.6	65	.61	.61	.57	270	484
	3d	12	3.8	450	12.0	6.3	80	1.6	70	.73	.90	.61	275	516
13......	1st	31	3.8	490	12.0	5.6	94	5.4	44	18.3	18.5	7.6	275	548
	2d	17	3.6	450	14.0	6.2	139	5.9	45	10.0	10.2	7.9	295	576
	3d	9	3.1	550	12.0	6.25	116	6.5	47	11.9	13.2	8.5	406	588
Gauging station	1st	415	3.7	215	13.0	8.9	31	2.0	14.9	.41	.60	3.1	94	164
	2d	259	3.3	250	18.0	7.2	49	1.6	14.9	.37	.94	3.3	120	204
	3d	92	3.2	250	10.0	8.25	38	2.4	19.9	.40	.89	4.2	140	196

[1] 1st visit, Mar. 27-Apr. 23; 2d, July 16-17; 3d, Oct. 15-16.

APPENDIX D.--COAL SAMPLE ANALYSES

Profile data for Lower Kittanning coal seam samples from two locations are shown in table D-1. Five supplementary coal samples were collected by the Bureau from various work areas within the Elkins demonstration project site in 1965. The results of analyses of these coal seams (Upper, Middle, and Lower Kittanning) are presented in table D-2.

TABLE D-1. - Lower Kittanning coal profile, Norton No. 2 Mine[1]

(Some of the profile data for these samples are included in table D-2; see "Norton No. 2" entries in that table.)

	Right rib, 4 right entry to main haulage, 1,200 ft from portal[2]	Left rib, 50 ft in portal of C, Kelly drift in highwall[2]
Roof	Draw slate	18 in top coal.
Floor	Hard clay shale	Gray, soft wet clay shale.
Section description	90	99.
	10 ft plus, black carbonaceous shale, 18 in; bright coal-top coat left in roof, 4 in bright coal mined; 1.5 in attrital coal (splinty); 8 in bright banded coal; 1.5 in attrital coal (splinty); 3.5 in bright banded coal; 1.5 in attrital coal (splinty); 1.5 in bright coal; 4.5 in attrital coal (splinty); 38 in bright banded coal with thin splinty streaks; 3 in shale parting; 3 in attrital coal (splinty); 20 in bright banded coal; 2 in plus, grayish shale floor rock.	18 in top coal (bright banded) left in roof; 22 in bright coal mined; 0.25-in fusain band; 36.5 in bright banded coal; 4 in shale parting; 21 in bright banded coal; 2 in plus, grayish, soft wet clay shale.
Sulfur, pct:		
Sulfate	0.11	0.
Pyritic	0.06	0.01.
Organic	0.61	0.57.

[1]Mar. 1965 data. [2]Location per mine operator's maps.

TABLE D-2. - Analyses of as-received Upper, Middle, and Lower Kittanning coal samples, percent

Mine (source)	Proximate analyses				
	Moisture	Volatile matter	Fixed carbon	Hydrogen	Ash
Fisher strip............	2.9	28.0	56.3	12.8	4.8
Flatbush No. 3..........	2.3	30.2	55.0	12.5	5.0
Proud Foot..............	2.6	28.8	53.5	15.1	4.8
Norton No. 1............	2.4	30.2	57.7	9.7	5.1
Sylvester...............	3.5	28.8	56.5	11.2	5.0
Norton No. 2:					
Right rib[1]............	3.1	27.2	58.4	11.3	4.9
Left rib[1].............	10.8	25.0	54.8	9.4	4.9
	Ultimate analyses				
	Carbon	Nitrogen	Oxygen	Sulfur[2]	Ash
Fisher strip............	72.3	1.5	7.9	0.7	12.8
Flatbush No. 3..........	74.1	1.5	5.8	1.1	12.5
Proud Foot..............	69.9	1.4	6.4	2.4	15.1
Norton No. 1............	76.6	1.5	6.3	.8	9.7
Sylvester...............	73.6	1.5	7.6	1.1	11.2
Norton No. 2:					
Right rib[1]............	73.8	1.4	7.8	.8	11.3
Left rib[1].............	65.4	1.3	18.4	.6	9.4

[1]Location identified in table D-1.
[2]Forms of sulfur:

	Sulfate	Pyritic	Organic
As received............	0.04	0.41	0.58
Moisture free..........	.04	.43	.61
Moisture and ash free..	.05	.50	.69

APPENDIX E.--CROSS-REFERENCE OF BUREAU AND EPA MINE SEAL NUMBERS

In previous studies by the EPA, the mine seals described in this report were identified by the numbers shown below.

Number used in this report	EPA number
1	RT5-2A
2	RT5-2
3	RT6-3
4	RT6-2A
5	RT6A-1
6	RT8B-3
7	RT6-23
8	RT6-25
9	RT6-5
10	RT6-9
11	RT6-12
12	RT6-6
13	RT9-11
14	RT8F-5

EPA designated the gauging station as RT9-2.

INT.-BU.OF MINES,PGH.,PA. 27322