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LONG-TERM ENVIRONMENTAL EFFECTIVENESS OF CLOSE DOWN PROCEDURES - EASTERN UNDERGROUND COAL MINES

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by

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory-Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report describes the long-term effectiveness of deep mine closures that have been or are planned to be implemented in the eastern United States coal mining regions. The data provide a basic understanding and a general assessment of the various sealing techniques and the problems the user may encounter with each. For further information contact the Resource Extraction and Handling Division, Industrial Environmental Research Laboratory-Cincinnati.

David G. Stephan
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ABSTRACT

The objective of the research project was to prepare an up-to-date document on deep mine closures that have been or are planned to be implemented in the eastern coal mining regions. The project was also to provide an initial overview of the effectiveness of the closure methods and the factors to which their effectiveness can be attributed. The effectiveness was evaluated in terms of a closure effect on mine drainage quality and quantity.

Sixty five mine sites were selected for the study. They represent a cross section of geological and mining frameworks, and cover all the known closure techniques. Available water quality and quantity monitoring records for pre- and post-closure periods and data on physical and mining character of the mines were compiled and complemented by determination of the major chemical pollutants on samples collected at the sites during wet and dry seasons.

The overall effect of the studied closures on mine water quality was found to be beneficial in terms of reduced acidity and increased alkalinity concentrations. The mine effluents from flooded shaft/slope and drift mines show generally better quality, although not consistently, when compared to the quality of mine discharges from open, air- or dry-sealed, or partially flooded updip drift mines. The effectiveness of the mine closures with respect to the mine effluent quality by comparison with the preliminary mine effluent guidelines was observed to be usually less than 50 percent effective.

The trend analyses of the pollutant concentrations and outputs for the pre- and post-closure periods show that the closures for more than half of the sites reversed or reduced increasing pollutant trends, augmented the already decreasing trends, and reduced variability in fluctuations of the water quality.

The degree of closure effectiveness with respect to the mine water quality improvement was found to be predominantly determined by the physical and mining framework of the sites and less by the closure technology.

This report was submitted in fulfillment of Contract No. 68-03-2166 by HRB-Singer, Inc. under sponsorship of the U. S. Environmental Protection Agency. This report covers the period from June 10, 1975 to July 10, 1976, and the work was completed as of December 31, 1976.

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LIST OF ABBREVIATIONS AND CONVERSION TABLE

ABBREVIATIONS

cm	-- centimeter(s)
m	-- meter(s)
km	-- kilometer(s)
km^2	-- square kilometer(s)
mg	-- milligram
kg	-- kilogram
l	-- liter
mg/l	-- milligram(s) per liter
mg/l/year	-- milligram(s) per liter per year
lpm	-- liter(s) per minute
μhos	-- micromhos
TDS	-- total dissolved solids
COD	-- chemical oxygen demand

CONVERSION TABLE

cm	-- 0.39 inches
m	-- 3.28 feet
km	-- 0.62 miles
km^2	-- 0.39 square miles
km^2	-- 249.60 acres
kg	-- 2.20 pounds
l	-- 0.26 gallons

ACKNOWLEDGMENT

This report was prepared by the Environmental and Social Analysis Group of HRB-Singer, Inc., State College, Pennsylvania 16801 under the direction of S. B. Cousin (Contract No. 68-03-2216). The report was submitted to the Industrial Environmental Research Laboratory-Cincinnati. The Project Officers for EPA were S. J. Hubbard and R. B. Scott. The principal authors were Milena F. Bucek, Jacque L. Emel, supported by Carolyn A. Petrus, James A. Schad, and Purificacion D. MacDonald. Ronald W. Stingelin offered technical guidance on regional coal geology and underground mining techniques. Program management was controlled by Elmer C. Stamm.

The support of the Institute for Research on Land and Water Resources, Pennsylvania State University, University Park, Pa. 16802 which performed the physical and chemical analyses on water samples and offered a significant contribution in statistical analyses is gratefully acknowledged. Thanks are especially given to Dama L. Wirries who contributed significantly to the section on Statistical Summary and Evaluation of Water Quality Data of this report. Thanks are also given to Stephen L. Morgan for performance of computer operations.

Special thanks are given to the owners and operators of the mines visited, as well as to the owners of adjacent property for granting us access to the sites and providing us with background information. The authors also wish to thank the representatives of Federal, State and local agencies, and industry, for their assistance and cooperation.

SECTION 1

INTRODUCTION

Commercial coal mining has been underway in the Eastern United States for over 200 years. As a result of this activity and its emphasis on profitable operations, there are literally thousands of partially mined, abandoned mines across the Eastern United States. Most of these are termed "family mines", that is, coal outcroppings on private land that were usually mined by the family of the landowner. Still others are the result of more advanced, larger undertakings using slope, drift, or shaft mining techniques that eventually became marginally profitable.

Many of these mines were responsible for water pollution problems even before they were abandoned. Such pollution resulted from surface or groundwater that flowed through the mine and was re-emitted into water supplies. Such drainage water can contain any combination of chemical elements that are either naturally occurring or a result of flowing through a mine that has disturbed the subsurface materials. The largest pollution concern is acidity caused by mineral sulfides, which inhibits many uses of the water for down-stream water users. For recreational or industrial use where high acidity is deleterious, a water supply affected by the acid mine drainage must be treated and/or avoided as polluted water.

In the late 1920's and early 1930's, the first research reports on mine sealing as an acid mine drainage abatement method began to appear, primarily as a result of the efforts of the Bureau of Mines. Under the auspices of the Work Projects Administration, the U. S. Public Health Service, and the U. S. Bureau of Mines, hundreds of mines, principally in Ohio, Pennsylvania, Kentucky, and West Virginia, were closed in the 1930's and 1940's largely by the erection of barriers designed to prevent air from entering the mine.

As knowledge of and concern for the environment expanded throughout the 1960's, so did the number of research projects and demonstration experiments bearing on abatement of acid mine drainage. Among them were many different closure methods, ranging from the rather simple technology of constructing walls in the mine openings or closing the entrances by filling them with spoil materials to the rather involved constructions of grouted double bulkheads designed to sustain high hydraulic pressures. Other approaches that are promising, but as yet untested relative to their effect on water quality are the closure methods related to mining techniques such as short-and long-wall underground mining, stowing, roof-collapse, or the very involved method of daylighting, which entails the complete removal of the mine overburden and the remaining coal with subsequent backfilling, grading, and revegetation of the area.

The awareness of the environmental need to abate and prevent acid mine drainage nationwide has led the Environmental Protection Agency to seek mine closure technology which can be effectively utilized. Since acid mine drainage is largely caused by abandoned underground mines, this study concerns itself with the long-term environmental effectiveness of underground mine closures. Numerous closure techniques have been used in the past, and engineering reviews of these methods have been documented. However, this study is an attempt to objectively document closure success on a regional scale relative to the quality and quantity of the drainage flow from the mines. Assessment and analyses of data collected during the study provide an evaluation of existing closure methods and recommendations for the further development of mine closure techniques.

The two main objectives of the study comprise (1) a preparation of an up-to-date document on deep-mine closure methods that have been or are planned to be implemented by private coal companies and/or are sponsored by State and Federal agencies, and (2) an initial overview of the effectiveness (relative to mine drainage quantity and quality) of past and present closure methods and the factors to which effectiveness or ineffectiveness might be attributable.

SECTION 2

CONCLUSIONS

The character of the data available for the analyses limits the conclusions to rather general and preliminary status. The major constraints on the conclusions are in the combination of the extreme variability of the pollutant concentrations and outputs, the rather short and discontinuous monitoring records, the use of historical data with inherent inconsistencies in sampling and laboratory methods, and an overriding influence of the physical and mining parameters, themselves time- and space-dependent, upon the mine effluent quality.

The overall evaluation of the water quality characterizing the mine discharges of the eastern coal mining regions shows large ranges and variability in the chemical pollutant concentrations. The effluents from flooded shaft, slope and drift mines show generally better quality, although not consistently, when compared to the quality of mine discharges from open, air- or dry-sealed, or partially flooded updip drift mines.

Regionally, the most severe acid mine drainage problem is related to the drift mines located in the Appalachian coal mining regions.

The most often used closure types are double and single bulkheads and air seals. Most of the sealing efforts that have longer monitoring records were sponsored by State or Federal agencies. Single bulkhead seals, and to a lesser degree the air seals, are the most frequently implemented methods used by private coal companies for the purpose of acid mine drainage abatement.

The overall effect of the studied closures on water quality is beneficial in terms of reduced acidity and increased alkalinity concentrations. The sulfate concentrations remained unaffected or increased, while total iron increased in the majority of cases.

Double bulkhead seals were effective in reducing acidity at 80 percent of the sites. The reductions ranged between 32 and 100 percent. Discharges through the sealed openings were eliminated in 30 percent of the sites. Total or partial flooding in double bulkhead sealed mines is a function of the permeability and soundness characteristics of the surrounding rocks.

The average reduction of acidity by air seals constructed in mines with shallow overburden is about 50 percent. There are indications that air sealing could be more effective if implemented in small drift mines with thicker overburden.

Permeable limestone seals are fully effective in neutralizing the mine effluent seeping through the seal. However, the water leakage around the seal periphery or sudden flushes of effluent through the seal results in considerable variability of the drainage quality. Neither of the observed seals has been successful in eliminating the flow through the seal, indicating that the expected "plugging" effect of the precipitate is not being realized.

The limited effectiveness of the sealing efforts with respect to the water quality improvements is determined predominantly by the physical and mining framework and less by the sealing technology.

The overall effectiveness of the mine closures, evaluated with respect to the mine effluent quality, by comparison with the preliminary mine effluent guidelines or with the drinking water quality standards, is usually less than 50 percent.

The trend analyses performed on available sufficiently long pre- and post-sealing records show that the mine closures for more than half of the studied sites reversed or reduced increasing pollutant trends, augmented the already decreasing trends, and also reduced the variability in fluctuations of the water quality.

The air seal seems to be the best sealing technique with respect to its effectiveness with time. Most of the double bulkhead seals studied on the project deteriorated with time and required more maintenance because of the danger of a "blowout".

The degree of mine drainage pollution control by use of mining methods such as short- or long-wall mining, daylighting, and also stowing or roof collapse could not be demonstrated on this project for lack of available water quality data.

SECTION 3

RECOMMENDATIONS

Although the effectiveness of the sealing efforts has been limited, these closure methods are still viable means of acid mine drainage control when implemented with full understanding of the physical and mining conditions of the sites in question. More research is needed to establish the physical and mining frameworks necessary for successful implementation of a sealing technique and to establish guidelines usable in this respect by private coal companies. The basic understanding of the interactions of water quality and quantity with the mine hydrological and geological background is a prerequisite to any planned sealing effort.

Because the scope of this study allowed only a rather general assessment of these relationships, further research is needed for better understanding of more specific sets of circumstances such as the function of overburden thickness and character for effectiveness of air sealing, the influence of hydrological character of a mine (including differences between high- and low-flow mines with respect to applicability of hydraulic seals), permeability characteristics of the mine floor with respect to success in mine flooding under different hydrostatic heads, evaluation of the pollution potential of groundwater aquifers in proximity to a flooded mine, etc.

It is also suggested that selected sealed sites that already have available water quality and quantity monitoring records, and possibly represent certain models of physical and mining parameters, be further monitored to allow more exhaustive evaluation of trends in the pollutant concentrations and outputs with time. The question to answer is how long a time period is necessary for a mine to reach a steady state with most of the residual pollutants leached out, and to what degree is the downward trend(if existent) influenced by the mine sealing in combination with the physical and mining framework.

As the updip drift mines in the Appalachian Coal Region generally contribute more significantly to the acid mine drainage problem than do the flooded shaft and slope mines, especially those located in the Interior Coal Region, these sites should have priority in future acid abatement studies.

The overall quality evaluation of the discharges from closed mines with respect to the mine effluent guidelines indicates that the set limits were often exceeded not only in cases of the most frequently studied pollutants such as acidity, sulfate, or total iron, but also in cases of the metallic elements such as nickel and zinc. Because there is a limited knowledge with regard to the abundance and distribution of the toxic trace metals in the mine effluents, and since the understanding of how they are affected by mine closure is inadequate, research should be initiated.

The discussed limitations of the sealing projects indicate a need for intensive research and development in the application of alternate closure techniques such as stowing, roof collapse, daylighting, down-dip, and long- or short-wall underground mining.

SECTION 4

TECHNICAL APPROACH

A multiple task approach was used on this project to ensure the satisfaction of the project objectives in an orderly and cost-effective manner.

Technically the project can be considered in terms of several basic work phases that are summarized below:

LITERATURE REVIEW

The literature review was used to provide input to site selection and to provide project personnel and the contractor with a summary of the research on and application of closure methods as of the present. The review also suggested data sources for the data procurement task. The emphasis of the review was on the effectiveness of different types of seals or closure methods, the use of these seals, experience with evaluating their success or failure, and the factors contributing to these results.

SITE SELECTION

The objective of this task was to select approximately 55 to 65 sites that would represent a cross section of abandoned underground coal mines east of the Mississippi river in the eastern coal mining regions (including the Pennsylvania anthracite region). The selected sites were to include all types of mining practices (drift, slope, and shaft mines), to be historically comprehensive from about 1930 onward, and most important, to cover all the known closure methods that vary from no particular action at all to rather involved sealing techniques or close-down methods such as stowing, shortwall mining, and others.

Approximately 200 locations were identified and characterized with regard to mine history, geologic environment, and closure method before the final selection.

The preliminary site population was identified through a literature review and telephone interview. State environmental and mining representatives, Bureau of Mines district manager, coal companies, the U.S. Geological Survey, state geological surveys, and also universities were contacted for information on the location of closure efforts.

The most important requirements for the site selection were the existence and availability of the water quality and quantity data (especially for the mine discharges before the closure), mine maps, geologic information, mine production dates, and closure engineering specifications.

The cooperation of a field contact and approval of the mine owner were also a necessary requirement in the final site selection.

The final decision to select 86 sites was based on maximization of the variety of parameter relationships and the control of the available resources for field data collection.

DATA PROCUREMENT

All the available data on the physical and mining backgrounds of the studied sites, and on the quality and quantity of the mine effluents were collected and compiled in a data base that is on file with the U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory, Cincinnati. The data were assembled as an input to the site selection and the data correlation and analysis tasks.

The data base is organized by mine sites, giving information on mine location by coordinates, nearby town, county, and state. The mining and physical parameters or constants describe the mine type, type and date of closure, production dates, total mined area, coal type, seam thickness, average thickness of the overburden, character and thickness of rocks in the overburden (shale, sandstone, and other rocks), absence or presence of calcareous material or of another coal seam in the overburden, strip mining in the mine proximity, sulfur content of the coal, structural dip of coal seam, and hydrologic type of mine.

Total overburden, soil, shale, sandstone, and other rock thicknesses in the overburden were calculated from lithologic logs and U.S. Geological Survey and State geological survey reports. From mine maps, field contact information, or engineering judgment, outlines of mined-out areas for each site were plotted on topographic maps. A grid was superimposed, and elevations were taken at grid intersections. The elevation of the coal seam (determined from mine maps or the outcrop) was subtracted from the intersection elevations and the results averaged to derive the mean overburden thickness. Quantitative estimates of soil thickness in the overburden were derived from geologic logs and soil maps. Sulfur content percentages were obtained from the U.S. Bureau of Mines Information Circular 8655.[a]

The area of water over the mines was calculated from topographic maps and field investigation.

The water quality and quantity data compiled in the data base are subdivided into two groups that describe the pre-closure and post-closure periods. The data in milligrams per liter are presented as monthly means. Total means for each of the two groups with standard deviations and number of

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[a] U.S. Bureau of Mines, The Reserve Base of Bituminous Coal and Anthracite for Underground Mining in the Eastern United States," Information Circular 8655 (1974).

observations are calculated for flow (in liters per minute) and pollutant concentrations. The concentrations are given, when available, for pH, alkalinity, total acidity, specific conductance, hardness, total dissolved solids, suspended solids, total iron, ferrous iron, sulfate, aluminum, magnesium, manganese, zinc, nickel, cadmium, mercury, dissolved oxygen, and chemical oxygen demand.

Pollutant outputs in kilograms per day and pounds per day for acidity, alkalinity, total iron, ferrous iron, and sulfates are calculated when information for both flow and pollutant concentrations are available. The total means and standard deviations are calculated for the pre- and post-sealing periods.

FIELD SURVEY

This task included monitoring the quality and quantity of the mine effluents and field inspections of the selected sites.

To demonstrate the extremes of water quality relative to flow rate and volume, two major sampling efforts were conducted. Maximum and minimum flow periods were determined for the Eastern United States using an average water year as a model. March was chosen to represent the wet season, and mid-October, the dry season.

Water samples collected at the selected mine sites were shipped to the Institute for Research on Land and Water Resources, Pennsylvania State University, for chemical analyses. Methods of sample preservation followed the EPA guidelines.[a] Chemical parameters subject to change in transport between field and laboratory were analyzed on site. A more detailed discussion of sample collection is given in Appendix B.

The field survey provided geologic and mining data not available from existing sources. Dip, slumping conditions, mine location relative to drainage, the presence of deep or strip mining in proximity to the site, and condition of the seal were assessed and measured in the field.

LABORATORY ANALYSES

The Institute for Research on Land and Water Resources at the Pennsylvania State University performed chemical analyses on water samples and characterized the quality of mine waters from a variety of inactive mines during both the dry and wet seasons of the year. A total of 199 samples were received from 85 mining sites located in Pennsylvania, Indiana, Illinois, Iowa, Ohio, West Virginia, Tennessee, and Kentucky.

Chemical analyses performed included pH, alkalinity, acidity, specific conductance, total dissolved solids, suspended solids, chemical oxygen demand, sulfates, ferrous iron, total iron, calcium, magnesium, manganese,

[a] Methods for Chemical Analysis of Water and Wastes, Methods Development and Quality Assurance Research Laboratory, National Environmental Research Center, U.S. Environmental Protection Agency (Cincinnati, 1974).

aluminum, cadmium, mercury, nickel and zinc. A listing of the results is given in Appendix B, Tables B-1 and 2.

The results of the laboratory analyses were used as a direct input to the evaluation of the acid mine drainage problem and the effectiveness of closures on a regional scale, and they are included in the data base.

SECTION 5

SITE LOCATION AND CHARACTERISTICS

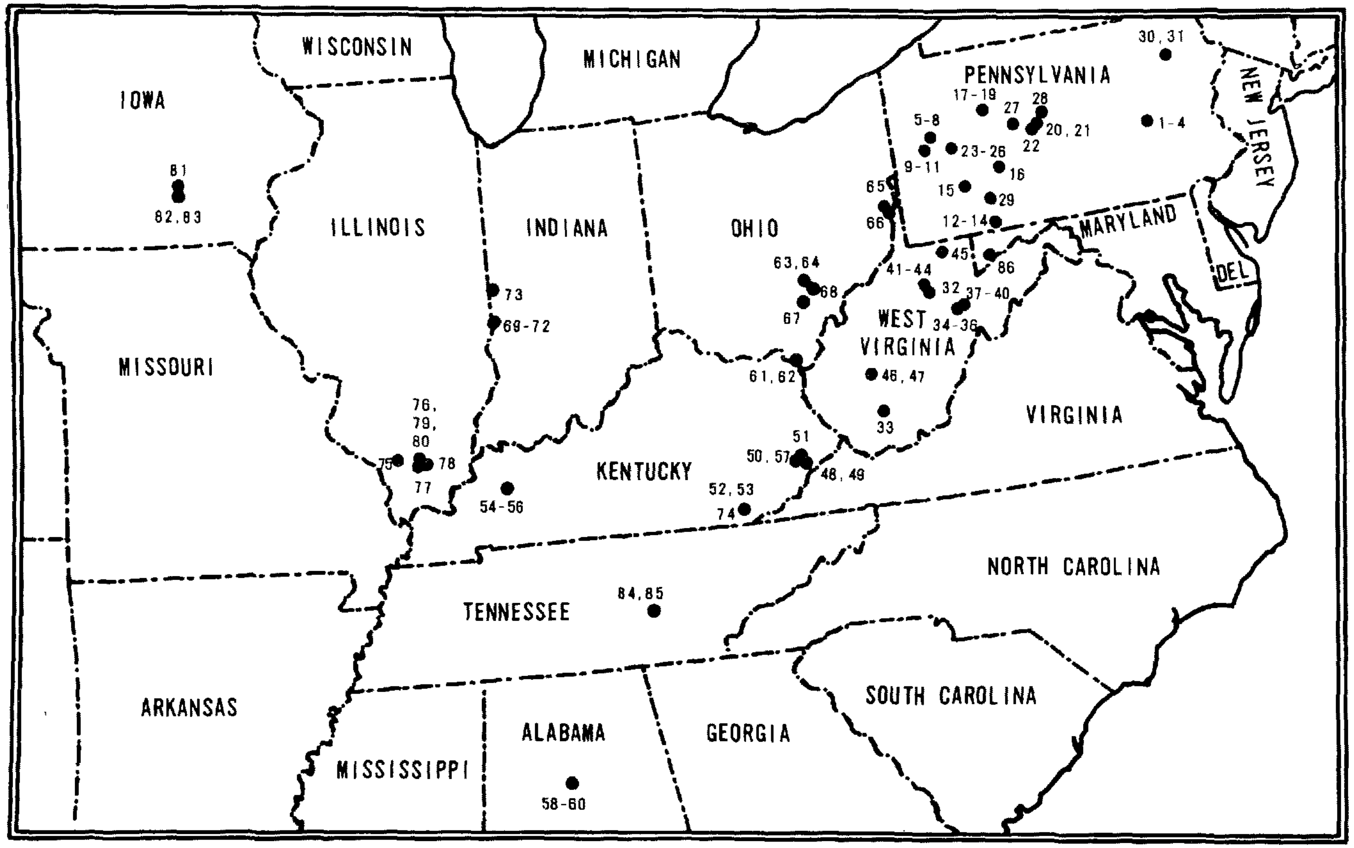
The 86 selected sites are located in Alabama, Illinois, Indiana, Iowa, Kentucky, Maryland, Ohio, Pennsylvania, Tennessee, Virginia, and West Virginia (Figure 1). Bituminous drift mines and bituminous and anthracite shaft and slope mines are included in the study population. Mine size ranges from only 0.01 to over 8.0 km^2. Production periods vary from 2 years to over 80 years, and the sample population includes mines active in the latter part of the 19th century and every decade of the 20th century to 1975.

A wide range of lithologic relationships is exemplified by the sites. Shale and sandstone ratios vary considerably among the mines, as do those involving coals and calcareous rocks above the mined seams. The thickness of the mined coal seam varies from 0.76 to 3.14 meters and sulfur contents differ from 0.6 to 4.2 percent. Total overburden thicknesses range from 7 to 165m for the drift mines and from 19 to 183m for the slope and shaft mines. Structural dip ranges from 25 degrees in the anthracite fields of Pennsylvania to nearly zero degrees in Illinois, Indiana, and Iowa.

The sample population also represents diverse hydrologic settings. Sites are located above drainage (normally in topographic highs), near drainage (a topographic low or stream valley), and below drainage. Annual precipitation ranges from 81 to 126 cm.

Closure methods represented include 12 double bulkhead and 11 single bulkhead seals, three permeable limestone seals, six earth seals, one clay seal, one grout retainer seal, and 18 slope-shaft seals. Eleven of the sites exhibit air seals. Two examples of stowing, one of short-wall mining, and one of a mine prepared for daylighting are present in the sample. Three sites display a combination of two or more closure methods, and 16 sites have not benefited from any type of close-down procedure. The sites represent closure activities undertaken from 1910 to 1975.

1. REPPLIER, PA.
2. VEITH, PA.
3. OTTO PRIMROSE, PA.
4. OTTO, PA.
5. ARGENTINE, PA.
6. KEYSTONE NO. 6, PA.
7. KEYSTONE NO. 10, PA.
8. KEYSTONE NO. 19, PA.
9. HILLIARD, PA.
10. LINDEY NO. 1, PA.
11. ISLE NO. 1, PA.
12. SHAW MINES-ELK LICK NO. 1, PA.
13. SHAW MINES-SL-118-3, PA.
14. SHAW MINES-SL-118-5, PA.
15. SALEM NO. 2, PA.
16. DRISCOLL NO. 4, PA.
17. RATTLESNAKE CREEK M., PA.
18. BUSKIRK, PA.
19. BRANDY CAMP, PA.
20. NEW WATSON, PA.
21. OLD WATSON, PA.
22. MILLS NO. 4, PA.
23. BULLROCK RUN, PA.
24. MAHONING CREEK, PA.
25. DECKER NO. 3, PA.
26. DECKER NO. 5, PA.
27. WOOLRIDGE NO. 2, PA.
28. UNKNOWN, PA.



29. DELTA, PA.
30. TAYLOR, WV.
31. STORRIES, WV.
32. 40-016, WV.
33. HELEN, WV.
34. RT 5-2, WV.
35. RT 5-2A, WV.
36. RT 9-11, WV.
37. SAVAGE, WV.
38. BIG KNOB NO. 1, WV.
39. BIG KNOB NO. 2, WV.
40. BIG KNOB NO. 6, WV.
41. 14-042 A, WV.
42. 62 008-3, WV.
43. 62 008-4, WV.
44. 62 008-5, WV.
45. STEWARTSTOWN, WV.
46. IMPERIAL COLLIERY NO. 8, WV.
47. IMPERIAL COLLIERY NO. 9, WV.
48. JACK'S CREEK, KY.
49. ARNOLD'S FORK, KY.
50. BUCKINGHAM, KY.
51. PRICE NO. 2, KY.
52. ARJAY NO. 4, KY.
53. BAKER NO. 1, KY.
54. EAST DIAMOND, KY.
55. ATKINSON, KY.
56. PLEASANTVIEW, KY.
57. BUCKINGHAM NO. 5, KY.
58. SAYRETON, AL.
59. LEWISBURG, AL.
60. NEW CASTLE, AL.
61. ELLISONVILLE, OH.
62. KELLY, OH.
63. ESSEX NO. 1, OH.
64. ESSEX NO. 2, OH.
65. PINEY FORK, OH.
66. FLORENCE, OH.
67. McDANIELS, OH.
68. BUCHTEL, OH.
69. MIAMI NO. 5, IN.
70. MIAMI NO. 10, IN.
71. VIKING, IN.
72. BENNETT, IN.
73. BLACK DIAMOND, IN.
74. BATES, IN.
75. BURNINGSTAR NO. 1, IL.
76. BUCKHORN, IL.
77. LAKE CITY, IL.
78. ENSMINGER, IL.
79. WATSON, IL.
80. CARBON FUEL, IL.
81. HULL, IA.
82. NEW LANNING, IA.
83. LOST CREEK, IA.
84. ROCK HEAD, TN.
85. PHIFERS NO. 1, TN.
86. DEER PARK, MD.

Figure 1. List and location of the mine sites studied on the project.

SECTION 6

GENERAL RESULTS OF DATA ANALYSES

The general conclusions on closure effectiveness and inherent physical and mining constraints are based on the data correlation and analyses that were done in three major phases. This threefold approach to the data evaluation was formulated after a preliminary multivariate analysis of all the data and was designed to optimize, within the scope of the project, the use of the available data, especially that on water quality and quantity.

The three basic approaches included: (1)statistical evaluation of the water quality data that characterize mine effluents from 85 mines in the eastern coal mining regions; (2)determination of closure effectiveness levels as related to percent reduction of pollutant concentration and outputs; and (3)evaluation of close-down procedure effectiveness by the closure type and mine case studies.

Ideally, the statistical evaluation of the water quality data collected for the eastern coal mining regions should show significant differences in the pollutant concentrations when comparing closed vs. open abandoned mines or water quality of samples from permanently inundated mines vs. samples from open mines above drainage, provided these factors have an overriding and final effect on the water quality. However, the rates of acid forming processes and transport of the pollutants are very strongly influenced by physical and mining parameters that themselves are time- and space-dependent and are in their combination often unique to each sampled locale.

The sampling design defined and limited within the scope of this project could not provide a sufficiently large data base to account for the complexity of the physical framework and the variability of the pollutant concentrations.

Another limiting factor encountered in the study was in the collection of meaningful data on quality and quantity of mine discharges before and after a closure. The available records usually consist of grab samples that are at best, collected weekly, but usually over longer time periods. There are also inconsistencies (inherent to any historical data) in sampling and laboratory procedures that introduce an error in the conclusions drawn from such data.

The results shown in the statistical summary of the pollutant concentrations in the mine effluents from the 85 sampled sites indicate wide ranges in the values, with some trends discernible in the data.

Two groups of sites were separated by cluster analysis performed on the water quality data. Each identified group of sites (Tables C-5 through 7) represents a cross section of sites with different closures or no closures at all. The group with the overall better water quality includes more sites where samples were taken from waters within inundated shaft/slope or hydraulically sealed mines. However, the observed modification in the mine effluent quality for both of the groups and for the range of closure types (including no closure at all) indicates that although the mine closures do modify the effluent quality to a certain degree, they do not have an overriding effect in this respect.

A varying degree of significance has been observed in relationships between the acid mine drainage chemical indicators such as pH, acidity, sulfate, and total iron and parameters that characterize the physical and mining background of a studied site. Generally, the multiple regression analysis of the data supports some of the already suggested relationships. The presence of calcareous rocks has beneficial influence on the pH and net acidity values, increases the sulfate and decreases the total iron concentrations. Positive trends or increases in acidity, sulfate, and total iron concentrations are related to the percent of sulfur in the coal. Strip mining in the site proximity results in lower pH values and increased acidity and total iron concentrations.

The overall effectiveness of the mine closures evaluated with respect to the mine effluent quality by comparison with the preliminary mine effluent guidelines or the drinking water standards is usually less than 50 percent, meaning that usually more than half of the samples exceeded the defined water quality guidelines or standards.

Most of the sealing efforts affected the acidity and pH levels in a beneficial way. The sulfate concentrations do not seem to be affected significantly. While the behavior of the total iron is rather erratic, its concentrations generally seem to increase after the mine closure. This can possibly be attributed to inadequate laboratory methods for determining the total and ferrous iron concentrations.

Although there is a considerable variability in the water quality of the mine effluents, there are often quite discernible trends present in the data that are indicative of long-term increases or decreases in the pollutant concentrations. The trend analyses performed for all of the sufficiently long pre- and post-sealing records show that the mine closures for more than half of the studied cases reversed or reduced increasing pollutant trends, augmented the already decreasing trends, and reduced the variability in fluctuations of the water quality. However, no general conclusions as to the effect of a particular closure on the pollutant trends can be drawn.

The irregularity in the mine responses to closure (or a closure method) suggests that the effectiveness is site specific. No single factor, but rather the interaction of many variables, is responsible for the failure or success of a closure. The volume of flow through the mine, the entering water's assimilative capacity, the amount of residual pollutants within the mine, the design and choice of the closure process, the physical characteristics of the mine-all are important factors that synergistically influence the effectiveness of the closure effort. The evaluations of closure effectiveness as discussed in this report should be always viewed in this perspective.

The closure methods that were most frequently implemented and studied were the sealing efforts, namely the ones concerned with construction of air, double bulkhead, and permeable limestone seals. As the effectiveness of these methods was often studied over prolonged periods of time, they have the best available water quality and quantity monitoring records. Most of these projects were sponsored by Federal and State agencies.

The first organized and extensive acid mine drainage abatement effort carried out under the Work Projects Administration (WPA) and Civil Works Administration Projects was responsible for sealing hundreds of abandoned coal mines. An overall evaluation of the WPA seals was never made, although some reports indicate considerable reductions of acid load discharges. An updating of these suggestions in this study was not possible for lack of adequate information about these seals.

The elimination of the oxygen access to mine workings through the mine overburden is the basic and most difficult problem dealt with in the air sealing efforts. The air access was not even eliminated under extraordinary measures that were taken during the sealing projects in Pennsylvania (Decker No. 3 Mine) and West Virginia (RT 9-11, Big Knob, and Savage Mines). All these mines have rather shallow overburden (22-24 meters) that is rather prone to subsidence or fracturing as a result of the undermining.

The reduction in acidity levels observed in mines closed with air seals was about 50 percent. The sulfate concentrations were observed to be mostly unchanged while the iron concentrations in several cases increased significantly.

The mines with thicker overburden should be better qualified for effective air sealing. This suggestion is supported by the case of Imperial Colliery No. 9 Mine that was air sealed in 1972. The average thickness of the mine overburden is 144m. Although the pollutant concentrations increased considerably after the sealing, they have been diminishing at considerable rates since then. There is a statistically significant relationship between the pollutant reduction rates and time at this mine.

The double bulkhead sealing resulted in reduction of acidity concentrations at 80 percent of the sites. The reductions ranged from 45 to 99 percent. The sulfate concentrations were reduced at 40 percent of the sites and increased significantly at 18 percent. The total iron concentrations behaved rather erratically; they increased substantially at about 50 percent of the sites and decreased by lesser degrees at the rest of the sites.

Double bulkhead seals were successful in total obstruction of the mine drainage through the sealed openings and in partial or total flooding of the mine in 30 percent of the cases. As the water levels and hydrostatic pressure in the mine increased, the mine waters were in almost all of the studied cases diverted through another mine opening, through weak points in the coal outcrop, in the surrounding rocks at the mine periphery and/or around the seal itself. Usually the contact between the seal and the mine floor was eroded first. The partial flooding of some of the mines can be attributed not only to the leakage resulting from the above described factors but also to an increased seepage rate through the mine floor resulting from an elevated hydrostatic head.

An extreme response to the elevated hydrostatic pressure in a mine is a sudden drainage or "blowout" of the accumulated mine water through the weakest and most strained point in the mine. The sudden release of large volumes of a mine effluent results in rather drastic changes in the downstream surface water quality, and in extreme cases it represents a considerable risk to human safety and property value. For these reasons, the hydraulic sealing should be implemented with extreme caution or not at all in mines either where expected hydrostatic pressures are not compatible with the soundness of the rocks or where the mine workings are too close to the surface.

As the overall influence of the hydraulic double bulkhead seals in respect to the effluent quality is only slightly more effective than that of the air seals, the latter type of sealing should be more appropriate for the mine with the high risk of "blowouts."

The single bulkhead seals are, along with earths seals, the closure methods most often used by private coal companies. The seals are very similar to the double bulkhead seals in their effect on the mine drainage quality and quantity. As they are not usually designed to sustain high hydraulic pressures, these seals are not effectively applicable to the high flow mines with potential for a considerable hydrostatic buildup.

The favorable effect of the permeable seals on the water quality is significant with respect to acidity and alkalinity concentrations and pH levels. The effluent discharges neutralized by the seal have alkalinity higher than acidity and pH above 6.0. The sulfate and total iron concentrations are generally unaffected. The flow continues through the studied seals several years after the construction and the "plugging" effect of the precipitate does not seem to be sufficient to stop the discharge. Most of the seals also show leakage around the seal and sudden flushes of the effluent through the seal during high flow periods. The short contact time of the effluent with the alkaline material results, then, in considerable deterioration of the effluent quality. For these reasons, permeable seals do not seem to be very applicable to high flow mines or to mines with sudden changes in their hydrological regime.

The degree of mine drainage pollution control resulting from closures related to mining techniques such as short- or long-wall mining, daylighting and also to stowing or roof collapse could not be demonstrated on this project for lack of available water quality data. Thus far, these techniques are not used as means of acid drainage control, although they seem to be rather promising in this respect.

The stowing, short- or long-wall mining, and roof collapse efforts are expected to result in reduction of void space in a mine, limitation of the oxygen-sulfide contact, and subsequent reduction or inhibition of the acid forming processes.

These methods can be used at the mine site where the other closure methods, namely sealing, are not too effective or are problematic because of the geological and hydrological conditions of the mine site. The advantage of the aforementioned methods (as opposed to mine sealing) is that they do not require any post-implementation maintenance, and some can be made more economically feasible when used for a dual purpose. Stowing, for instance, can be used for mine drainage control and subsidence control. However, the effectiveness and feasibility of these methods is also limited by the physical and mining conditions and will require further research and demonstration to assure their optimal implementation.

SECTION 7

STATISTICAL SUMMARY AND EVALUATION OF WATER QUALITY DATA FOR 85 SELECTED MINES OF THE EASTERN COAL MINING REGIONS

The study of water quality of closed and open abandoned underground coal mines was undertaken to permit an overall assessment of the acid mine drainage problem and effectiveness of closures on a regional scale.

Eighty-five sites were selected to represent a cross section of planned or implemented closure methods within the physical and mining framework of the eastern coal mining regions. The sites were visited and sampled during the dry season (Phase 1) and wet season (Phase 2) in October 1975 and March 1976, respectively.

The chemical parameters determined are acidity, alkalinity, pH, sulfate, total and ferrous iron, specific conductance, total dissolved solids, suspended solids, COD, manganese, calcium, magnesium, aluminum, cadmium, mercury, nickel, and zinc. The results of the chemical analyses for both dry and wet seasons (Phases 1 and 2) are given in Appendix B, Table B-2. The samples were analyzed by the Institute for Research on Land and Water Resources, The Pennsylvania State University. The Institute also performed the statistical evaluation of the water quality data.

Four major data sets that were subdivided by the nature of the collected samples include (1)drainages from closed drift mines (SE); (2)mine drainages from abandoned but open drift mines (UN); (3)interior mine waters from shaft or slope mines or inundated closed drift mines (SO); and (4)surface waters in proximity of the mine sites (OT).

The statistical evaluation of the data is presented in four steps that include (1)data summary; (2)cluster analysis; (3)regression analysis; and (4)an overall evaluation of mine drainage quality.

DATA SUMMARY

For the purpose of the statistical evaluations, the data sets were tested for normality. For the respective data sets, functions of the moments, such as indicators of skewness and kurtosis were calculated and the significance of their departure from the expected values of a normal population were examined. The bulk of the parameters exhibited a normal distribution in the logarithmic form, except for the variables pH and alkalinity, which proved normal in linear form. COD, mercury, and nickel proved to be non-normal for the transformations tested, partly, because many of the values obtained were less than the detection limit of the analytical procedures employed. For the purposes of the statistical analyses, values listed as less than the detection limit were assigned a value equal to one-half of that limit.

A computer program "STSUM" was utilized for testing normality in the series of parameters. The outputs that include values of the mean, variance, standard deviation and moment ratios for each parameter, given in form of computer printouts, are on file with the U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory, Cincinnati. The printouts also include plots of frequency distributions of the chemical parameters for each of the four data sets and each sampling phase.

Statistical summaries of the chemical parameters show a considerable range in the water quality exhibited for the four major data sets, (Appendix C, Tables C-1 through 4).

The samples taken from inundated shaft/slope mines or closed drift mines show generally better water quality when compared to samples taken at the rest of the sites. An improvement of the water quality in a majority of the samples was observed for the wet sampling season.

CLUSTER ANALYSIS OF THE WATER QUALITY DATA

Cluster analysis was used to examine the nature of the data distribution and implement a classification if, in fact, two distinct groups were in evidence. The patterns of variation of sites across their water quality characteristics were examined and then were grouped by their profile similarity.[a,b]

Classification of samples into groups was accomplished through the use of the Fortran program CLUS developed by Rubin and Friedman.[b,c] Data are initially converted into a principal component matrix which insures that sources of variation are linearly independent. Samples are grouped according to the differences in the variables, or more exactly, with respect to the variations in linearly independent components.

The CLUS program includes a number of criteria that may be used to determine the "best" partition of n sites into j clusters. They all depend

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[a] R. C. Tyron and D. E. Bailey, Cluster Analyses, McGraw-Hill (New York, 1972).

[b] G. H. Hall, Data Analysis in the Social Sciences: What About the Details, Proceedings Fall Joint Computer Conference (Las Vegas, 1965).

[c] J. Rubin and H. P. Friedman, A Cluster Analysis and Taxonomy System for Grouping and Classifying Data, New York Scientific Center, I.B.M. Corp. (New York, 1967).

on the fundamental relationship that the total variation (T) is composed of the variation between groups (B) plus the variation within groups (W). The best grouping is the one that maximizes the between-group variations and minimizes the within-group variations. In the analysis, two criteria were examined, namely the Wilks-Lambda criterion, which is the logarithm of the ratio between the determinant of (T) and (W) and the Mahalanobis D^2 criterion. With the latter the distance between groups is compared with distance within groups, again maximizing the variation between groups as compared with that within groups.

The variables used in the cluster analysis include pH, acidity, specific conductance, dissolved solids, suspended solids, sulfates, ferrous iron, total iron, and percent sulfur in the coal seam. The data base incorporated only those sites which were sampled in both phases, that is in October 1975 and March 1976, and included observations for mine drainages from abandoned closed mines, abandoned but open mines, and mine waters from inundated mines.

Analyses were made on individual phases as well as on the pooled data set. In each situation, two distinct groups were identified.

The sites that clustered in Group 2 exhibit better overall water quality than those in Group 1. They are characterized by higher pH values and lower concentrations of acidity, sulfate, and ferrous and total iron. The ranges and averages of the values are given in Appendix C, Tables C-5 through 7.

Some shifting of the sites between the groups was noted from low flow (Phase 1) to high flow (Phase 2) sampling periods. This can be attributed to anticipated variations of the pollutant concentrations resulting from changes in the mine hydrological conditions.

The overall water quality of some of the mine effluents was better during the dry season (Phase 1) sampling period when compared to the wet season (Phase 2) period. This was the case of mine sites that include the air-sealed Big Knob 1, 2, and 6 and Savage mines, two earth-sealed mines (Buskirk and Mills No. 4), two shaft mines from the anthracite region (Otto and Otto Primrose), three hydraulically sealed mines (Argentine, Isle No. 1, and Salem No. 2), and one unsealed mine (Old Watson). The reversed trend was observed also for two shaft mines (Veith and Burningstar No. 1), and drift mines closed by single bulkhead seals (Mines 62008-4 and 40016) and a permeable limestone seal (Mine 62008-3).

The majority of sites that clustered in the Group 2 that is characterized by better quality are the inundated shaft and slope mines (Miami No. 5, Lost Creek, Lake City, and Bennett Mines) or drift mines that were closed by double bulkhead seals (Keystone No. 6, 10, and 19 and Hilliard Mines). Two mines that were earth-sealed also belong to this group.

The better overall water quality of the interior mine waters is in agreement with the generally accepted theory that a lack of oxygen in a mine will reduce the rate of pyrite oxidation and production of the mine water pollutants. However, the observed shifting of the sites between the two water quality groups and presence of limestone in the overburden at some of the sites makes it difficult to determine to what degree the relatively lower pollutant concentrations can be attributed to the mine inundation or how much is inherent in the physical framework of the mine, including the hydrological changes.

REGRESSION ANALYSIS

To gain some insight into the relationship of the physical background of a mine and the mine effluent quality concentrations, a multiple regression analysis was performed on selected data.[a,b]

The selected independent variables that characterize the mine setting include the presence of calcareous rocks in the overburden (C), the presence of another coal seam in the overburden (ACS), the evidence of strip mining in proximity to the studied site (SM), and the percent sulfur in the coal mined at the studied site (%S). The first three variables are qualitative; either "1" or "0" was assigned to each observation denoting the presence or absence of a given feature.

The dependent variables pH, acidity, sulfate, and total iron, were regressed individually on the three qualitative and one quantitative variables using the Fortran program, "Statistical Analysis of Single Equation Stochastic Models," developed by M. C. Hallberg.[c] Results of the analysis are given in Table 1.

Examination of the table reveals that although little of the variance in the dependent variables is explained by the dummy variables, the response given is consistent with theory. The presence of calcareous rocks is seen to increase the pH and decrease acidity and total iron. The neutralizing effects of limestone are understood and it is known that in groundwaters containing measurable alkalinity, the solubility of siderite commonly limits ferrous iron concentrations.

Adjacent coal seams appear to enhance water quality, their presence suggesting higher pH values and lower levels of acidity and iron.

As expected, localized strip mining results in lower pH values and increased acidity and iron. Positive trends in acidity, sulfate and total iron are related to the percent sulfur in the coal.

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[a] George W. Snedecor and W. G. Cochran, Statistical Methods, Iowa State University Press,Ames (Iowa, 1962).

[b] J. Johnston. Econometric Methods, McGraw-Hill (New York, 1973).

[c] M. C. Hallberg, Statistical Analysis of Single Equation Stochastic Models Using the Digital Computer, Agricultural Experiment Station, The Pennsylvania State University, Agricultural Economics and Rural Sociology 78 (February, 1969).

TABLE 1. CONTROLS OF SELECTED PHYSICAL PARAMETERS ON MINE EFFLUENT QUALITY

Dependent variables	Independent variables C*		ACS+		SM†		%S			
Phase 1-dry sampling season (October 1975):	b#	% var**	b	% var	b	% var	b	% var	R^2	F Ratio
pH	0.23	1.0	1.18	11.6	-0.62	0.3	0.17	1.3	0.14	1.82
Net Acidity	-5.83	0.0	-350.3	9.6	243.7	3.2	84.6	2.5	0.15	1.98
Sulfate	151.5	3.2	356.9	5.8	0.05	0.0	470.7	27.3	0.36	6.30++
Total Iron	-43.2	-0.4	-13.9	0.0	35.7	1.7	52.5	9.5	0.10	1.31
Phase 2-wet sampling season (March 1976):										
pH	0.11	0.2	0.36	0.8	-0.55	2.6	-0.04	0.1	0.03	0.34
Net Acidity	-137.1	0.9	-60.3	0.5	145.6	3.9	134.5	8.8	0.14	1.53
Sulfate	76.3	1.0	159.5	1.3	85.3	0.5	338.9	14.5	0.17	1.93
Total Iron	-28.5	-0.6	0.9	0.0	39.1	3.5	51.2	15.1	0.18	2.03

* Presence of calcareous rock in the overburden.
\+ Presence of another coal seam in the overburden.
† Strip mining in proximity.
§ Percent of sulfur in coal.
\# Regression coefficient.
** Percent variance explained by the independent variable.
++ Significant at 1 percent probability level.

Only one equation is seen to be significant at a reasonable probability level.

Supplementary information provided by the addition of other definitive variables would enhance the explanation of variance in the quality parameters.

MINE DRAINAGE QUALITY

An ultimate goal of acid mine drainage abatement efforts is to improve the effluent quality to approach or to meet the water quality standards.

To evaluate the sampled mine effluents in this respect, the concentrations of several chemical parameters were compared with the preliminary effluent guidelines for mine waters that were given in the draft copy of a report prepared by Skelly and Loy for the U.S. Environmental Protection Agency.[a] A list of the sites where the effluent exceeded the guidelines for pH, total iron, aluminum, manganese, nickel, zinc, and suspended solids, is given in Appendix C, Table C-8. A distribution of the number of samples from closed mines that exceeded the guidelines or the drinking water quality standards is given in Table 2.

TABLE 2. DISTRIBUTION OF SAMPLES THAT EXCEEDED THE EPA PRELIMINARY EFFLUENT GUIDELINES OR DRINKING WATER STANDARDS

Parameter	Percent of samples exceeding guideline or standard	Limit
pH	65	6.0*
Total iron	72	3.5 mg/l*
Net acidity	66	0
Suspended solids	28	35.0 mg/l*
Aluminum	42	2.0 mg/l*
Nickel	55	0.20 mg/l*
Zinc	45	0.20 mg/l*
Manganese	45	2.0 mg/l*
Sulfates	55	250 mg/l+
Dissolved solids	70	500 mg/l+
Cadmium	0	0.01 mg/l+
Mercury	0	0.002 mg/l+

* Mine drainage guideline.
\+ Drinking water standard.

[a] Skelly and Loy, Inc., Development Document for Effluent Limitations, Guidelines, and Standards of Performance for the Coal Mining Point Source Category, U.S. Environmental Protection Agency (January, 1975).

The drinking water standards were used for concentrations of sulfates, dissolved solids, cadmium, and mercury. The latter two parameters were the only ones in which all the analyzed samples met the quality standards. The dissolved solids and sulfate concentrations exceeded the standards for 55 and 70 percent of the samples. More than half of the samples exceeded the guidelines set for total iron, net acidity, pH, aluminum, nickel, zinc, and manganese. Total iron exceeded the set guideline most frequently of all the parameters (by 72 percent).

The high percentage of samples that exceeded the effluent guidelines of the drinking water standards indicates that the overall effectiveness of the mine closures in this respect is limited and usually less than 50 percent successful.

SECTION 8

CLOSURE EFFECTIVENESS AS RELATED TO REDUCTION OF POLLUTANT CONCENTRATIONS AND OUTPUTS

The effectiveness of mine closure methods is evaluated here in terms of water quality improvement and reduction of pollutant outputs.

Changes in the mine effluent quality and quantity are expressed in percentages of reduction or an increase of the major pollutant concentrations or outputs comparing the pre-sealing and post-sealing periods. The chemical constituents considered in the evaluations are acidity, sulfate, total iron, and pH. These are the pollutants that are indicative of the acid mine drainage pollution problem and hence the most often monitored.

The data base that contains all the available water quality and quantity data for the studied sites is used as a major input to analyses. The percentages of reductions or increases are calculated for the total means of pre- and post-sealing periods. The results are compiled by types of closure and by individual sites in Tables 3 through 12.

The considerable variability of the chemical parameters, the rates of mine discharges, and the absence of data for some sites or rather short monitoring records for others have to be taken into consideration in evaluating the changes.

In order to account for some of these concerns, a statistical test of the reliability of the difference between the means of pre- and post-sealing parameters was computed for each set of parameter concentration and load wherever data permitted (at least three observations per parameter per sampling period). The test entails calculation of the standard error of the difference between the means by taking the square root of the sum of each mean's squared standard error. The actual distance between the means was then divided by this product and the estimated ratio compared with tabular t-values for given degrees of freedom to test for the significance between the means.

For this test, the level of significance that must be met by the ratio is generally considered to be at least 0.10; there are only 10 chances in 100 that a difference as large as that being tested could have happened by sampling of the same population. Similarly, for a ratio significant at 0.01 (or 0.05), there is only one chance (or five) in 100 that the difference could be due to sampling of the same population.[a]

[a] W. J. Dixon and F. J. Massey, Jr., Introduction to Statistical Analysis, McGraw-Hill Co. (New York, 1969).

To show patterns in the water quality data that might be undiscernable because of the variability or fluctuation in the raw data, trend analyses were performed for acid, total iron, and sulfate concentrations and loads using the principle of least squares.

A regression formula was used to calculate the intercept, slope, and standard error of the slope or trend line. The magnitude of the standard error relative to the coefficient illustrates the reliability of the line as an estimator, and, to a great extent, the variability of the constituent concentrations or loads. In general, the regression coefficient is significant if its value is larger than the standard error value.

The closure methods that have pre- and post-sealing monitoring records will be discussed. They include air seals, double and single bulkhead seals, and permeable limestone seals.

AIR SEALS

Eleven air-sealed sites located in Pennsylvania, West Virginia and Ohio were studied in this project. A list of these and their location are given in Figure 1. Three of the mine sites (Essex No. 1, Kelly, and Elk Lick No. 1) were sealed in the 1930's as part of the Work Projects Administration projects, and one site (Imperial Colliery No. 9) was sealed in 1975 by a private company. The U.S. Bureau of Mines sponsored a very extensive water quality monitoring program in conjunction with the air sealing of Decker No. 3 Mine. Mine RT-9-11 was sealed as part of the Elkins demonstration project sponsored by several Federal agencies and the State of West Virginia. The latter agency also sponsored the air sealing of Big Knob and Savage Mines in the Shavers Fork watershed. The very involved study of acid discharges under controlled oxygen levels at McDaniels Mine in Ohio was sponsored by the Water Quality Office of the U.S. Environmental Protection Agency.

Six of the 11 sites have both the pre- and post-sealing data to allow calculations of pollutant reductions or increases. Five of the sites have sufficient data for the trend analysis. Tables 3 through 5 and Tables D-1 through 3 summarize the calculations.

Three mines (Decker No. 3, RT 9-11, and Savage) show measurable improvements in acidity concentrations, with reductions by 57, 45, and 50 percent, respectively. Sulfate concentrations were favorably effected at Decker No. 3 Mine, while the differences in sulfate concentrations at RT 9-11, Imperial Colliery No. 9, Big Knob No. 1, 2, and Savage Mines are not significant at the 0.10 level and can be considered basically unchanged. Total iron concentrations were also reduced at two sites (Decker No. 3 and Big Knob No. 2); however, significant increases (over 100 percent) were found at Big Knob No. 7 and Savage Mines.

The pollutant outputs were also impacted differently from site to site. Acidity outputs decreased significantly at Decker No. 3, Big Knob No. 2, and Savage Mines by 81, 42 and 41 percent and remained basically unchanged at RT 9-11 and Big Knob No. 1. Sulfate outputs increased by 71 percent at RT 9-11, and they were reduced significantly at the Decker No. 3 Mine;

TABLE 3. PERCENTAGE CHANGES OF POLLUTANT CONCENTRATIONS IN EFFLUENT DISCHARGES FROM AIR-SEALED MINES; PRE- AND POST-CLOSURE PERIODS

Mine name	Acidity R*	Acidity I+	Alkalinity R	Alkalinity I	Sulfate R	Sulfate I	Total Iron R	Total Iron I
Decker No. 3	57	-	#	#	31	-	71	-
RT 9-11	45	-	#	#	19	-	59	-
Imperial Colliery No. 9	-	107	#	.4	21	-	-	147
Big Knob No. 1	-	1	#	#	-	14	57	-
Big Knob No. 2	-	8	-	150	-	10	-	125
Big Knob No. 6	#	#	#	#	#	#	#	#
Savage	50	-	-	16	-	2	-	109

* Pollutant reduction in percent.
\+ Pollutant increase in percent.
\# No pre- or post-sealing data available.

TABLE 4. PERCENTAGE CHANGES OF POLLUTANT OUTPUTS FROM AIR-SEALED MINES; PRE- AND POST-CLOSURE PERIODS

Mine name	Acidity R*	Acidity I+	Sulfate R	Sulfate I	Total Iron R	Total Iron I
Decker No. 3	81	-	70	-	81	-
RT 9-11	-	21	-	71	-	62
Imperial Colliery No. 9	#	#	#	#	#	#
Big Knob No. 1	5	-	5	-	-	198
Big Knob No. 2	42	-	30	-	76	-
Big Knob No. 6	#	#	#	#	#	#
Savage	41	-	24	-	-	37

* Pollutant output reduction in percent.
\+ Pollutant output increase in percent.
\# No pre- and post-sealing data available.

TABLE 5. SIGNIFICANCE OF SCORES FROM TEST FOR DIFFERENCE BETWEEN PRE- AND POST-CLOSURE MEANS FOR AIR SEALS

	Acidity		Total Iron		Sulfate	
Mine name	Concentration	Output	Concentration	Output	Concentration	Output
Decker No. 3	26.64*	6.41*	19.31*	5.93*	17.62*	4.81*
RT 9-11	15.14*	.57	23.80*	1.60	1.02	2.06+
Imperial Colliery No. 9	ID†	ID	ID	ID	ID	ID
Big Knob No. 1	.06	.04	2.39+	1.95§	.64	.10
Big Knob No. 2	.66	2.74*	.83	1.05	.50	1.07
Big Knob No. 6	ID	ID	ID	ID	ID	ID
Savage	3.70*	2.34+	2.28+	.49	.47	.88
Essex No. 1	ID	ID	ID	ID	ID	ID
Kelly	ID	ID	ID	ID	ID	ID
McDaniels	2.10+	ID	ID	ID	ID	ID
Elk Lick No. 1	ID	ID	ID	ID	ID	ID

* Significant at 0.01.
\+ Significant at 0.05.
† Insufficient data; fewer than two observations.
§ Significant at 0.10.

they remained unchanged at the rest of the sites. The changes in total iron outputs were very similar to those of sulfate.

The Decker No. 3 is the only mine where concentrations and outputs of all three pollutants were reduced. The pollutant concentrations decreased on the average by 50 percent.

The effect of air seals on the water quality is beneficial only in terms of the reduction of acidity (about 50 percent). The sulfate concentrations were observed to be unchanged or increased, and the iron concentrations in several cases increased significantly.

The quality of the effluent from the air-sealed mines as compared to the mine effluent guidelines and/or water standards is rather poor. Three of the 11 air-sealed sites are producing discharges with alkalinity higher than acidity, and only two of the sites meet the effluent guideline of pH 6.0. Sulfate concentrations acceptable by the drinking water quality standards (250 mg/l) are found at eight sites, and total iron concentrations at or below the mine effluent limit (3.5 mg/l) are present in the discharges of five of the sites.

DOUBLE BULKHEAD SEALS

Twelve sites closed by the double bulkhead technique were investigated during the course of this study. They are located in Pennsylvania (Argentine, Keystone No. 6, 10, and 19, Isle No. 1, Hilliard, Lindey No. 1, Shaw SL-118-5, and Salem No. 2), in West Virginia (RT 5-2 and 62008-5) and in Tennessee (Phifers No. 1). All were sealed within the last decade. All the sealing efforts in Pennsylvania were sponsored by the Commonwealth of Pennsylvania as part of Operation Scarlift. The West Virginia sites were closed under the sponsorship of the U.S. Environmental Protection Agency and Tennessee site by the University of Tennessee and the Tennessee Valley Authority. The mine locations are given in Figure 1. Eleven out of 12 sites have both pre- and post-sealing data to allow calculations of pollutant reductions. Tables 6 through 8, and Tables D-4 through 9 summarize all the calculations.

The double bulkhead seals were successful in total obstruction of mine discharges and subsequent mine flooding in four of the 12 studied sites. The Lindey No. 1 (sealed in 1970), Phifers No. 1 (sealed in 1975), and Keystone No. 6 (sealed in 1975) sites exhibited no discharge during either the October 1975 or the March 1976 site survey. The RT 5-2 mine portal did not leak for 2 years after the seal was installed (1969-71), but is draining now because a safety valve installed in the seal was opened. The water impounded behind the seal was draining through the RT 5-2A opening sealed with a permeable limestone seal.

Flow was reduced significantly at the 62008-5 mine portal to an average of 0.85 liters per minute (lpm). There was no flow observed at the Shaw SL-118-5 hydraulically sealed portals in October 1975 but a 3 lpm discharge was observed in March 1976. No flow during the dry season was observed at the Salem No. 2 and Keystone No. 10 sites, and discharges in the wet season were measured at 7 lpm and 1 lpm for the respective sites.

TABLE 6. PERCENTAGE CHANGES IN POLLUTANT CONCENTRATIONS FOR PRE- AND POST-CLOSURE PERIODS IN DOUBLE BULKHEAD-SEALED MINES

	Acidity		Alkalinity		Sulfate		Total Iron	
Mine name	R*	I+	R	I	R	I	R	I
Argentine	50	-	-	1454	54	-	31	-
Argentine OB†	72	-	-	8736	-	130	7	-
Keystone No. 6	§	§	§	§	§	§	§	§
Keystone No. 6 OB	86	-		100	65	-	-	235
Keystone No. 10	57	-	-	3713	-	238	-	539
Keystone No. 10 OB	84	-	-	2734	-	97	-	627
Keystone No. 19	93	-	-	100	92	-	5	-
Keystone No. 19 OB	95	-	-	100	56	-	-	1
Hilliard	-	16	-	616	§	§	-	267
Hilliard OB	61	-	-	9830	§	§	-	613
Lindey No. 1	§	§	§	§	§	§	§	§
Lindey No. 1 OB	99	-	§	§	§	§	7	-
Shaw SL-118-5	34	-	§	§	46	-	40	-
Shaw SL-118-5 CD#	20	-	§	§	34	-	62	-
Salem No. 2	32	-	-	0	48	-	49	-
Salem No. 2 OB	97	-	-	100	94	-	70	-
RT 5-2	-	16	§	§	14	-	42	-
RT 5-2 OB	-	61	§	§	§	118	-	137
Phifers No. 1	§	§	§	§	§	§	§	§
Phifers No. 1 OB	100	-	§	§	56	-	30	-
Isle No. 1	53	-	-	405	§	§	46	-
Isle No. 1 OB	86	-	-	377	§	§	-	62
62008-5	52	-	§	§	13	-	-	19

* Pollutant reduction in percent.
\+ Pollutant increase in percent.
† Samples taken from observation borings.
§ No pre- or post- data available.
\# Combined drainage from several mine openings.

No apparent overall change in the rate of effluent discharges took place by sealing the Isle No. 1, Hilliard, and Argentine mine openings. The discharge rate at the Keystone No. 10 opening increased by nearly 600 percent; as a result of the diversion of mine water from the previously draining Keystone No. 6 and No. 19 openings through this portal.

The double bulkhead sealing resulted in reductions of acidity concentrations at all except two sites. The discharges from Hilliard mine show basically no change, but the acidity concentrations in the flooded mine behind RT 5-2 seal increased by 61 percent. The reductions observed at the mine sites range from 32 to 99 percent. The difference between the concentration means for the Argentine site is not significant at the 0.10 level.

The sulfate concentrations have been reduced at the majority of the sites with the reduction rates ranging from 14 to 94 percent. At the Keystone No. 10 site the post-sealing sulfate increased by 238 percent. The interior mine waters from RT 5-2 and Argentine Mines show a significant sulfate increase.

TABLE 7. PERCENTAGE CHANGES IN POLLUTANT OUTPUTS FOR PRE- AND POST-CLOSURE PERIODS IN DOUBLE BULKHEAD-SEALED MINES

	Acidity		Alkalinity		Sulfate		Total Iron	
MINE NAME	R*	I+	R	I	R	I	R	I
Argentine	81	-	38	-	32	-	82	-
Keystone No. 6	†	†	†	†	†	†	†	†
Keystone No. 10	-	246	-	156	-	2822	-	4096
Keystone No. 19	100	-	-	100	99	-	90	-
Hilliard	-	203	-	500	†	†	-	1550
Lindey No. 1	†	†	†	†	†	†	†	†
Shaw SL-118-5	†	†	†	†	†	†	†	†
Shaw SL-118-5 CD §	†	†	†	†	†	†	†	†
Salem No. 2	98	-	†	†	98	-	98	-
RT 5-2	76	-	†	†	85	-	87	-
Isle No. 1	54	-	†	335	†	†	54	-
62008-5	96	-	†	†	93	†	90	-

* Pollutant reduction in percent.
\+ Pollutant increase in percent.
† No pre- and post- data available.
§ Combined drainage from several mine openings.

The total iron concentrations behaved rather erratically and increased at about half of the sites and decreased at the other half. However, the

TABLE 8. SIGNIFICANCE OF SCORES FROM TEST FOR DIFFERENCE BETWEEN PRE- AND POST-CLOSURE MEANS: DOUBLE BULKHEAD SEALS

	Acidity		Total Iron		Sulfate	
Mine name	Concentration	Output	Concentration	Output	Concentration	Output
Argentine	0.97	2.25*	0.79	4.99+	4.20+	0.34
Keystone No. 6	NF†	NF	NF	NF	NF	NF
Keystone No. 10	2.36*	0.88	0.70	0.78	4.08+	1.75§
Keystone No. 19	ID#	ID	ID	ID	ID	ID
Hilliard	0.29	0.58	0.85	0.69	ID	ID
Lindey No. 1	NF	NF	NF	NF	NF	NF
Shaw SL-118-5	1.52	ID	4.52+	ID	1.46	ID
Shaw SL-118-5 CD**	2.42*	ID	10.41+	ID	4.93+	ID
Salem No. 2	4.09+	5.44+	1.01	4.59+	3.61+	5.76+
RT 5-2	0.42	4.27+	1.64§	4.10+	0.41	5.08+
Phifers No. 1	NF	NF	NF	NF	NF	NF
Isle No. 1	2.23*	1.58	1.59	1.64§	ID	ID
62008-5	ID	ID	ID	ID	ID	ID

* Significant at 0.05.
\+ Significant at 0.01.
† No flow observed during post-sealing period.
§ Significant at 0.10.
\# Insufficient data; fewer than two observations.
** Combined drainage from several mine openings.

rates of reduction range from 5 to 70 percent, and the rates of increases are often above 100 percent and reach up to 627 percent.

Although the quality of the mine effluent was considerably affected by the mine closure, especially with respect to the acidity and alkalinity levels, only four sampled sites show levels of alkalinity higher than those of acidity while pH values are below 6.0 at 10 of the sites. Most of the sites exceed the mine effluent guideline for the total iron concentrations. The sulfate concentrations are higher than 250 mg/l in five cases.

SINGLE BULKHEAD SEALS

Eleven mines sealed with single bulkhead seals located in West Virginia, Ohio, Kentucky, and Pennsylvania were studied. Locations of the mines are shown in Figure 1.

The sealing efforts in the West Virginia mines (Mine No. 40016 and No. 62008-4) were sponsored by the U.S. Environmental Protection Agency and all the mines in Ohio (Ellisonville, Piney Fork, and Florence) and Kentucky (Buckingham and Price No. 2) were sealed by private coal companies. Three Pennsylvania sites (Decker No. 5, Woolridge, and Bullrock Run mines) were also sealed by private coal companies while the Pennsylvania Department of Environmental Resources sponsored extensive abatement projects in Rattlesnake Creek watershed as part of the Operation Scarlift, Project Sl 132, 2-101-1.

Evaluation of single bulkhead seals is limited because of the lack of pre-sealing quality and quantity data. Only four of the survey sites have even one observation before closure. The summary of the total means of pollutant concentrations and loads and percent of their post-sealing increase or reduction is given in Table 9, and Tables D-10 through 13.

The most distinctive reduction in flow took place at the Rattlesnake Creek Mine where the pre-sealing discharge was measured at from 611.5 to 2128.0 lpm and post-sealing flow was nonexistent in October 1975 and minimal in March 1976. Flow was reduced for at least one year at the Mine 40-016 and 62008-4 sites; however, it is now in excess of the pre-sealing measurements. In the case of the 62008-4 site, the increase was partially due to obstruction of flow at an interconnected portal (62008-5).

There are no pre-sealing flow measurements for any of the other mines, but it is assumed the seals reduced flow at the Bullrock, the Decker No. 5, and Ellisonville Mines, where discharges average only 7, 7.5, and 2.0 lpm, respectively.

Acid and total iron concentrations were significantly decreased by closure at the 40-016 and 62008-4 sites. Acidity was reduced at the Rattlesnake Creek Mine and total iron was significantly reduced at the Bullrock Mine site. Acidity increased at the Bullrock Mine as did sulfates, but the intensive surface mining of the area may be responsible for the augmented measures rather than any effect the sealing might have had. Alkalinity increased at the Bullrock site, as well.

TABLE 9. PERCENTAGE CHANGES IN POLLUTANT CONCENTRATIONS FOR PRE- AND POST-CLOSURE PERIODS IN SINGLE BULKHEAD-SEALED MINES

Mine name	Acidity R*	Acidity I+	Alkalinity R	Alkalinity I	Sulfate R	Sulfate I	Total Iron R	Total Iron I
62 008-4	63	-	-	100	16	-	79	-
Decker No. 5	†	†	†	†	†	†	†	†
Woolridge No. 1	†	†	†	†	†	†	†	†
Bullrock Run	-	1329	-	38	-	9	94	-
Buckingham	†	†	†	†	†	†	†	†
Price No. 2	†	†	†	†	†	†	†	†
Ellisonville	†	†	†	†	†	†	†	†
Piney Fork	†	†	†	†	†	†	†	†
Florence	†	†	†	†	†	†	†	†
Rattlesnake Creek	46	-	-	3	†	†	†	†
40-016	51	-	†	†	†	†	38	-

* Reduction in concentration in percent.
\+ Increase in concentration in percent.
† No pre- and post-data available.

Sulfate concentrations (other than those at Bullrock Mine) show some small fluctuations between sampling period means; however, none of the reductions or increases are large enough in view of the standard deviations to assume that the single bulkhead seals have any impact on them.

Of the nine mines discharging in October 1975 and March 1976, four show alkalinity in excess of acidity (alkalinity has not been measured for the Woolridge Mine), seven show sulfate in excess of the drinking water standards, and seven have total iron discharges in excess of the 3.5 mg/l mine effluent limit.

PERMEABLE LIMESTONE SEALS

The effectiveness of the permeable limestone seals was studied at three sites in West Virginia. These are mines 62008-3 near Clarksburg, RT 5-2A near Coalton, and the "unknown" mine near Stewartstown. Location of the mines is shown in Figure 1. Construction and monitoring of mine discharges was sponsored by the U.S. Environmental Protection Agency.

The presence of the permeable limestone seals resulted in a significant decrease in acidity concentrations and loads at all of the three studied sites (Tables 10 through 12 and Tables D-14 and 15). However, in the case of Mine 62008-3, the short monitoring record does not allow for statistical validation of the result.

TABLE 10. PERCENTAGE CHANGES IN POLLUTANT CONCENTRATIONS FOR PRE- AND POST-CLOSURE PERIODS IN EFFLUENT DISCHARGES FROM MINES SEALED WITH PERMEABLE LIMESTONE SEALS

	Acidity		Alkalinity		Sulfate		Total Iron	
Mine name	R*	I+	R	I	R	I	R	I
62008-3	44	-	-	100	-	10	18	-
Stewartstown	62	-	†	†	8	-	64	-
Stewartstown OB§	-	6	†	†		55	-	82
RT 5-2A	84	-	†	†	-	35	25	
RT 5-2A OB	-	60	†	†	-	134	-	127

* Reduction in percent.
\+ Increase in percent.
† No pre- and post-data available.
§ Sample from observation boring behind seal.

TABLE 11. PERCENTAGE CHANGES IN POLLUTANT OUTPUTS FROM MINES CLOSED WITH PERMEABLE LIMESTONE SEALS COMPARING PRE- AND POST-SEALING PERIODS

	Acidity		Alkalinity		Sulfate		Total Iron	
Mine name	R*	I+	R	I	R	I	R	I
62008-3	-	17	-	100	-	42	-	22
Stewartstown	90	†	†	†	79	†	90	-
RT 5-2A	99	†	†	†	96	†	98	-

* Reduction in percent.

\+ Increase in percent.

† No pre- and post-data available.

The concentrations of sulfate remained relatively unaffected at two sites and were significantly increased at Stewartstown. Total iron concentrations were slightly diminished at Mines 62008-3 and RT 5-2A and decreased by 64 percent at Stewartstown. The variability of the concentrations was either unaffected or increased. The water quality behind the seals at RT 5-2A and Stewartstown was deleteriously affected by the closures.

Water quality of the discharges from the three permeable seals depends on the length of the effluent contact with the seal and its neutralizing effect. The effluent that seeps through the seal has higher alkalinity than acidity concentrations, and pH levels that meet the mine effluent guidelines of 6.0. However, as the seal at Stewartstown was recently breached, the effluent does not meet the guidelines.

The total iron and sulfate concentrations of all the three mine discharges exceed the given mine effluent guidelines and the drinking water standards.

TABLE 12. SIGNIFICANCE OF SCORES FROM TEST FOR DIFFERENCE BETWEEN PRE- AND POST-CLOSURE MEANS: PERMEABLE LIMESTONE SEALS

	Acidity		Total Iron		Sulfate	
Mine name	Concentration	Output	Concentration	Output	Concentration	Output
62008-3	0.62	ID*	0.33	ID	0.29	ID
Stewartstown	3.15+	2.43†	3.25+	5.89+	0.55	6.55+
RT 5-2A	14.77+	5.67+	2.50†	4.78+	3.12+	45.41+

* Insufficient data; fewer than two observations.

\+ Significance at 0.01.

† Significance at 0.05.

SECTION 9

EFFECTIVENESS OF CLOSE-DOWN PROCEDURES BY CLOSURE TYPE AND MINE CASE STUDIES

The preceeding chapters dealt with the more generalized view of the closure effectiveness levels in an attempt to arrive at some common underlying relationships among the closure effectiveness and the physical and mining factors. However, as indicated by the previous analyses, the unique situation at most of the localities affects the closure effectiveness and should therefore be addressed.

In this section, the mines are grouped by type of closure and discussed by case.

AIR SEALS

Air sealing of underground mines involves placing impermeable materials in all mine openings through which air may enter. One entry, usually the lowest entry to the mine, is provided with an air trap which allows water to discharge from the mine, but prevents the entrance of air. In a successfully air sealed mine the oxidation of sulfide minerals is retarded and formation of the mine drainage pollutants controlled.[a]

Decker No. 3 Mine, Kittanning, Pennsylvania

The Decker No. 3 Mine was sealed in May 1966 as part of the U.S. Bureau of Mines effort to evaluate the effectiveness of air sealing and indicated the factors that determine the overall character of the acid mine discharges. The mine effluent flow rate and quality was monitored continuously from 1963 to 1968. The atmosphere in the sealed mine was sampled periodically, and the differential air pressure across the seal was recorded.[b] An example of the seal is given in Figure 2.

The water quality of the mine discharge before closure was characterized by acidity concentrations averaging 486 mg/l, sulfate concentrations

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[a] L. R. Scott and R. M. Hays, Inactive and Abandoned Underground Mines, Water Pollution Prevention and Control, EPA 440 9-75-007, U. S. Environmental Protection Agency (Washington, 1975).

[b] N. N. Moebs, Mine Sealing: A Progress Report, Proc. Second Symposium on Coal Mine Drainage Research (Pittsburgh, 1968).

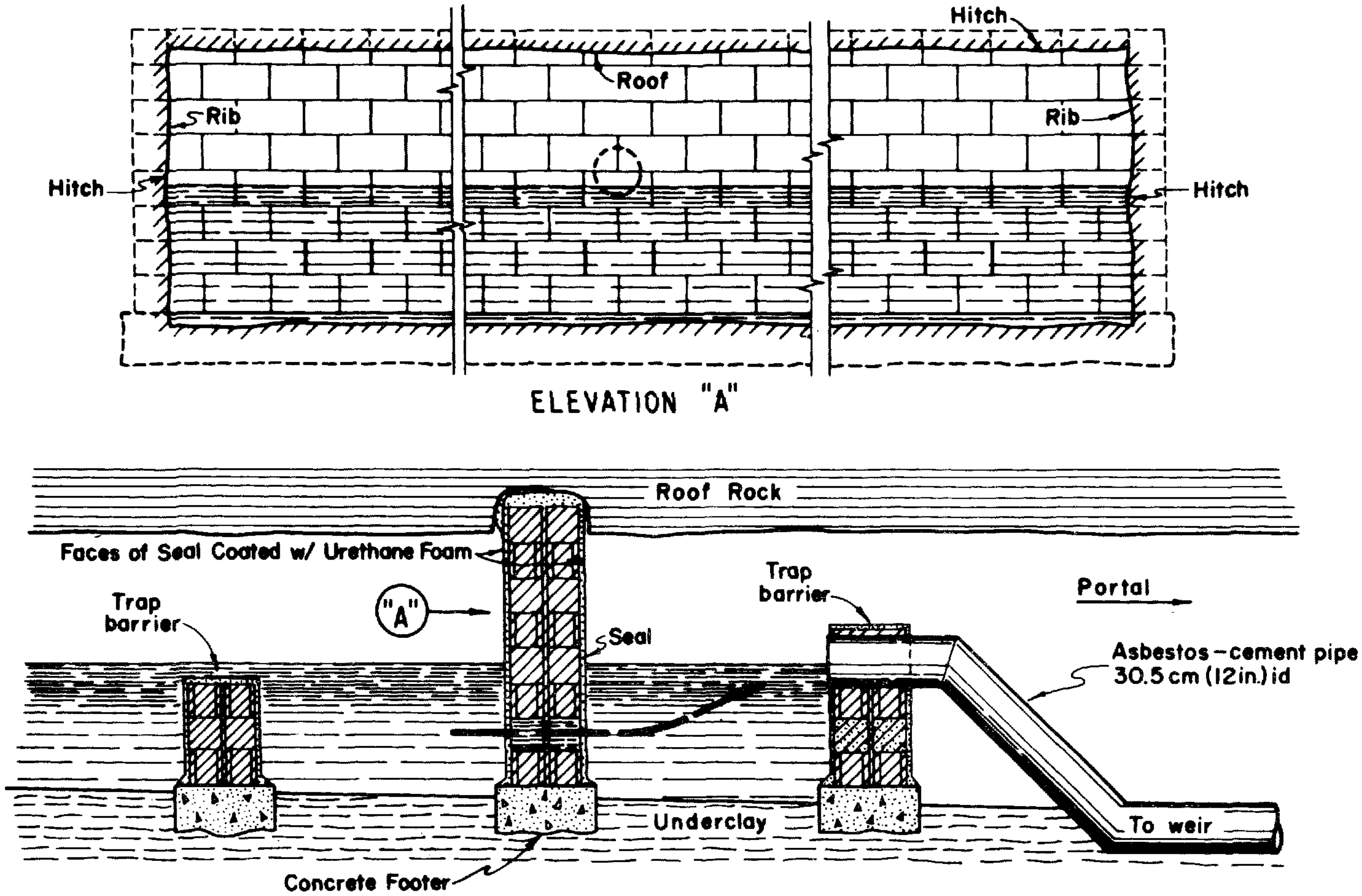

Figure 2. Example of an air seal constructed by U.S. Bureau of Mines at Decker No. 3 Mine as shown in R.L. Scott and R.M. Hays, Inactive and Abandoned Underground Mines, EPA-440/9-75-007.

of 1282 mg/1, and total iron of 142 mg/1. The sealing of the mine resulted in reduction of all three pollutants. The post-sealing grand means for acidity, sulfate, and total iron show 57, 31, and 59 percent reductions. The test for difference in means specified probabilities of less than one percent of obtaining these reductions (or large differences) simply due to sampling error. There is also a decrease in the variability of each of the three parameters following installation of the seal as exemplified by comparison of the pre- and post-sealing standard deviations of the means in Tables D-1 through 3.

Post-sealing acidity, sulfate, and total iron outputs (loads) show reductions of 81, 70, and 81 percent, respectively. Again, the difference in the pre- and post-sealing sampling periods are large enough to be significant at the 0.01 level (1 percent probability). Comparison of standard deviations of the load means before and after sealing suggest a decrease in water quality and quantity fluctuations as well.

The monitoring record of the Decker No. 3 Mine is the most exhaustive of the mines involved in this study, with 343 observations for pre-sealing acidity, sulfate, and total iron loads and concentrations, and 173 and 135 observations for post-sealing concentrations and loads, respectively.

Figure 3 (trends of concentrations) illustrates the sudden decrease in the concentrations of acid, sulfate, and total iron immediately after sealing. The rate of the sulfate reduction becomes faster with time rising from 150 mg/1 per year to 176 mg/1 per year. However, the rates of decrease for acidity and total iron are reduced by completion of the seal.

Load rates for all parameters are shown to be decreasing before closure. The effect of the seal was to reduce these rates from 277.0 kg/year to 34.2 kg/year for acidity, from 527.1 kg/year to 79.0 kg/year for sulfate, and from 88.5 kg/year to 11.7 kg/year for total iron. Each of the concentrations and load coefficients is significant beyond the 0.01 level.

It is obvious from the graphic portrayal of the monthly means (Figure 3) as well as from the standard deviations of the means and the standard errors of the estimate, that the water quality was fluctuating considerably more preceding the closure. It is also apparent that the concentrations and loads for all three parameters decreased suddenly following installation of the seal.

There is a marked reduction in pollutant concentrations and loads indicated by the chemical analyses of the two samples taken almost seven years after the monitoring of the site by the U.S. Bureau of Mines ended. The acidity concentrations dropped to 17.6 and 1.6 mg/1, while pH levels were above 5.5. The measured alkalinity was found to be 26.2 and 10.9 mg/1. Concentrations of sulfates and total iron decreased to 210.0 mg/1 and 4.1 mg/1 levels.

The Decker No. 3 is a small drift mine (.18 km^2) which produced from 1950 to 1959. It has an average overburden of 22.5m composed mostly of shale.

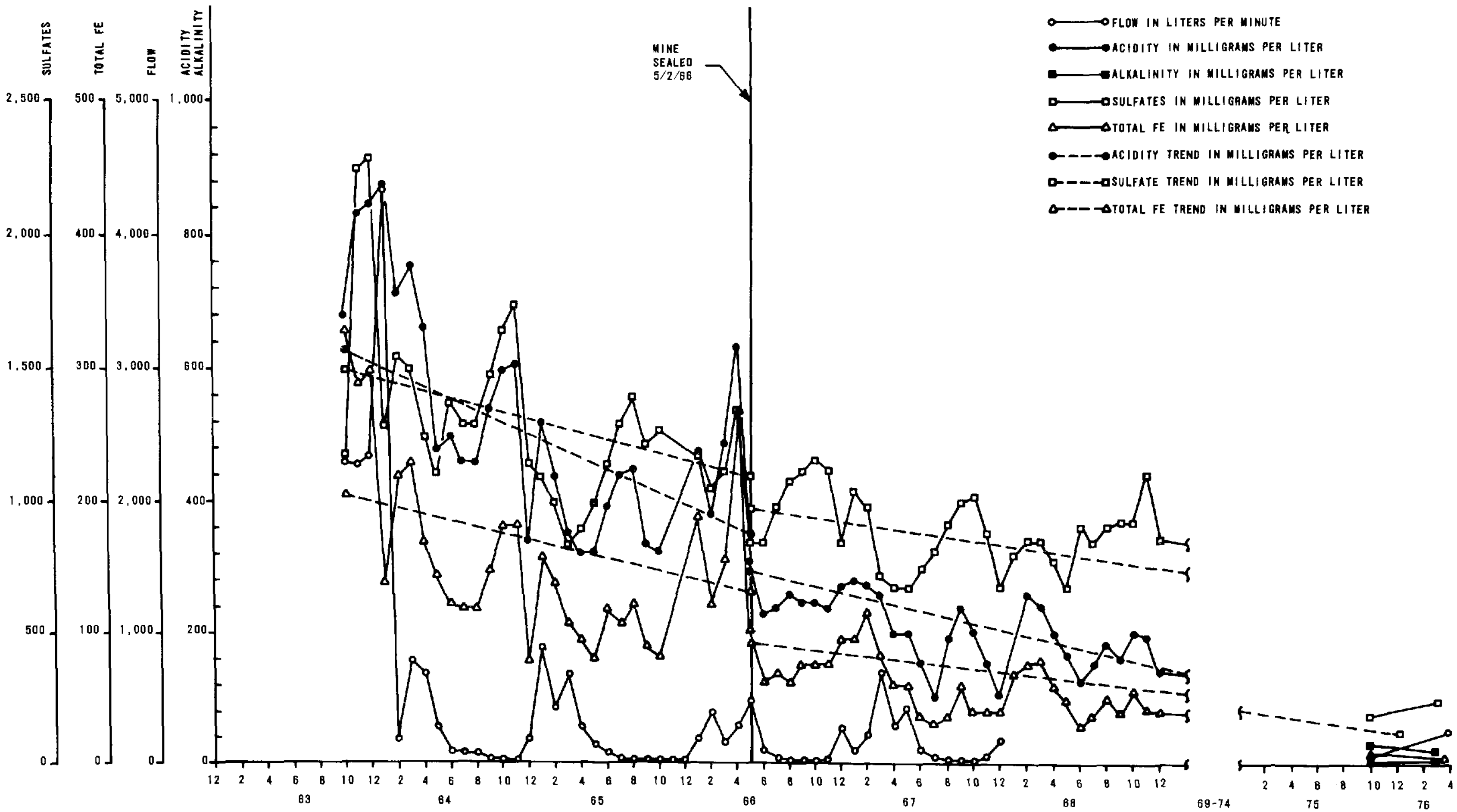

Figure 3. Decker No. 3 Mine, pollutant concentrations and trends.

Dip of the coal seam is approximately 4.0 degrees. The mined seam is 0.9 m thick and has a sulfur content of 2.2 percent. There is no mining in proximity to the site. The mine is located above drainage.

Mine RT 9-11, Pumpkintown, West Virginia

This mine was wet sealed as part of the Elkins Demonstration Project, a cooperative effort undertaken by several federal agencies and the state of West Virginia during 1964 in the Roaring Creek and Grassy Run watershed, Randolph County. Eleven wet seals were also constructed in a large underground mine complex in proximity to the RT 9-11 Mine. An important part of the objective of the project was to determine the effect of air sealing upon water quality.[a]

Considerable effort was expended to seal off all air entrances to the RT 9-11 Mine. Mine discharge was monitored by EPA on a monthly basis from February 1964 to May 1971. Two samples were taken in October 1975 and March 1976 by HRB-Singer.

The low pH levels ranging from 2.6 to 3.1 found before sealing changed subsequent to closure. Post-sealing levels range between 1.7 and 3.4. The concentration of acidity was reduced 45 percent comparing the pre-sealing mean of 570 mg/l to the post-sealing mean value of 315 mg/l. The iron content was reduced by 25 percent from the pre-sealing mean of 94 mg/l to the post-sealing average of 70 mg/l. Comparison of the pre- and post-sealing means for the sulfate concentrations indicates an increase of 19 percent due to sampling points in June 1968 and April 1969 when the sulfate concentration levels rose to 4,730 and 2,410 mg/l, respectively.

The test for difference in the means specifies a difference between the pre- and post-sealing means for acidity and total iron concentrations significant at or above the 0.01 level. However, the test of the difference between the means of the sulfate pre- and post-sealing observations indicates a probability of greater than 10 percent that the difference could have happened by sampling of the same population; the same is true for the sulfate concentration. Thus, there is insufficient evidence to conclude that there has been any sulfate concentration change as a result of the air-sealing of the mine.

The post-sealing mean pollutant outputs increased as a result of the augmented flow from the sealed portal. Comparison of pre- and post-sealing grand output means show an increase of 21 percent acidity, 62 percent total iron, and 71 percent sulfate. Only the difference between the pre- and post-sealing means of sulfate outputs is statistically significant at probability levels above 0.10, however. The differences between the acidity and total iron means are too small to suggest that they represent different popula-

[a] Ronald D. Hill, Elkins Mine Drainage Pollution Control Demonstraton Project, in: Third Symposium on Coal Mine Drainage Research, Federal Water Quality Administration, U.S. Dept. of the Interior (Pittsburgh, 1970).

tions with regard to levels of acidity or total iron outputs.

Standard deviations of the means for concentrations and loads imply a decrease in the variability of all three parameter outputs and in acidity concentrations while the total iron and sulfate concentrations variability appears to be increased upon sealing.

The installation of the air seal resulted in a marked increase in the rate of reduction of acidity, sulfate, and total iron concentrations and loads (see Figure 4). Before the closure, the acidity concentrations were decreasing at a rate of 17 mg/l/year while the acidity loads were increasing at a rate of 5.8 kg/year. The post-closure trends show an acidity concentration reduction rate of 24 mg/l/year and a load output reduction rate of 5.2 kg/year.

Sulfate concentrations were rising at a rate of 90 mg/l/year before sealing and were decreasing at 86 mg/l/year succeeding closure. The load measures indicate an increase of 8.6 kg/year prior to closure. The regression coefficient shows the post-closure loads decreasing at 3.2 kg/year.

All coefficients are significant at or above 0.15 with the exception of the total iron post-sealing concentration coefficient (significant at the 0.20 to the 0.30 level) and the total iron pre-sealing load coefficient (significant between 0.15 and 0.20).

At present acidity is averaging 136 mg/l and alkalinity is zero. Total iron (averaging 18 mg/l) is considerably in excess of the mine effluent standard of 3.5 mg/l. Based on the October 1975 and March 1976 samplings, sulfate averages 260 mg/l.

The RT 9-11 is a small drift mine with mined out area of about 0.2 km^2. It is located above drainage with overburden thickness approximately 36m. The overburden consists of sandstone and shale present in about the same proportions.

Out of 12 seals that were installed during the Elkins demonstration project in the Roaring Creek and Grassy Run Watersheds, the Rt 9-11 mine sealing effort was the only one that had beneficial impact on the mine water quality. The effect of 11 seals that were placed in a large underground mine complex is rather questionable. Not all of the mine openings were closed and there was no water quality improvement observed after the completion of the project (R. B. Scott, 1976, personal communication).

Big Knob Mine, Portal Nos. 1, 2, and 6, Bowden, West Virginia

The West Virginia Department of Mines air-sealed several abandoned underground coal mines at the head of Taylor Run, a tributary of Shavers Fork in Randolph County, West Virginia. This action was taken after a reported fish kill at the Bowden hatchery in 1966 attributed to the acid mine drainage flushed from the abandoned mines. The mines were sealed by cement block-type air and dry seals.

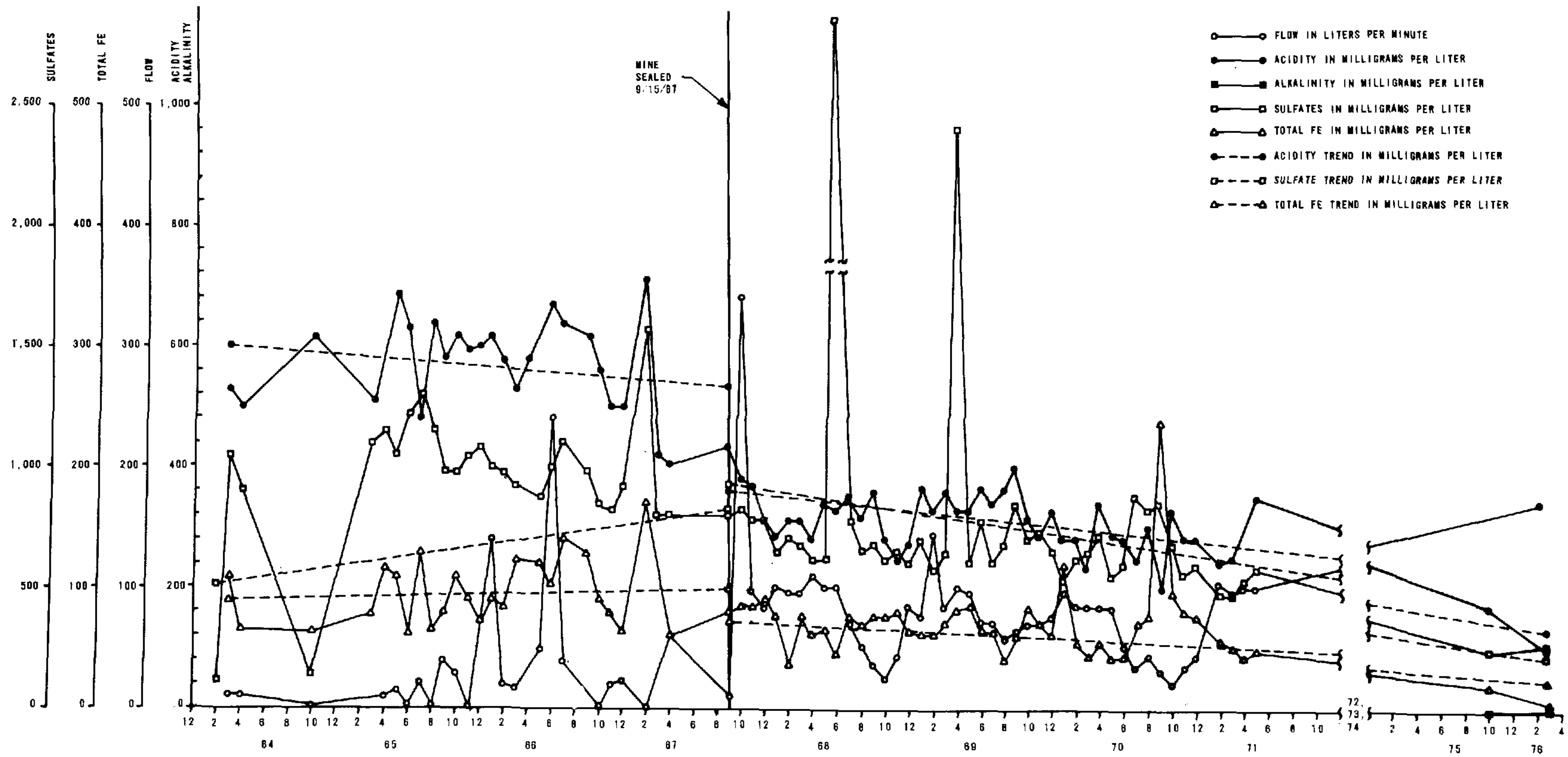

Figure 4. RT-9-11 Mine, pollutant concentrations and trends.

Six wet seals were installed in the Big Knob mine portals in October 1967. The discharges from the openings were sampled and evaluated by the Environmental Protection Agency, Mine Drainage Field Laboratory, Norton, West Virginia, for a period of approximately two years (1966 through 1970) before the sealing.[a]

The Big Knob Mine is a relatively small (0.22 km^2) drift mine located above drainage. The mine overburden averages 44m, of which 23m is shale and 20m sandstone. Sulfur content of the coal is 0.6 percent. The mine was active from 1950-59.

Big Knob No. 1 --

The measured pH levels of the mine effluent at the No. 1 portal are approximately the same before and after the sealing (3.2 versus 3.3). Comparison of the mean pollutant concentrations and outputs for the pre- and post- sealing sampling periods indicate no statistically significant change in acidity or sulfate levels. Total iron concentrations and outputs increased nearly 125 percent, however, and both differences in means are significant above the 0.10 level.

If judged in terms of major pollutant means reduction, seal effectiveness must be considered unsuccessful. Comparison of the pollutant standard deviations further strengthens this conclusion. Variability of the water quality is greater following closure, especially with regard to acidity and sulfate.

The trend analyses (Figure 5) indicate an immediate increase in all three parameter concentrations upon closure. Prior to sealing, the pollutant constituents were decreasing at a faster rate then after sealing. Acidity was decreasing twice as fast; sulfate, 1 1/2 times as fast; and total iron 4.5 times as fast. The loads, increasing slightly prior to closure, began decreasing at rates of 0.03 to 1.1 kg/year. The pre- and post-sealing acidity output regression coefficients, though the best measure of the relationship between the output levels and time, are not significant at or above .20. The combined fluctuation of acidity concentrations and flow result in considerable output variability.

Big Knob No. 2 --

The water quality of mine discharges from this portal has been altered little by the air seal. Comparison of pre- and post-sealing means indicates only one statistically significant reduction, that of acidity output. Preceding closure, acid outputs averaged 2.1 kg/day while post-closure values averaged 1.2 kg/day.

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[a] Robert B. Scott, Evaluation of Shaver's Fork Mine Seals, Mine Drainage Pollution Control Activities, Office of Research and Monitoring, U.S. Environmental Protection Agency (Norton, 1971).

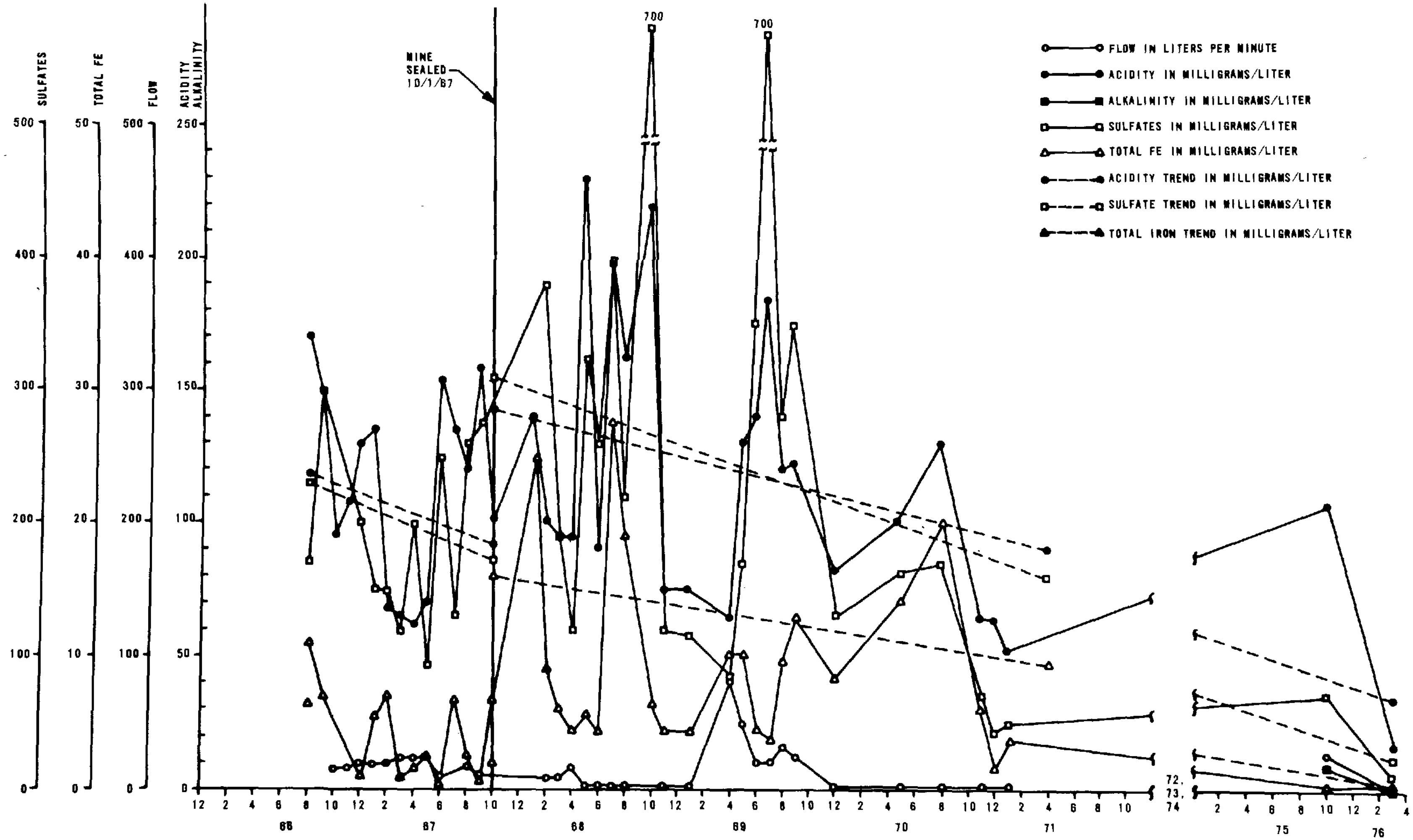

Figure 5. Big Knob No. 1 Mine, pollutant concentrations and trends.

Overall, the discharge is similar to the effluent from Big Knob No. 1. The pre- and post-sealing means for pH are both 3.3. Total iron is 8 mg/l before and 3 mg/l following closure, indicating a reduction of total iron as opposed to the increase shown for Big Knob No. 1. As stated previously, however, there is not sufficient difference between the pre- and post-sealing means, with regard to the observations at portal No. 2, to conclude that the reduction is due to the effect of the seal.

Acidity concentration means are 76 mg/l and 83 mg/l for the two periods; sulfate concentration means are 120 mg/l and 131 mg/l for the pre- and post-sealing periods, respectively. Sulfate and total iron loads vary only slightly between pre-sealing and post-sealing observations: from 3.1 kg/day to 2 kg/day for sulfate and from 0.2 kg/day to 0 kg/day for total iron.

The standard deviations (Tables D-1 through 3), reflective of variability, are reduced after sealing only for total iron concentrations and outputs. Sulfate and acid concentrations and loads increase in irregularity.

Trends for observations of the discharge at Portal No. 2 also resemble those for the discharge at Portal No. 1. There is a pronounced augmentation of acidity, total iron, and sulfate concentrations upon closure (Figure 6) and rates of reduction are slower after sealing than before (Appendix E).

All concentration coefficients are significant at the 20 percent level. Outputs, (which were slightly increasing or decreasing), remain at nearly the same levels. With the exception of the sulfate pre-sealing regression coefficient, load regression coefficients are not significant at the 20 percent level.

Big Knob No. 6 --

No monitoring was undertaken at this portal preceding sealing. Post-sealing data indicate discharge outputs very similar to those found at the No. 1 and No. 2 portals. Means for concentrations of total iron, acid, and sulfate are lower for the observations at this portal (See Tables D-1 through 3), however, the pH level is very similar at 3.9.

Chemical analyses of samples collected on this project indicate acidity concentrations averaging 55 mg/l at Big Knob No. 1, 56 mg/l at Big Knob No. 2, and 20 mg/l at Big Knob No. 6. Zero alkalinity was measured for all the samples. Sulfate concentrations average 29 mg/l, 48 mg/l and 34 mg/l at the three portals and total iron averages 0.4 mg/l, 0.8 mg/l, and 0.1 mg/l, respectively.

<u>Savage Mine, Bowden, West Virginia</u>

The Savage Mine, located approximately 0.3 km from the Big Knob Mine, was also sealed by the West Virginia Department of Mines in response to the

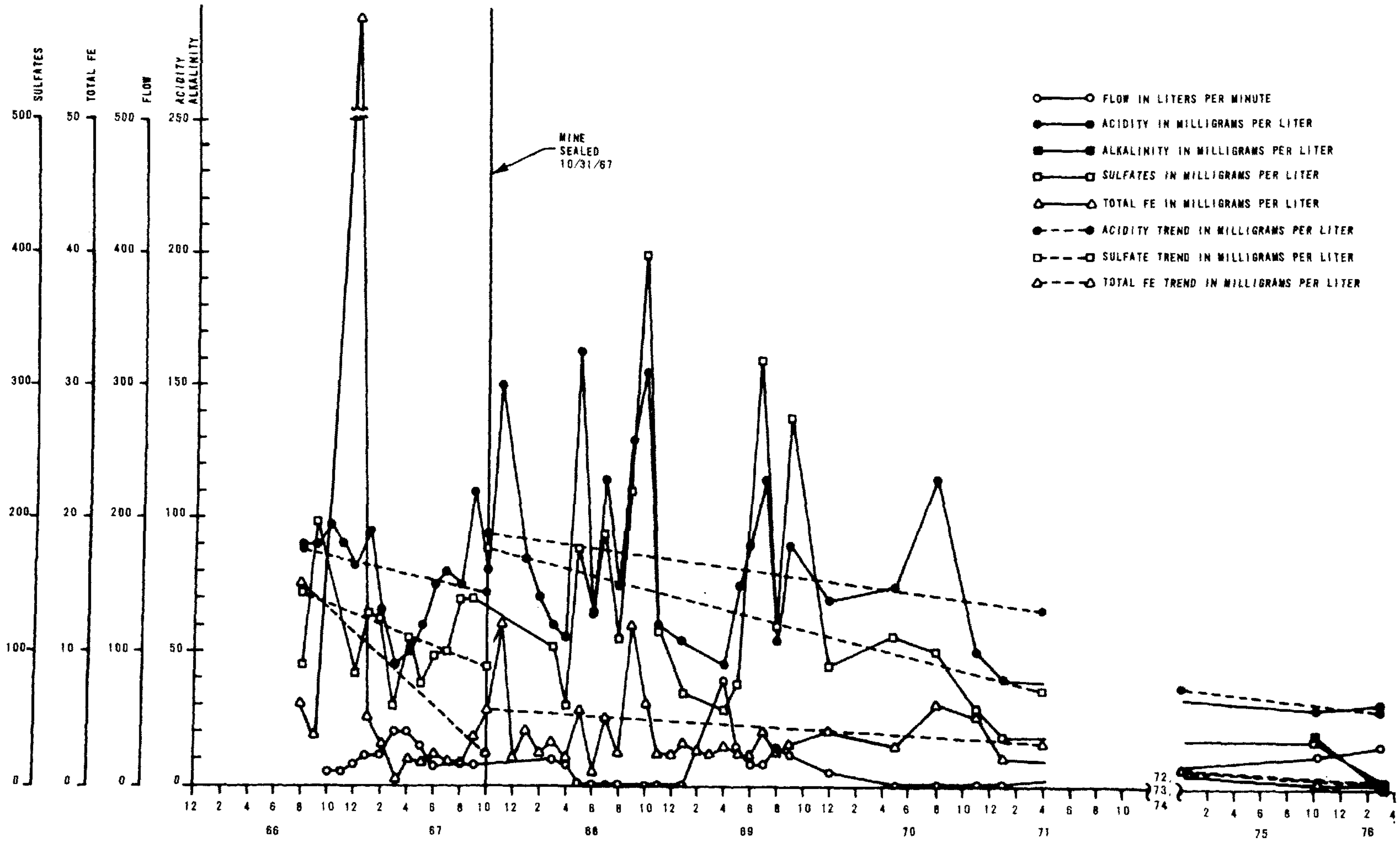

Figure 6. Big Knob No. 2 Mine, pollutant concentrations and trends.

fish kill at the Bowden hatchery in 1966. Two seals, one "wet" and one "dry" were placed in the mine portals in November 1967.

It is a small drift mine (0.33 km^2) that produced in a low sulfur seam (0.6 percent) from 1950-59. The seam overburden is about 42m.

The mine discharges were monitored regularly from July 1966 to January 1971 by the Water Quality Office, Norton Mine Drainage Field Laboratory, West Virginia. Two sampling points were obtained as part of this project in October 1975 and March 1976.[a]

The major effect of the air seal upon the water quality of the discharge from this mine was to reduce acid concentrations and outputs. Acidity, which averages 24 mg/l for the pre-sealing period, decreased to an average of 12 mg/l succeeding the installation of the seal. The variability of the acidity was markedly reduced after sealing, as well (see the standard deviations in Tables D-1 through 3). Acid loads were reduced from 1.9 kg/day to 0.8 kg/day as a result of the closure.

Sulfate loads and concentrations were also reduced after sealing, however the difference in the means are not statistically significant at the 10 percent level. Thus, there is insufficient evidence to attribute this reduction to the effect of the seal.

Total iron concentrations increase upon sealing, and the test for difference in the means defines this increase as significant at or above 0.05. The pre-sealing concentration mean is 0.5 mg/l and is increased to a mean of 1 mg/l after sealing. The total iron output mean is also higher for the post-sealing period; however, the difference between the two (0.1 kg/day to 0.2 kg/day) is too small to assume any real change.

Although alkalinity concentrations were found to be reduced succeeding closure, pH levels increased. However, differences are, again, too small to attribute to the effect of closure.

Trend analyses suggest the effect of the seal is to reduce the rate of decrease of acidity (in terms of both concentration and output) after an immediate reduction in concentration (see Figure 7), to change the direction of the sulfate concentration trend from increasing to decreasing, to lower the rate of increase of sulfate outputs and total iron concentrations, and to increase the rate of total iron outputs (see Appendix A). With the exception of acid and sulfate pre-sealing concentrations, the regression coefficients explaining these relationships are significant at the 15 percent level.

The standard deviations of the means of the concentrations and loads suggest that sulfate and acidity concentration variability is reduced by the

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[a] Robert B. Scott, Evaluation of Shaver's Fork Seals.

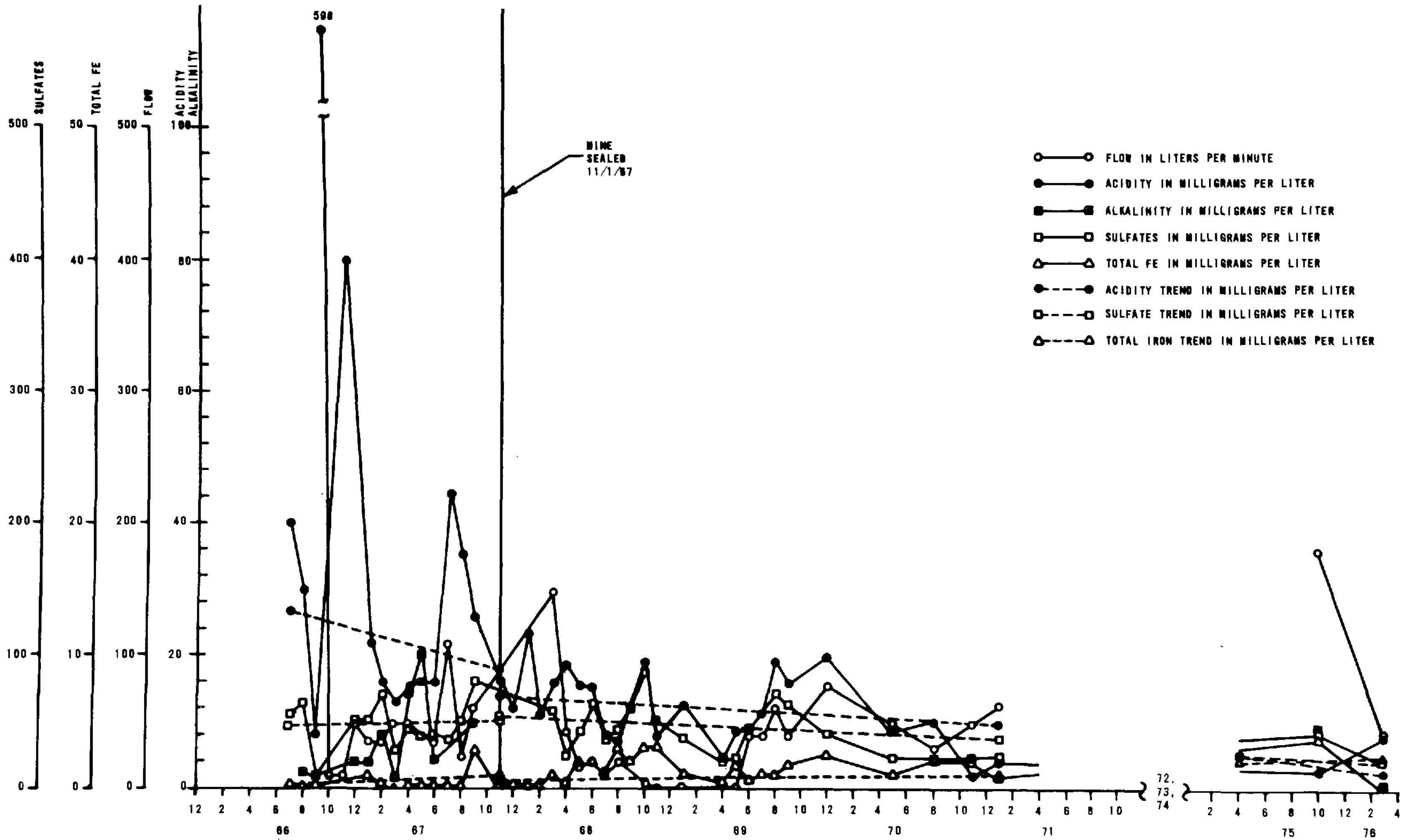

Figure 7. Savage Mine, pollutant concentrations and trends.

seal and total iron loads and concentrations remain about the same. Fluctuations of sulfate and acidity loads increase following sealing.

There is reason to assume that error has been introduced with regard to flow measurements at this mine because the mine drainage discharge is located in the path of a small stream. Mine discharge flow had to be estimated as a portion of the total flow during the sampling of October 1975 and March 1976.

According to analyses of the most recent samples, acidity averages 14 mg/l in concentration, alkalinity averages 0.3 mg/l, total iron averages 2 mg/l, and sulfate averages 36 mg/l.

Imperial Colliery No. 9, Burnwell, West Virginia

The Imperial Colliery No. 9 Mine was air-sealed in 1972. An evaluation of the seal effect on water quality is rather difficult in this case because of limited water quality records available. The pre-sealing mine water quality is characterized by a pH level of 6.1, acidity concentrations higher than alkalinity concentrations with values of 68 mg/l versus 38 mg/l, sulfate concentrations of 705 mg/l, and total iron levels of 2 mg/l.

Imperial Colliery No. 9 produced from year 1948 to 1972 in a seam with a sulfur content of 0.9 percent. The area of the mine is 1.11 km^2 and overburden thickness averages 149 meters. Shale composes 47 percent of the thickness; and sandstone, 35 percent. Dip is 2.0 degrees. The mine is near the local drainage base level.

The post-sealing water quality data show no changes in pH levels, reduction of sulfates by 21 percent, and indicate marked increases in total iron and acidity concentrations (147 percent and 107 percent respectively). The significant increase in acidity and total iron concentrations was observed about one year after the sealing. The acidity levels reached 290 mg/l, while total iron reached its maximum at 16 mg/l. Since then, there was a downward trend in their concentration levels. Acidity levels for the post-sealing data are mostly higher than those of alkalinity. Tests for difference in the means were not conducted as there is only one pre-closure observation.

There are no flow data available for the mine except for the two most recent sampling points. Outputs of acidity, sulfates, and total iron were calculated to be 1.6 kg/day, 22.5 kg/day, and 0.3 kg/day, respectively.

A regression analysis was performed on the acid, sulfate, and total iron concentrations following closure. There is a statistically significant 5 percent relationship between the decrease of pollutant concentrations and time. Acidity concentrations are diminishing at the rate of 80 mg/l/year; sulfate concentrations at 164 mg/l/year; and total iron concentrations at 2 mg/l/year.

The most recent sampling results indicate acid concentrations of 26 mg/l, alkalinity of 73 mg/l, total iron of 4 mg/l, and sulfate of 351 mg/l.

McDaniels Mine, Northeast of Lake Hope, Vinton County, Ohio

The McDaniels Mine was closed in conjunction with the development of a research facility to study pyrite oxidation and the resulting acid mine drainage. The work was performed by The Ohio University Research Foundation and sponsored by the Water Quality Office, U.S. Environmental Protection Agency.[a]

The original air seal, constructed of concrete blocks in 1957 was repaired and a new pressure type manhole cover was installed in May 1965. This cover was open when the site was visited on this project in October 1975.

The water quality of the mine effluent was regularly monitored from May 1965 to September 1970. The atmosphere within the mine was controlled at different oxygen levels. The operating conditions in the mine for given periods were as follows:

Time Period	Operational Mode	O_2 Concentrations
10-65 to 10-66	Base Conditions	21%
10-66 to 8-67	Nitrogen Purge	1-2%
8-67 to 11-67	Oxygen Addition	21 - 35%
11-67 to 8-68	Air Purge	21%
8-68 to 10-69	Air Seal	21 - 10%
10-69 to 9-70	Nitrogen Purge	0.25 - 0.5

The changes in the recorded acidity and sulfate concentrations are shown in Tables D-1 and 2.

Between August 1968 and October 1969 the mine was monitored in an uncontrolled mode and closed with a conventional air seal. The gas composition within the mine reached a steady state value. Seasonal patterns of acidity concentrations do not appear to change relative to the periods before and after.

During the period when the mine atmosphere was kept at oxygen levels of 0.25 to 0.5 percent, the acidity and sulfate loads decreased by 60 to 70 percent.

Essex No. 1, Kelly, and Elk Lick No. 1 Mines

An extensive mine sealing program under Work Projects Administration and the Civil Works Administration was carried out during the periods from

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[a] The Ohio State University, Research Foundation, Pilot Scale Study of Acid Mine Drainage, U.S. Environmental Protection Agency, Research Series, 14010 EXA 03/71 (1971).

1933 to 1939 and from 1947 to 1949. The program was administered by the U.S. Public Health Service in the states of Ohio, Pennsylvania, West Virginia, Indiana, Illinois, Kentucky, Tennessee, Maryland and Alabama.[a] The Kelly and Essex No. 1 Mines in Ohio and the Elk Lick No. 1 Mine in Pennsylvania were sampled. There is no exact information regarding seal construction in these mines. Usually the WPA sealing was done by placing dry seals in all entries except for one where an air seal was placed to allow water to discharge.

The Essex No. 1 Mine is located in the Hocking Valley coal field, near New Straitsville in Ohio. Water quality for this small mine is characterized by a pH level of 7.0, alkalinity higher than acidity (comparing average values of 214 mg/l to 10 mg/l), total iron concentrations averaging 4 mg/l, and sulfates averaging 35 mg/l. The flow from this mine was measured 6 lpm during the dry season and 11 lpm during the wet season. There are no water quality data available for the pre-sealing conditions, thus, the evaluation of closure effectiveness in terms of water quality improvement is not possible. Comparison of the water quality here with two unsealed mines (Essex No. 2 and Buchtel) that occur in the proximity of this mine is not too helpful in this respect, as the Buchtel Mine water quality data is fairly comparable with the Essex No. 1 data, while the discharges from the Essex No. 2 Mine are characterized by very poor water quality with pH levels below 4.0, acidity concentrations of 177 mg/l, total iron of 35 mg/l, and sulfates of 500 mg/l.

All of these mines are located in the Middle Kittanning coal seam that is overlain in some sections by the Freeport limestone. It is possible that the high alkalinity and high pH levels of the discharges are more likely related to the lithology of the overburden than to the effect of the mine sealing.

The Kelly Mine is located near Ironton, Lawrence County, in Ohio. The Kelly Mine is a small drift (0.02 km^2) with an average overburden thickness of 18 meters. It is located above the local drainage, the overburden is mostly shale with no calcareous materials present. The sulfur content of the coal is 2.6 percent. Only one sample was collected and analyzed for the mine discharge. The water quality is characterized by a low pH (3.1) and by acidity, total iron, and sulfate concentrations of 585 mg/l, 7 mg/l and 610 mg/l, respectively.

The Essex No. 1 and Essex No. 2 sites are alike except for the absence of the seal in the No. 2 and for their location with respect to the water table. The Essex No. 2 Mine is located near drainage while the Essex No. 1 Mine lies above the local drainage level.

Similar to the Essex sites, the Buchtel is a small drift mine mined in

[a] W. C. Lorenz, Progress in Controlling Acid Mine Water: A Literature Review, U.S. Bureau of Mines, Information Circular 8080 (1962).

the 1930's. All three mines are characterized by predominantly sandstone overburdens. The Essex mines have both calcareous rock and another coal seam in the overburden. Sulfur content of the mined seams is 1.70 percent for the Buchtel and 2.0 percent for the Essex sites.

Elk Lick No. 1 Mine is a part of the extensive Shaw Mine Complex. The mine started draining after several hydraulic seals were successfully constructed in several openings presumably in the same mine complex and the accumulated waters started to overflow through this then unknown opening. It is believed that this opening was air sealed in the 30's.

Chemical analyses of the October 1975 and March 1976 samples collected on this project show zero alkalinity and indicate acid concentrations averaging 1057 mg/l, total iron concentrations of 323 mg/l, and sulfate concentrations of 1856 mg/l.

DOUBLE BULKHEAD SEALS

The double bulkhead seals are constructed by placing two retaining bulkheads in the mine entry and then placing an impermeable seal in the space between the bulkheads. The front and rear bulkheads are placed to provide a form for the center seal. This seal is formed by injecting concrete or grout through the front bulkhead, if accessible, or through vertical pipes from above the mine. Bulkheads have been constructed with quick setting cement and grouted coarse aggregate. An example of a grouted double bulkhead seal is given in a construction drawing in Figure 8.

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 performed to increase strength and reduce permeability.

Argentine, Keystone No. 6, Keystone No. 10, and Keystone No. 19 Mines, Pennsylvania

The Argentine and Keystone Mines are located in northern Butler County, Pennsylvania. These relatively large drift mines were producing in the Clarion seam during the late 1800's and early 1900's. As a result of acid mine discharges from these mines many miles of streams in the Slippery Rock Creek watershed became severely polluted.

The survey to recommend and design pollution abatement measures in this watershed was performed under the Commonwealth of Pennsylvania Operation Scarlift, Project No. SL 110. Hydraulic seals were recommended and designed for all entries by John Foreman of Gwin, Dobson, and Foreman, Inc., Altoona, Pennsylvania.

Installation of these double bulkhead seals was accomplished by injection through boreholes above the entries. After completion of the bulkheads, grout was injected into the surrounding bedrock to prevent leakage around the bulkheads. For sampling purposes, an observation well was drilled behind the seal.

Monthly data on flow, pH, alkalinity, acidity, total iron and sulfates were collected and analyzed during 1969 by Gwin, Dobson, and Foreman, Inc. for the state of Pennsylvania.

Argentine Mine --

This large drift mine (1.21 km^2) is located near Argentine, Pennsylvania. Mean overburden at this site is 45m with 33m of shale, 4m of sandstone, and 8m of calcareous rock and coal. The mined coal seam is about 1m thick with a sulfur content of 2.7. The dip of the beds in the area is 3.0 degrees. The main portal is located near drainage; however, most of the mine is below the water table. Annual precipitation averages 102.26 cm.

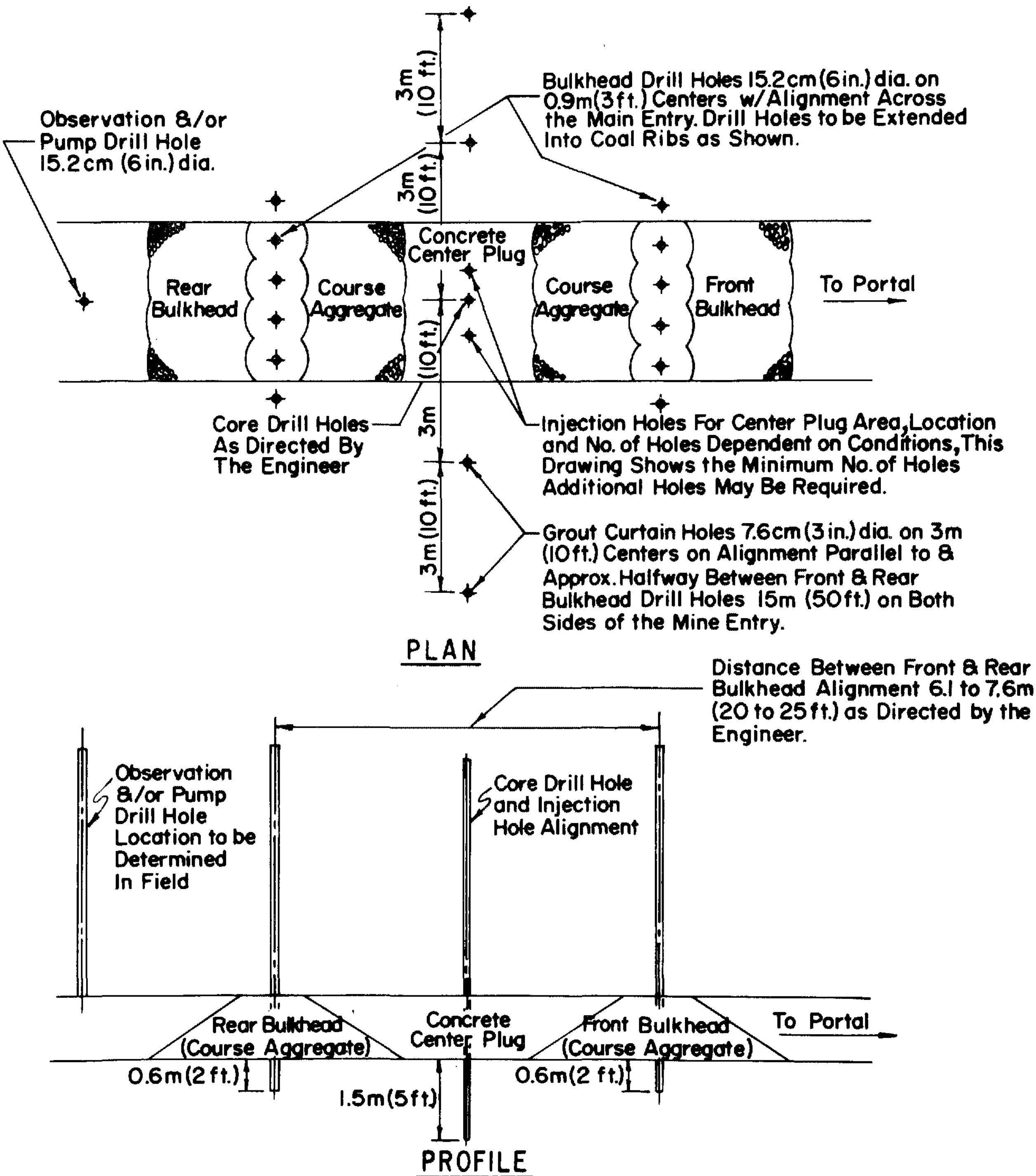

Figure 8. Construction drawing of a grouted double bulkhead deep mine seal as shown in R. L. Scott and R. M. Hays, Inactive and Abandoned Underground Mines, EPA-440/9-75-007.

Hydraulic seals were placed in four entries during September 1972 by the Allied Asphalt Company. Comparison of the pre-and post-sealing means for acidity, sulfate, and total iron concentrations indicate reductions of 50, 54, and 31 percent respectively. Outputs for these three parameters decreased 81, 32, and 82 percent respectively. According to the test of the difference between the means, the reductions in acidity outputs, total iron outputs, and sulfate concentrations are significant at the 1 percent level. Alkalinity appears to have increased overall, but it is erratic and the increase of 1454 percent calculated from the means must be considered in light of the large post-sealing standard deviation. The pH levels have not been impacted by closure. Before sealing, pH measurements averaged 5.9; following closure, the mean pH values were indicated to be 5.4.

Regression analysis results show acid concentrations increasing by 28 mg/l/year, total iron decreasing by 0.3 mg/l/year, and sulfates increasing by 103 mg/l/year before sealing. Post-sealing trends suggest that total iron decreases at a much higher rate, that is, by 41 mg/l/year, while sulfates increase at a higher rate (113 mg/l/year) after the initial drop. There are not enough observations of acid concentrations following closure to estimate a trend.

Standard deviations and standard error estimates suggest that variability of the major parameters is increased by the seal.

The dry season sampling done on this project showed acidity concentrations of 59 mg/l and an alkalinity of 4 mg/l. Wet season sample analyses show zero alkalinity and 9 mg/l acidity. Total iron and sulfate concentrations for the dry season were measured to be 30 mg/l and 120 mg/l, and, for the wet season, 3 mg/l and 148 mg/l.

Keystone No. 6, No. 10, and No. 19 Mines --

These mines are located near Boyers in Butler County, Pennsylvania and are believed to be part of a large mine complex that covers several square kilometers. From mine maps of the area, it appears that the mines are interconnected.

Overburden for the Keystone Mines or mine sections varies from 44m at No. 10 to 29m at No. 19. The preponderance of the overburden is shale. Sandstone thickness is approximately 3.5m and calcareous rocks and coal average 9m. The mined coal seam thickness is 1 meter and the sulfur content averages 2.7 percent. Bed dip is 3.0 degrees.

The Keystone No. 6 and No. 19 Mines are located below drainage. Keystone No. 10 is situated near drainage. Average annual precipitation is 102.26 cm over the mine complex. All of the mines or mine sections were hydraulically sealed during June 1975.

Keystone No. 6 -- Based on the HRB-Singer field observations of October 1975 and March 1976, the seal obstructs flow completely. Prior to closure, flow from the mine averaged 392 lpm; the water quality of the mine discharges was characterized by the average concentration of acidity, total iron and sulfate as 104 mg/l, 5 mg/l and 381 mg/l, respectively.

Keystone No. 10 -- According to the chemical analysis of the samples collected by the HRB-Singer field team, acidity concentrations have decreased from a pre-sealing mean of 16 mg/l to 6 mg/l. Post-sealing alkalinity has increased from the pre-sealing mean of 4.3 mg/l to 166.2 mg/l. Total iron and sulfate concentrations also increased after sealing.

The test for difference between the means shows the reduction of acidity concentrations significant at the 5 percent level and the increase in sulfate concentrations and outputs significant at the 1 and 10 percent levels respectively. Changes in total iron concentrations and outputs, as well as acidity outputs, are too small to suggest they are from different populations.

Water is flowing over the grout curtain and flow has risen from an average of 20 lpm pre-sealing to 115 lpm post-sealing. The hydrologic condition of the mine may be influenced by the stream flowing over the top of the mine, and by the stripped area and old spoil piles in its proximity. It is more probable that the flow obstruction at portals No. 6 and No. 19 has resulted in the water backing up and discharging at this opening. The regression analysis suggests that total iron, acid, and sulfate concentrations were decreasing prior to sealing. There are insufficient data to define trends following the sealing.

Keystone No. 19 -- The Mine discharge through this portal has been reduced from a pre-closure mean of 25 lpm to 1 lpm (no flow was observed in October, 1975). Acidity has been reduced from an average of 102 mg/l to 7 mg/l and alkalinity has risen from zero to 7.1 mg/l. Sulfate concentrations have diminished by 92 percent from a mean of 364 mg/l before closure to 30 mg/l following closure. Comparison of total iron concentrations indicates a slight decrease. However, in view of the size of the pre-sealing standard deviation (Table D-7), it cannot be assumed that there is any real change in the amount present.

Because of the reductions in flow and concentrations, loads have also been reduced considerably.

According to the trend analysis, acid concentrations were decreasing at 10 mg/l/year. Total iron and sulfate concentrations were increasing at 3 and 124 mg/l/year preceding closure.

Isle No. 1, Hilliard, and Lindey Mines, Moraine State Park, Pennsylvania

The Isle No. 1, Hilliard, and Lindey are small drift mines located in Moraine State Park, Butler County, Pennsylvania. The mines were sealed by hydraulic grouted aggregate seals as part of the Pennsylvania Operation Scarlift, Project SL 105-3. The work, sponsored by the Pennsylvania

Department of Mines and Mineral Industries, was performed by B. H. Mott and Sons, Inc.

The major objective of this project was to restore the aesthetic appearance of the area and ensure good water quality in Lake Arthur.

The double bulkhead seals were constructed by placing coarse, dry aggregate through vertical drill holes. The bulkheads were grouted to form solid front and rear seals. Concrete was poured in the void between the bulkheads to form a center plug. At each mine entry, curtain grouting of adjacent strata was performed for a minimum of 15 meters on both sides of the seals.[a]

The mine discharges were monitored from 1967 (about 2 years before the sealing project was completed) to 1971.

Isle No. 1 Mine --

The sealing work done at this mine site consisted of installing mine seals in six mine entries and grouting 1,000 feet of outcrop. The work was finished in November 1969.

The mine discharges were monitored 2 years before the sealing. The mine was reported to be flooded after the sealing under high water conditions and partly flooded under low conditions. No flow from the entries was observed in 1973. Two of the entries were found to be discharging when the site was visited in October 1975 and March 1976. The leakage is through the seal contact with the mine floor. The flow from the western-most opening (No. 64A) was measured to be 8 lpm in October 1975 and 38 lpm in March 1976. Comparing the two post-sealing discharges with the pre-sealing average flow of 24 lpm, it seems that the pre-sealing rates have been reestablished.

Concentration and output averages for acid and total iron decreased approximately 50 percent as a result of the closure. Sulfate concentrations remained essentially unchanged, alkalinity was measured considerably higher than before closure, but only the acidity concentration and total iron output reductions are significant according to the test for difference between the means (see Table 8).

The area of the Isle No. 1 Mine is approximately 0.13 km^2. Overburden averages 45 meters and consists of about the same proportions of shale and sandstone. The mined coal seam is 0.7m and is characterized by a sulfur content of 2.8 percent. The mine is positioned near drainage.

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[a] John W. Foreman and D. C. McLean, Evaluation of Pollution Abatement Procedures, Moraine State Park, Environmental Protection Technology Series, EPA R2-73-140 (Washington, 1973).

Hilliard Mine --

The Hilliard Mine was closed by placing bulkhead seals in two mine entries and constructing a 300m grout curtain. The sealing was finished by June 1970.

Closure resulted in inundation of the mine and changes in the quality of water inside the mine. The quality of the effluent before the sealing was characterized by low pH levels ranging between 3.7 and 4.3, average acidity concentrations of 70 mg/l, alkalinity of 0.5 mg/l, and total iron of 4 mg/l. After the sealing, the water inside of the mine became alkaline with 9830 percent increase in the alkalinity and a 96 percent decrease in acidity. The total iron concentrations decreased by 613 percent to 34.7 mg/l (see Table 6 and Tables D-4 through 7).

The mine effluent that is leaking from the mine around the seal does not exhibit such significant changes in the water quality. Acidity and alkalinity levels increased 16 and 616 percent respectively, in comparison to the mine discharge before sealing, while total iron concentrations increased by 267 percent. None of these increases are statistically significant, however (see Table 8).

The flow from the mine in October 1975 and March 1976 was measured at 4 lpm and 47 lpm. Flow averaged 14.5 lpm preceding closure. The average acidity outputs were increased from 0.9 kg/day to 2.7 kg/day. This difference is rather small relative to the magnitude of the standard deviations. It can be assumed there is no difference in the pre- and post-sealing acidity outputs.

The Hilliard Mine is a drift mine that has a mined-out area of about 0.3 km^2. The mine was under production from 1905 to 1935. The mine overburden is approximately 27m thick. The mine is below drainage for the most part. The mined coal seam averages 0.9m and has a sulfur content of 2.8 percent.

Lindey Mine --

The deep mine sealing work in the Lindey Mine consisted of placing double bulkhead seals in five entries and an airshaft, and 300m of grout curtain. The sealing work was completed in August 1970.

There was no flow observed from the sealed entries. Monitoring of two observation holes in the Lindey Mine indicate that the mine has been flooded in high mine water conditions and partly inundated during dry seasons.[a]

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[a] Gwin Engineers, Inc., Report of Mine Drainage Project MD-8A, Moraine State Park Watershed Area, Butler County, Commonwealth of Pennsylvania (1968).

The mine effluent before the closure was characterized by average acidity levels of 432 mg/l, low pH levels ranging from 3.2 to 6.7 and very low alkalinity averaging 0.1 mg/l. The water in the inundated mine became more alkaline after the sealing. The alkalinity concentrations increased to 24.8 mg/l (after sealing) while acidity decreased to a mean of 6 mg/l. There was a 7 percent decrease observed for the total iron concentrations comparing 20 mg/l and 19 mg/l for pre-sealing and post-sealing conditions, respectively.

The Lindey Mine is a large mine with about 58 km^2 of mined area. The overburden thickness is 28m that consists of 9m of shale and 17m of sandstone. There is also another coal seam (1.4m) in the overburden. The seam is 1 meter thick, with an average sulfur content of 2.80 percent. Dip is 2.0 degrees. The mine is located above drainage.

Salem No. 2 Mine, Keystone State Park, Pennsylvania

Salem No. 2 is a drift mine that covers an area of 1.2 km^2. It is located in the Middle Kittanning coal seam. The mine overburden is characterized by a predominance of shale over sandstone and an absence of calcareous material. The mined coal seam is 1.3m in thickness, with a sulfur content of 1.7 percent. The mine is above drainage.

The sealing project, No. SL 122-3, was jointly sponsored by the Pennsylvania Department of Environmental Resources and the United States Environmental Protection Agency. The site was selected for the demonstration of a gel seal construction by Dravo Corporation. Two non-discharging mine entries were sealed with double bulkhead aggregate seals with concrete pressure grouted center plugs. A discharging entry was selected for injection of the gel material. A reinforced concrete bulkhead was placed in the mine entry where the gel seal was to be constructed. The seal was to be placed through a vertical borehole from the surface. The laboratory test indicated that the used chemical grout exhibited a controllable setting time which should allow a stiff, gel-like plug to be formed in the mine cavity without the benefit of retaining bulkheads. After placement of the gel seal, fly ash also was to be pumped into the mine side of the seal in order to neutralize any leakage that escaped the seal.

The formation of the seal was never completed as the slurry was diluted by the mine drainage before a gel was formed. Additional curtain grouting (Project SL-122-3-2) to control the acid mine drainage was performed approximately 1 year after the main sealing effort.[a]

The mine discharges were monitored since 1967. The pre-sealing water quality is characterized by pH levels consistently below 3.0, acidity concentrations averaging 494 mg/l, and a relatively high concentration of total

[a] Neville K. Chung, Investigation of Use of Gel Material for Mine Sealing, EPA R-2-73-135, Office of Research and Monitoring, U.S. Environmental Protection Agency (1973).

iron ranging between 40 mg/l and 345 mg/l. The average pre-sealing sulfate concentrations were calculated at 1176 mg/l. Trend analysis indicates the latter three parameters were decreasing before closure (Appendix E).

The mine was inundated as a result of the sealing. Chemical analyses of the samples taken from a mine pool indicate considerable reductions of all the major pollutants. Acidity concentrations were reduced by 97 percent sulfate and total iron by 94 percent and 70 percent. Alkalinity increased from 0 to 57 mg/l.

A french drain that collects seepage from the three sealed entries discharges into a small creek downstream from the Keystone Lake. Chemical analyses of the samples taken from the drain discharge also show improved quality when compared to the pre-sealing quality of the effluent discharging from the main portal. Acidity, sulfate, and total iron concentrations were reduced by 32, 48, and 49 percent, respectively.

The hydraulic sealing of the mine entries resulted in considerable decrease of flow and consequently in reduced pollutant outputs. Provided that all the seepage from the mine is collected in the french drain, the acidity outputs were reduced by 98 percent from 162.3 kg/day to 3.5 kg/day. Sulfate and total iron outputs were reduced by 98 percent.

Shaw Mines, SL 118-5, Meyersdale, Pennsylvania

Five hydraulic double bulkhead seals were installed in entries to a rather complex and extensive abandoned mine, located in the Pittsburgh and Redstone seams, in November 1972. Sulfur content of the mined seams is 1.7 percent.

Overburden of the mine averages 30 meters and is predominantly composed of shale. The complex is generally above drainage.

Project SL 118-5 was done as part of the extensive reclamation work in the Shaw Mine Complex area that was sponsored by the Commonwealth of Pennsylvania under the "Operation Scarlift" program. The bulkheads were constructed of pressure grouted coarse aggregate with the center plug filled with concrete. A grout curtain was placed across the center plug to further secure the water-tightness of the seal.

The water quality of mine discharges has been monitored since 1967. The chemical analyses indicate a very highly acidic pre-sealing mine effluent with pH levels ranging between 2.1 and 3.4, and average acidity, total iron, and sulfate concentrations of 1505 mg/l, 459 mg/l, and 2915 mg/l, respectively.

Post-sealing averages show reduction in concentrations of acidity to be 34 percent; of sulfate, 46 percent; and of total iron, 40 percent. Only the reduction in total iron concentrations is confirmed by the test for difference in the means. The seepage at the time of the March 1976 sampling was about 3 lpm. There was no seepage observed when the mine was inspected during the dry season in October 1975. The hydraulic seals seem to be effective and although there are no observation wells to measure water levels in the mine, the mine workings are most likely flooded.

Regression analyses of concentration show data reversal of the increasing pre-closure acid and sulfate trends and a diminution in the rate of total iron decrease (Appendix E).

Mine 62008-5, Clarksburg, West Virginia

A double bulkhead seal was placed in Opening No. 5 of Mine 62008 adjacent to openings No. 4 and No. 3 where single bulkhead and permeable limestone seals were constructed. The seal was constructed by hydraulically placing two bulkheads of quick-setting bentonite and sodium silicate slurry. The core between the bulkheads was filled with an inexpensive injected cement slurry grout. This seal was completed in June 1969.

The seal was effective in inundating the mine, and seepage through the seal did not occur until September 1970. The average pre-sealing flow of 9.5 lpm was reduced to an average 0.8 lpm, recorded between November 1970 and June 1971. There was no measurable seepage observed in October 1975 and March 1976.

The water quality of the mine effluent improved after the sealing with respect to acidity concentrations, which were reduced by 52 percent from an average of 2260 mg/l to 1090 mg/l. The average concentrations of sulfates and total iron did not change significantly. Sulfate concentrations decreased by 13 percent, and total iron increased by 19 percent.

The reduction of flow also resulted in a decrease in pollutant outputs of better than 90 percent for all parameters as compared to those values before sealing.

Mine RT 5-2, Coalton, West Virginia

Mine RT 5-2 is a small drift mine (0.14 km^2) located in the Kittanning coal seam, near Coalton, West Virginia.

A double bulkhead seal was constructed in mine entry No. 1. The bulkheads were built of quick-setting self-supporting cementitious materials. The core between the two bulkheads was filled with limestone aggregate that was made impermeable by grouting with light cement. The double bulkhead seal was constructed in front of a previously built air seal.[a,b]

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[a] Robert B. Scott, Evaluation of Shaver's Fork Seals.

[b] Halliburton Company, New Mine Sealing Techniques for Water Pollution Abatement, Water Pollution Control Research Series 14010 DMO 03/70, Federal Water Quality Administration (1970).

The construction of the seal was done by the Halliburton Company under the sponsorship of the U. S. Environmental Protection Agency. The contract was awarded to study various methods of constructing bulkhead seals.

The mine discharges were regularly monitored from 1964 to 1971 by the Halliburton Company and later by the U. S. Environmental Protection Agency, Norton Mine Drainage Field Site.

The RT 5-2 Mine is considered to be a high-flow mine with the pre-sealing flow rates ranging between 36 and 2089 lpm.

The hydraulic sealing of the mine was successful and no leakage from the RT 5-2 opening was apparent when inspected in September 1971. The hydrostatic head behind the seal stabilized above 2m after January 1970 with only slight variations in the water levels in the mine. The increased water elevation in the mine resulted in discharges through opening No. 2 that was subsequently closed by a permeable limestone seal (RT 5-2A).

The quality of the water behind the seal deteriorated considerably after the sealing and flooding of the mine. Acidity increased from the pre-sealing average by 61 percent, from 683 mg/l to 1107 mg/l. Concentrations of sulfate increased by 118 percent from 660 mg/l to 1438 mg/l, and that of total iron by 137 percent from 212 mg/l to 502 mg/l.

Until the drainage pipes were opened (between 1971 and October 1975) the water from the inundated mine was discharged through the permeable limestone seal constructed in opening No. 2. The effect of the seal on the effluent quality is discussed in the section on permeable seals.

According to samples collected in October 1975 and March 1976, flow rates (averaging 104 lpm for the two measurements) are within one standard deviation of the pre-sealing mean of 373 lpm. Pre-sealing acidity and sulfate concentration averages have been nearly re-established, however total iron concentrations are significantly lower. All three major parameter outputs are reduced from pre-sealing averages as well (see Tables 6 through 9 and Tables D-4 through 9).

<u>Phifers No. 1 Mine, State Park, Tennessee</u>

The Phifers No. 1 Mine, a small drift mine (0.1 km^2) located in the Richland coal seam, was closed by a double bulkhead seal in November 1975. The seal was constructed of limestone aggregate bulkheads grouted with a cement mix.

The sealing of the mine was part of the Piney Creek Project sponsored by the University of Tennessee and the Fish and Wildlife section of the Tennessee Valley Authority.

The quality of the mine effluent before the sealing was characterized by pH levels ranging between 2.9 and 3.0, and average acidity, sulfate, and total iron concentrations of 83 mg/l, 109 mg/l, and 14 mg/l, respectively. Flow from the mine was measured at 11 lpm.

No seepage from the mine opening was observed after the mine sealing and the mine workings were inundated. Chemical analysis of a water sample taken from the inundated mine 5 months after the sealing shows large changes in the water quality. The post-sealing pH level increased to 7.4, acidity concentrations decreased by 100 percent while alkalinity, not detected before the sealing, was measured at 132 mg/l. Sulfate and total iron concentrations were reduced by 56 percent and 30 percent.

This mine intersects the water table and has a relatively thin shale overburden. There is no coal or calcareous rock present.

The Richland seam is approximately 1.5 meters thick at the site with a sulfur content of 2.2 percent.

SINGLE BULKHEAD SEALS

Single bulkhead seals are usually constructed of poured concrete, quick setting cement material or grouted aggregate. They can be also constructed of other materials such as masonry blocks, rocks, or bricks.

Some of the single bulkheads are constructed in openings where there is no or little danger of a buildup of hydrostatic head (dry seals) while some single bulkhead seals are designed as hydraulic seals capable of sustaining higher hydrostatic pressures.[a]

Mine No. 40-016, Lost Creek, West Virginia

Two openings in the small drift mine, No. 40-016, were closed by the installation of two grouted aggregate bulkheads. The seals were constructed by placing a graded limestone in the mine that was subsequently grouted to form a solid plug. The seal construction was performed by the Halliburton Company.[b]

After the seals were installed in December 1967, massive leaks were observed around and through the seals. As a result of remedial grouting done in 1968, the leakage was reduced but not stopped. Flow rates were reported to be about 7-11 lpm, but increased considerably about three years later when the average flow in 1971 was reported at 67 lpm. Leakage was also reported to be through the coal surrounding the seal. Samples from the mine discharge were periodically collected and analyzed between September 1968 and June 1971. Only one sampling point for the pre-sealing water quality is available.

The effect of the seal on the water quality is characterized by 51

[a] L.R. Scott and R. M. Hays, Inactive and Abandoned Mines.

[b] Halliburton Company, New Sealing Techniques.

percent reduction in acidity and 38 percent reduction in total iron concentration. In view of the limited data on water quality from the mine prior to sealing, reduction values should be considered with some caution. No pre-sealing data on sulfate concentrations are available.

The trend analysis of the pollutant concentrations shows significant negative trends for the post-sealing concentrations of all three major parameters. The acidity concentrations fluctuated considerably for approximately two years after sealing, with values ranging from 34 mg/l to 380 mg/l, but have decreased at an overall rate of 22 mg/l/year. The two sampling points in October 1975 and March 1976 indicate that these decreasing trends have continued. For both observations, alkalinity was measured as higher than acidity.

Acidity and total iron outputs decreased considerably following closure. As a result of the massive leaks observed in 1971, they increased, but did not reach pre-sealing values.

The condition of the seal has deteriorated since 1971 and massive leaks were observed in October 1975. The measured flow from Portal No. 1 was 95 lpm. The portals are slumped and covered with vegetation and it is not possible to determine the condition of the seal. The immediate area of this site has been extensively mined and it is likely that the blasting from a surface mining operation or disturbance of the recharge area has contributed to the failure of this abatement effort.

Mine 40-016 produced in a high sulfur seam (3.0 percent), 1.8m thick from 1904 to 1930. The overburden averages 15.24m. The major area of the mine is positioned above the local drainage base level.

Mine No. 62008-4, Near Clarksburg, West Virginia

A quick-setting, sodium silicate cement single bulkhead seal was constructed in the No. 62008 Mine, opening No. 4, adjacent to two other openings (No. 5 and No. 3), sealed with a double bulkhead and a limestone plug. The seal was constructed by the Halliburton Company under the auspices of the Federal Water Quality Administration (presently EPA) in November 1968.

No seepage was observed between the seal and the surrounding rocks until September 1969. Since then, the leakage rate has increased from one lpm to 66 lpm, the latter rate measured in October 1975.

The water quality data base is rather limited, especially for the pre-sealing period. Mine discharge was monitored regularly from September 1969 until June 1971. Two additional samples were obtained in October 1975 and March 1976.

There is a rather pronounced downward trend in the acidity concentrations for the post-sealing period of observation. The overall reduction of acidity is 63 percent, comparing the pre-sealing measured value of 1170 mg/l to 446 mg/l. There is also a downward trend indicating an overall reduction in the post-sealing sulfate and total iron concentrations of 16 and 79 percent, respectively.

The considerable increase in the rate of flow from this opening resulted in overall increases of the pollutant loads. This observed discharge augmentation is probably due to the diversion of water from Portal No. 5 where the double bulkhead is obstructing its passage, as well as to the surface mining impacts on the local hydrologic system or the stabilization of that system over time after its alteration by the surface mining.

Rattlesnake Creek Mine, Brockway, Jefferson Co., Pa.

A single bulkhead and a slurry trench were constructed to abate the acid discharges from a deep mine in the Rattlesnake Creek watershed. The construction was performed under "Operation Scarlift" Project SL 132-2-101.1 by Trans-Continental Construction Company, Inc.

The deep mine seal was constructed of a brick wall that was plastered with Lumnite cement mortar and coated with Colma Bonding Compound. The wall was reinforced by steel bars protected by placement of concrete over 2 feet thick.

The deep mine closure was effective in hydraulically sealing the mine opening. There was no flow observed in October 1975 and only a limited flow in March 1976. The measured flow from the mine before the sealing ranged from 611 lpm to 2128 lpm.

In terms of the water quality, the mine effluent seeping around the seal shows 46 percent decrease in acidity concentrations, no change in measured pH levels, slight decrease in sulfate concentrations (3 percent), and an increase in total iron concentrations from 7 mg/l to 8 mg/l (6 percent). The outputs of the pollutants from the mine portal are presently negligible because of the reduced flow.

Subsequent to closure, the mine was partially inundated and leakage began through the coal seam along the surface mine highwall. To control this leakage and to secure the planned flooding of the mine, a slurry trench was constructed along the seam outcrop. The work consisted of about 2,800 m^2 of 0.6m thick slurry trench wall. The water in direct contact with the alkaline material of the trench shows an increase in pH and alkalinity levels and a decrease in acidity. Observation wells placed within a few feet above and below the slurry trench, sampled in March 1976, show a change in the pH levels from 3.2 to 5.3 and a decrease in acidity concentrations from 101 mg/l to 13 mg/l.

A french drain that discharges into Rattlesnake Creek was installed to collect seepage along the slurry trench and the sealed portal. The water quality of this composite drainage has been monitored since the sealing project was completed. The acidity concentrations range between 97 and 266 mg/l with pH levels consistently below 3.5.

As the mine effluent was discharged in the Rattlesnake Creek before and also after the implementation of the abatement project, the creek water quality can best indicate the overall effectiveness of the project that includes the deep mine sealing, construction of the slurry trench, and also some regrading of the spoil materials from strip mining along the coal outcrop. The stream has been monitored since 1972, with the sampling point located several feet downstream of the french drain discharge.

The chemical analysis of the water samples indicates no significant changes in the water quality in respect to acidity, alkalinity, and pH levels. The acidity concentrations show rather low variability of the constituent with the pre-closure average of 6.9 mg/l compared to the post-closure average of 6.1 mg/l. There was basically no change in average alkalinity concentrations observed at values of 11.8 mg/l and 11.6 mg/l for the pre-and post-closure conditions.

On the other hand, the sulfate concentrations increased by 171 percent from an average of 62.5 mg/l to 170.1 mg/l, and the total iron concentrations increased by 45 percent from 0.7 mg/l to 1.2 mg/l. No comparison of pollutant loads could be made as there are very few flow measurements for the post-closure period.

The deep mine sealing resulted in mine flooding and diversion of flow away from the mine portal through the spoil materials between the highwall and the creek. The original flow system, controlled by the strata inclination to the northeast toward the local discharge area, Rattlesnake Creek, was actually restored.

The slurry trench acted as an impermeable barrier to further enhance the mine flooding, but it could control the flow into the spoils only in a limited way since the water flows over and under the trench as a result of raised water level and increased hydrostatic heads. The neutralizing effect of the alkaline material in the trench has had an immediate effect on the water quality in its proximity but, as the neutralized water seeps through the spoil materials, the water quality deteriorates rapidly.

Bullrock Run Mine, Kittanning, Pennsylvania

The Bullrock Run portal of the Mahoning Mine No. 1 was sealed with a reinforced concrete seal that was designed to sustain hydrostatic head buildup behind the seal up to 150 feet. The seal was constructed by the Carpenter Coal and Coke Company in 1975.

Effluent leakage of 6 and 8 lpm from around the seal was observed during the October 1975 and March 1976 site inspections. Comparison of water quality before and after the sealing shows no change in pH levels but some increase in acidity concentrations. The acidity increased from 10 to 27 mg/l.

The measured alkalinity levels were always higher than those of acidity. The sulfate concentrations increased by 9 percent from 206 to 224 mg/l and total iron concentrations decreased by 94 percent from 16 to 1 mg/l. The average post-sealing pollutant outputs or loads of acidity, sulfates, and total iron were calculated to be 0.3 kg/day, 2.3 kg/day, and 0.1 kg/day respectively. No flow measurements are available for the pre-sealing conditions.

The increase in concentrations of some of the pollutants can possibly be attributed to extensive strip mining in the close proximity to the mine and contamination of the mine discharges from all surface mine spoils.

Decker No. 5, Kittanning, Pennsylvania

Two single bulkhead seals were constructed in the main portals of Decker No. 5 mine by the Powell Coal Company. The seal was constructed as a 0.4m thick cement block wall in November 1972. Three sampling points available for the post-sealing discharges were collected by the Department of Environmental Resources and by the HRB-Singer field team. No pre-sealing water quality data are available.

There was no flow around or through the seal reported in 1973, but leakages of 11 and 4 lpm were measured in October 1975 and March 1976. The seal itself is presently covered over by spoil material. Water quality of the effluent is characterized by low pH levels ranging from 1.9 to 3.2 and acidity, sulfate, and total iron concentrations ranging between 49 and 178 mg/1, 75 and 360 mg/1, and 9 and 40 mg/1, respectively. There is no significant difference between the chemical quality of the effluent from this sealed mine and other unsealed deep mines in its close proximity (the Department of Environmental Resources, stream and mine drainage analyses, water quality records in files, Harrisburg, 2/13/73). Thus, the effect of the mine sealing on the effluent quality seems to be rather small.

Price No. 2 and Buckingham Mines, Wheelright, Kentucky

The Price No. 2 and the Buckingham Mines are parts of a huge mine complex at the intersection of Knott, Floyd, Pike, and Letcher Counties in eastern Kentucky. Both of these mines are approximately 1 km^2 in size and both were mined between 1950 and 1970. The overburden of the Price No. 2 mine is predominately shale with another coal seam present. Sandstone is the predominate rock in the Buckingham overburden. Coal is present in the overburden here as well. The sulfur content of the mined coal seam in both cases is 0.90 percent.

Both mines are located above drainage, and there is no discharge from either of them. They were closed by the Island Creek Coal Company by the construction of concrete blocks or rock walls in the mine portals. According to a representative of Island Creek Coal Company, there used to be water behind the about 1m high concrete block dam at the Price No. 2 portal; however, there was no evidence of any flow in October 1975 or March 1976. There was some dampness in front of the Buckingham seal but there was no way of determining whether or not there was in fact any water behind the concrete block wall.

Two unsealed mines located in close proximity to the sealed mines, also part of the Wheelright complex, were sampled during October 1975 and March 1976 as well. The water quality of the mine effluent discharged from Jack's Creek Mine is characterized by pH 7.2 and alkalinity considerably higher than acidity, comparing average values of 251 mg/l to 0.10 mg/l. The sulfate and total iron concentations are 303 mg/l and 5 mg/l, respectively. Very similar water quality was indicated by chemical analyses of samples taken from the nearby mine, Buckingham No. 5. This mine is not part of the Wheelright complex, although it is adjacent to it. The measured pH levels of the mine effluent were 5.1 and 6.8, the alkalinity levels were five times higher than those of acidity, and sulfate and total iron were found at rather low average concentrations of 52 mg/l and 0.2 mg/l, respectively.

As these unsealed mines are located in the same coal seam and have similar mining histories, the quality of the mine water which once drained from the Price No. 2 and the Buckingham Mines should be very similar. It is believed that the sealing of these portals was not to abate the mine drainage pollution but rather for security reasons.

<u>Ellisonville, Piney Fort, and Florence Mines; Lawrence, Jefferson, and Belmont Counties, Ohio</u>

The Ellisonville Mine, located north of Ironton, is a small drift mine (.10 km^2) that produced in a seam with a 2.6 percent sulfur content. The Florence Mine is also a small drift mine (0.01 km^2) which produced in a seam of 4 percent sulfur. Located near Adena, the Piney Fork is a mine of 5.64 km^2, producing in a seam of 2.9 percent sulfur.

The Ellisonville Mine was closed in early 1950. The sealing was done by constructing a cinder block wall in the mine openings. The quality analysis of the discharges shows high acidity of 1221 mg/l, zero alkalinity, pH of 3.0, and sulfate and total iron concentrations of 1020 mg/l and 150 mg/l, respectively.

The information on the site mining history and the sealing effort are very limited and do not allow any evaluation of the sealing effectiveness. However, the poor water quality of the mine effluent suggests a rather limited effect of the seal.

A partial sealing effort in the Piney Fork Mine by the Consolidation Coal Company was done to stop drainage from part of the mine into the main haulageway that has been used for underground transportation of coal from a surface mining operaton. Several cement block walls were constructed in the openings. As they were not designed to sustain high hydrostatic pressures, the water that has ponded behind these seals has to be pumped.

Samples were taken from the unsealed and sealed parts of the mine to determine possible differences in the water quality. The results of the chemical analyses show no significant differences between the samples. The water quality is characterized by high alkalinity concentrations, that is, 343 mg/l for the sealed part of the mine and 438 mg/l to 568 mg/l for the unsealed part. The measured pH levels are always above 7.0. It seems that the calcareous character of the overburden has an overriding effect on the quality of the mine water.

Sulfate and total iron concentration values were 370 mg/l and 2 mg/l in October 1975.

The overburden characteristics of the Florence Mine, sealed in 1961, are similar to those of the Ellisonville and Piney Fork Mines, and the mine drainage is also of somewhat similar quality. Alkalinity in concentration is very high at 507 mg/l, and acidity is only 1 mg/l. Total iron and sulfate concentrations are 227 and 3050 mg/l, respectively.

PERMEABLE LIMESTONE SEALS

Sealing of underground mines with permeable seals involves the placement of permeable alkaline aggregate in mine openings where acid water may pass through it. As the acid water passes through the alkaline material neutralization occurs and precipitates are formed. These precipitates fill the void space in the aggregate and, in time, the seal actually becomes a solid single bulkhead seal which induces flooding of the mine.[a] A typical cross section of permeable aggregate seal is shown in Figure 9.

Stewartstown Mine, Stewartstown, West Virginia

This mine was closed in August, 1974, by ECI-Doletanche, Inc., under contract with the Environmental Protection Agency. It is a small (0.1 km^2) drift mine in which production was discontinued in January 1974.

The mine is characterized by a mean overburden thickness of 34m. Lithology of the overburden is characterized by predominance of shale over sandstone, no calcareous rocks and presence of another coal seam. The mined seam is 0.9m thick and averages a sulfur content of 3.1 percent. The sealed portal sampled in this study is located near drainage.

Four permeable seals and grout curtains were installed to close the mine. Each mine seal was constructed by pneumatically injecting limestone aggregate and additives into the mine entries. The voids between the roof and seal were grouted with a cement, fly ash, and bentonite grout mixture. Strata adjacent to the mine seals were pressure grouted for a minimum distance of 9.1 meters on both sides of the mine entries.[a]

The mine discharges have been monitored regularly since February 1974 by the U.S. Environmental Protection Agency, Norton Field Office. The lowest seal (relative to elevation), known as No. 2, was the only seal draining at the time of the first sampling by the HRB-Singer field team in October 1975. At that time, the seal was in good condition with little seepage around the periphery. There was one meter of water standing behind the seal.

[a] L. R. Scott and R. M. Hays, Inactive and Abandoned Mines.

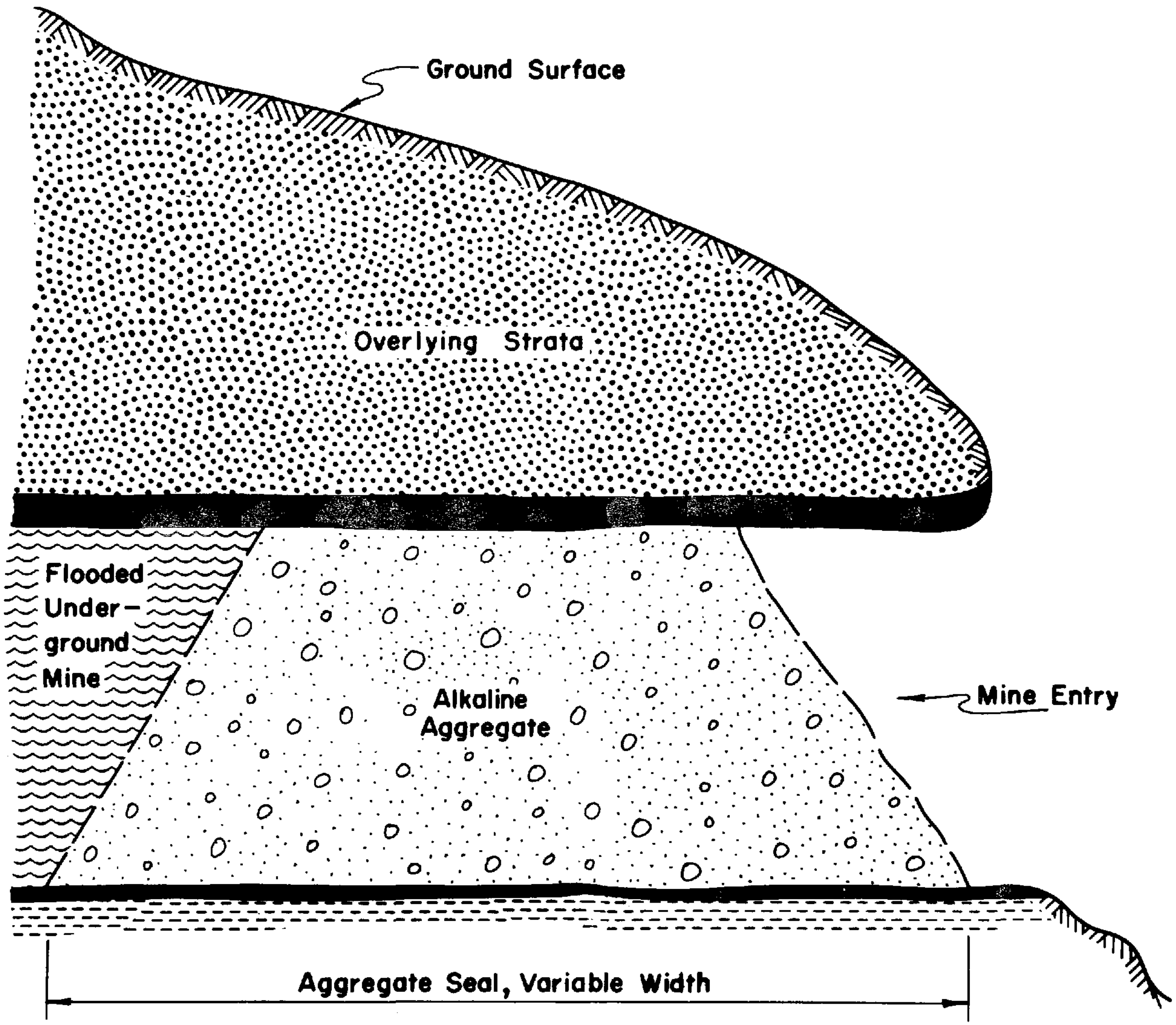

Figure 9. Typical cross section of a permeable aggregate seal as shown in R.L. Scott and R.M. Hays, Inactive and Abandoned Underground Mines, EPA-440/9-75-007.

By the second sampling, in March 1976, the seal in the No. 2 portal was breached and water was flowing over and around it at the rate of 1.44 lpm. It was not possible to determine the water levels in the mine as the obervation well was inaccessible.

Overall, the water quality shows considerable improvement since installation of the seal. Acidity decreased immediately upon closure (see Figure 10). A comparison of the pre- and post-sealing sampling period concentration means discloses a reduction of 62 percent (significant at .01) from 595 mg/l to 224 mg/l. Alkalinity concentrations rose immediately upon sealing to 205 mg/l. After the seal failures, alkalinity plunged to zero, pH levels decreased to 3.00, and acidity increased to 406 mg/l.

The water quality data for the post-sealing conditions show considerable variability of acidity concentrations (see standard deviations in Table D-14) and pH levels. Values for acidity vary from 3 to 680 mg/l with pH levels ranging between 2.7 and 6.8.

The irregularity of the two parameters is a result of an intermittent contact of the mine effluent with the alkaline material of the seal. Water contact with the seal can be minimized by leakage around the seal and through rock units in its proximity or by a brief residence time of water seeping through the seal during increased flow or heightened hydrostatic pressure, resulting in insufficient neutralization.

Regardless of the several instances where the mine effluent was flushed out without being neutralized by contact with the limestone material, the chemical analyses of the effluent show an overall decrease in acidity during the post-sealing period. Furthermore, alkalinity almost always exceeds acidity.

Total iron and sulfate concentrations were reduced after the closure. Total iron decreased by 64 percent. Sulfate concentrations were reduced from 1316 mg/l to 1208 mg/l. In view of this small difference between the means, it is highly probable that the sulfate concentrations were not, in fact, altered because of sealing.

As a result of the decrease in flow from the mine, there is a decrease in the output of all three major pollutants. On the basis of the sampling period means comparisons, acidity loads are reduced by 90 percent, total iron by 90 percent, and sulfate by 79 percent. The statistical test for difference in the means indicates that the magnitudes between the pre- and post-sealing sampling period means are large enough to assume they are from two different water quality populations.

The regression analysis suggests the effect of the seal is to either reverse increasing trends or quicken the rate of a decreasing trend. While the regression coefficients listed in Appendix E are the best estimators of the trends, the pre-sealing concentrations and loads fluctuate so greatly that none of the representative coefficients are significant even at the 20 percent level.

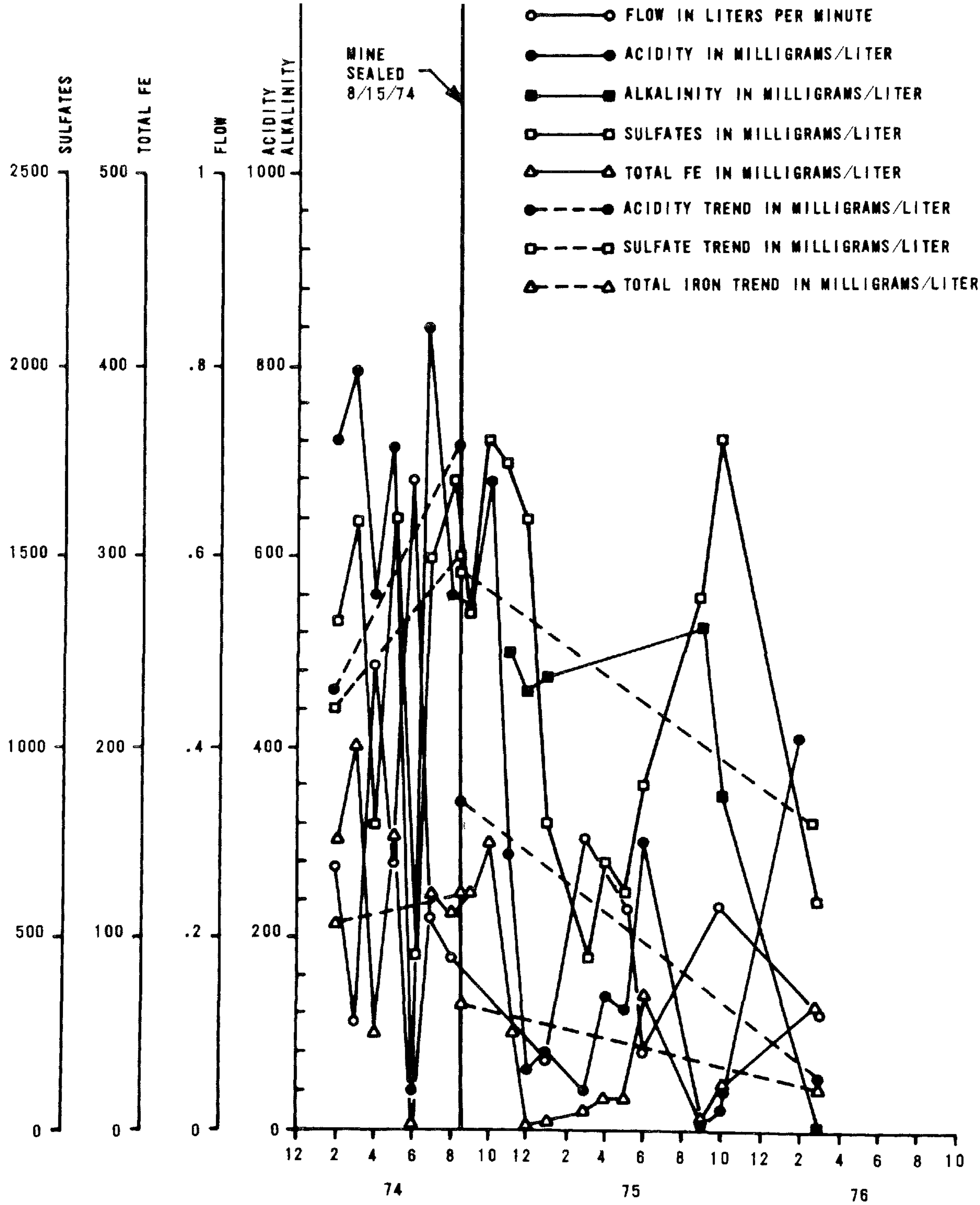

Figure 10. Stewartstown Mine, pollutant concentrations and trends.

Mine RT 5-2A, Coalton, West Virginia

As described in the section on air seals, this site is a drift mine with approximately 39 meters of overburden consisting of 23m of shale, 13m of sandstone, and 0.9m of calcareous rock. The thickness of the mined coal seam is 2.4m and the sulfur content is 2.0 percent. Dip of the rock beds is approximately 10.0 degrees. The mine is located near drainage and the average annual precipitation is 109.8 centimeters.

RT 5 Mine was mined periodically from 1904 to 1950 and closed in September 1969 by the Halliburton Company under the auspices of the U.S. Environmental Protection Agency. The construction of the permeable bulkhead seal in the RT 5-2A portal was undertaken after the water impounded behind the double bulkhead seal in RT 5-2 portal began to discharge through this, then unknown, opening.

The work was performed by constructing a permeable bulkhead seal of graded limestone aggregate and agricultural lime in the drift. The void space between the mine roof and the aggregate was grouted as a precautionary step in the event water behind the seal would reach the mine roof.[a]

Mine discharges were monitored from January 1964 until September 1971. Water from inside the mine was also sampled regularly. Chemical and quantitative measurements of water discharging from RT 5-2 were used for the pre-sealing and post-sealing comparisons of the discharge from RT 5-2A since it was not draining until the other portals were closed.

The neutralizing effect of the permeable seal had a significant impact on the acidity of the mine discharge. Comparison of the pre- and post-sealing means for acid concentrations indicates an 84 percent decrease. The statistic for the difference in the means also attests to the acid reduction (see Tables 10 through 12, and Tables D-14 through 15). As of June 1971, alkalinity had increased by over 300 percent and was generally higher than acidity. The impact of the seal on sulfate and total iron has been less pronounced. The total iron concentrations decreased from the pre-sealing 212 mg/l to 160 mg/l. The deviations from the means are rather large, and indicate considerable fluctuation in the total iron concentrations. This is also true of pre- and post-sealing sulfate concentrations, that increased 35 percent after sealing.

Comparison of the total averages of the pollutant outputs for the two sampling periods (pre- and post-sealing) indicates 99 percent reduction in acidity, 98 percent reduction in total iron, and 96 percent reduction in sulfates. The seal has reduced the variability of the parameter outputs, as well, especially those of acidity and sulfate.

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[a] Robert B. Scott, Evaluation of Bulkhead Seals, Office of Research and Monitoring, National Environmental Research Center, Cincinnati, Ohio, U.S. Environmental Protection Agency (1972).

The trend analysis of the pollutant concentrations indicate pre-sealing increase in the sulfate and total iron concentrations. These have been maintained also after the mine closure (Figure 11).

Since the last recorded sampling of the portal by the Norton Mine Drainage Field Office in August 1971, the pipes of both the RT 5-2 and RT 5-2A seals (used for monitoring quality within the mine), have been opened and allowed to drain freely. This was done to alleviate any danger of the considerable hydrostatic head behind the seals. As a result of this change in the hydrologic setting of the mine, the two chemical analyses done for samples collected in October 1975 and March 1976 were not included in the calculations of means, standard deviations, or statistical analyses.

The two seals are now functioning as air seals and are both in good condition. Flow from the RT 5-2A portal has not increased more than 10 percent from the 12.5 lpm mean calculated from the post-sealing sampling period data in July 1971. Acid and total iron concentrations have risen to pre-sealing levels again; however, sulfate concentrations are lower than either the pre- or post-sealing means.

The quality of water that inundated the mine after the sealing was observed to have deteriorated considerably (Figure 12). Acidity concentrations increased by 60 percent comparing the total means of acidity for the pre-sealing mine discharges (683 mg/l) with the total means of acidity indicated for the samples taken from behind the permeable seal (1093 mg/l). The sulfate and total iron concentrations increased by 134 percent and 127 percent, respectively. The average pH levels of the post-sealing mine discharges were 5.7 as compared to 2.9 inside of the mine.

Mine 62008, Portal No. 3, Clarksburg, West Virginia

Mine 62008 is a small (0.1 km^2) drift mine located above drainage. Dates of mining are unknown. The overburden consists of approximately 23m of shale, 18m of sandstone, and 0.9m of calcareous rocks or coal. Average dip is 4.0 degrees. The mined coal seam is 2m thick with a sulfur content of 3.10 percent. Surface mining was conducted in close proximity to the mine.

Portal No. 3 of the mine was sealed with a permeable type limestone aggregate plug (Portals No. 4 and 5 were closed by double and single bulkhead seals) in June 1969. The aggregate was so graded that acid mine water flowed through the plug with sufficient retention time to be neutralized. The finished seal of aggregate filled the 1.3m by 3.6m drift maintaining 7m of roof contact and 10m of floor contact. Some settling occurred after several days leaving a gap between the top of the stone and the roof of the mine.[a]

The Halliburton Company, under the sponsorship of the U.S. Environmental

[a] Robert B. Scott, Bulkhead Seals.

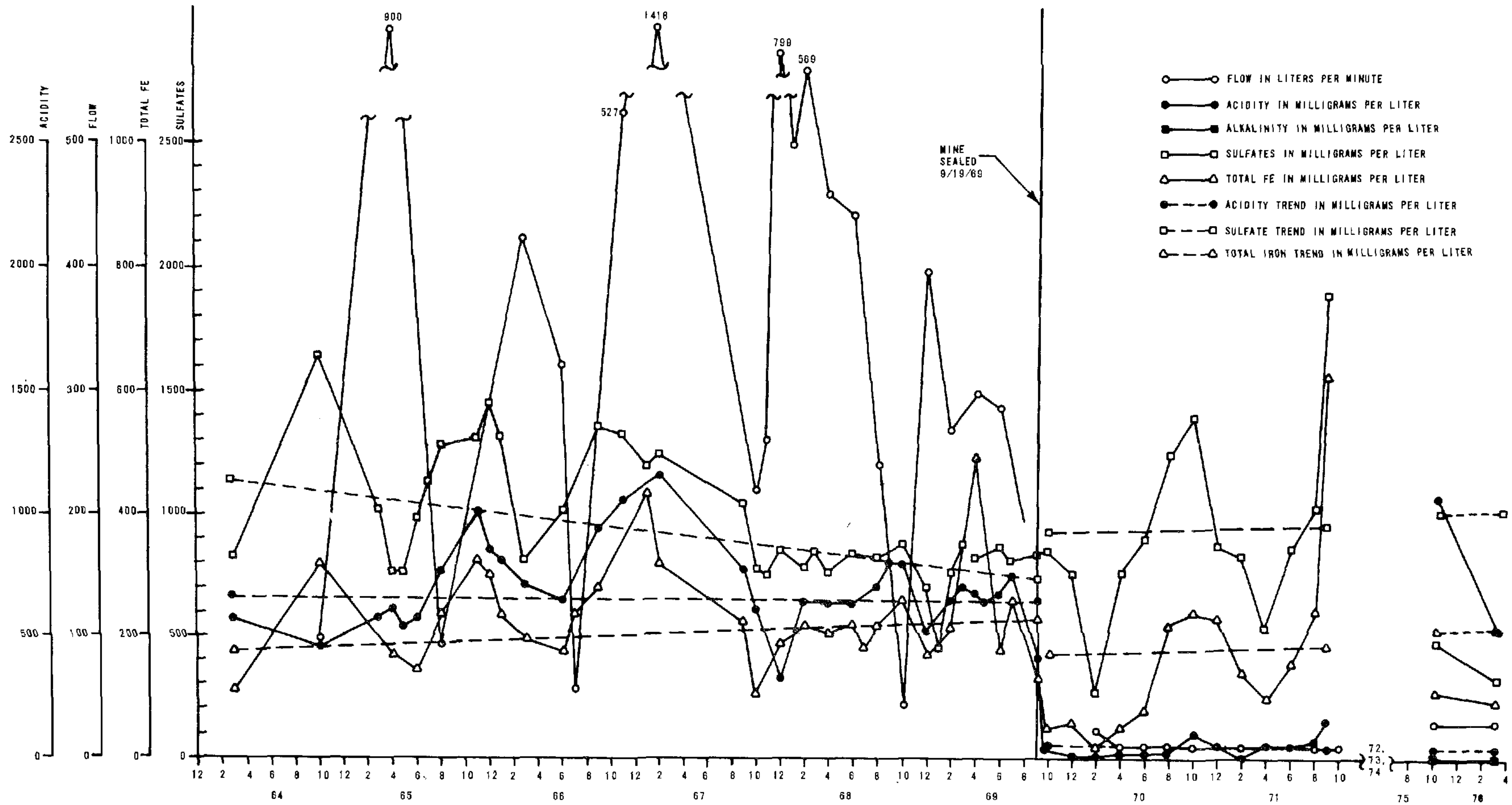

Figure 11. RT5-2A Mine, pollutant concentrations and trends.

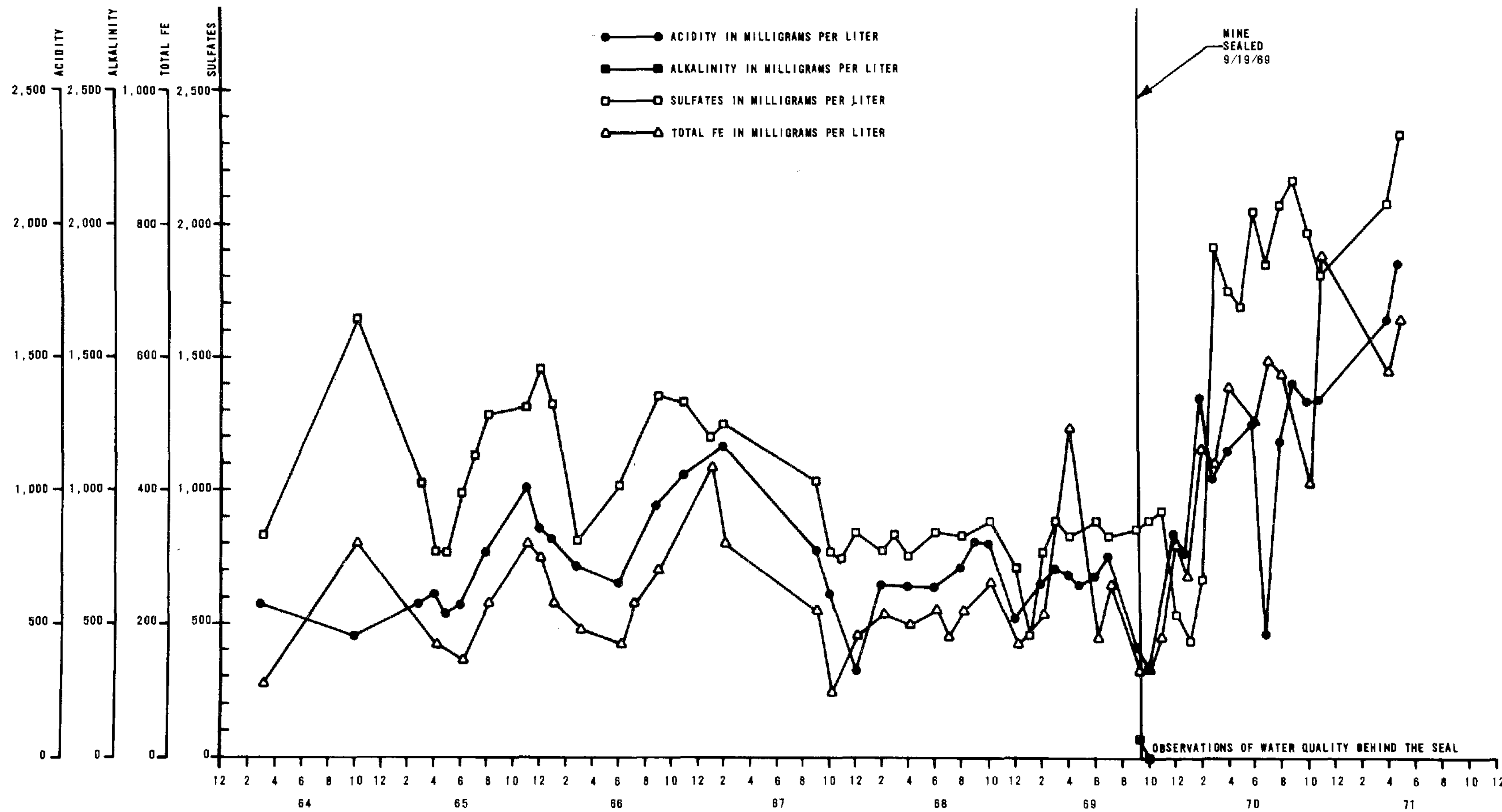

Figure 12. RT5-2A Mine, pollutant concentrations; post-sealing data are for water quality from inundated mine.

Protection Agency, constructed the seals and monitored the mine discharges from 1968 to 1969. The post-sealing monitoring was continued by the EPA Norton Mine Drainage Field Office until 1971.

The lack of pre-sealing monitoring severely limits the reliability of any evaluation of the effects of the seal. A comparison of the pre- and post-sealing concentration means suggests a decrease in both acidity and total iron and an increase in alkalinity, pH, and sulfates. Comparison of the means relative to the standard deviations indicates that the only probable real change takes place with regard to pH and alkalinity. Differences in the pre- and post-sealing means of acidity, total iron, and sulfates are not large enough to assume they are not from the same population (Figure 13).

The increase in pH from 3.6 to 6.6 and in alkalinity from zero to 207 mg/l is due to the introduction of carbonate from the seal to the water exiting from the mine. During the post-sealing sampling period, average alkalinity concentrations were generally higher than those of acidity.

The mine effluent discharge decreased considerably immediately after sealing. During 2 years following the closure, flow remained slightly below the pre-sealing value of 11 lpm. In October 1975, however, flow exceeded the pre-sealing levels and reached 26 lpm. This rise in flow contributes to the apparent augmentation of pollutant outputs (see Table D-15) after closure.

Trend analysis performed for the post-sealing data shows acid and sulfate concentrations and outputs decreasing. On the average, acid concentrations are decreasing at 4.9 mg/l/year, however, there is considerable fluctuation in this rate. This variability may be due to the reported water leakage over the top of the seal, thus occasionally limiting the contact of the mine water with the alkaline material of the seal. Acid outputs are decreasing at rates of 0.16 kg/year. Sulfate concentrations are decreasing at 55.10 mg/l/year, while outputs are decreasing at 0.2 kg/year.

The coefficients for total iron concentrations and outputs suggest they are increasing, but the amount of deviation is comparatively large, and the coefficients are not significant statistically.

This seal is still in good condition, and the increased alkalinity and decreased acidity show that water is continuing to be neutralized by the seal.

SHAFT AND SLOPE SEALS

Shaft and slope entries are commonly filled with miscellaneous materials, covered, or fenced off for public safety. Because these entries also act as conduits for mine water drainage, they are hydraulically sealed. The placement of a hydraulic seal involves opening the shaft or slope and recovering all debris. A suitable sealing zone in the strate is then located. The entry is then backfilled to the sealing zone with miscellaneous fill, and the impermeable seal is placed. The sealing operation is

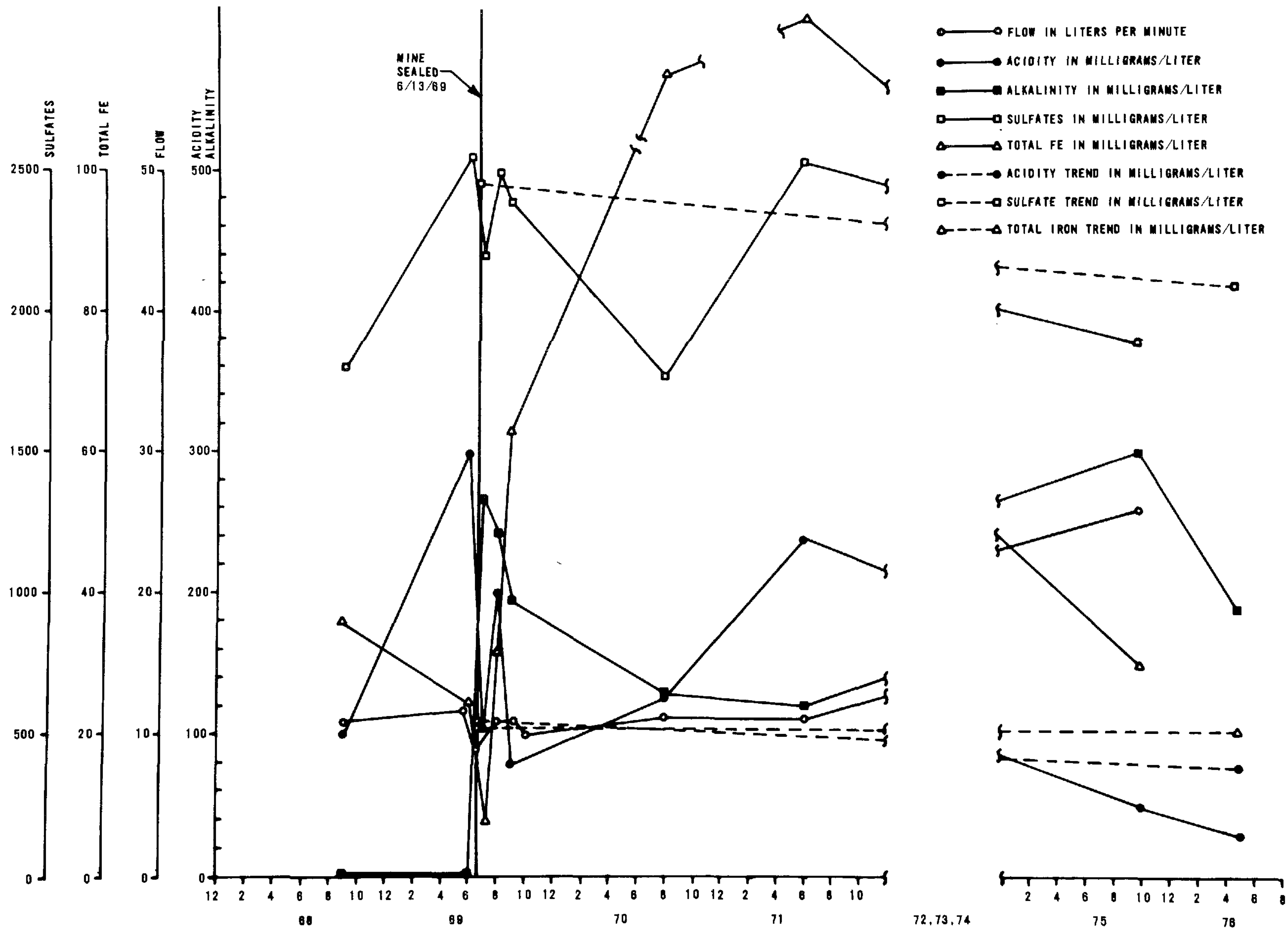

Figure 13. Mine No. 62008-3, pollutant concentrations and trends.

completed by backfilling the shaft to ground level[a].

Eighteen sealed shaft or slope mines located in Pennsylvania, Kentucky, Indiana, Illinois, and Iowa were selected as sites to be studied on this project. Locations of the sites are shown in Figure 1. All the mines are below drainage and are flooded most of the time.

There are no available historical water quality data for the pre-sealing periods of these mines. Only two samples collected during this study characterize the post-closure mine water quality. The assessment of the influence of these closures on the mine water quality is therefore impossible. Moreover, the closures at the studied sites were not designed or constructed to improve the mine effluent quality, but were placed over the openings mainly for safety purposes.

The available water quality data indicate seven out of 12 sites with alkalinity exceeding acidity and pH levels equal to or above 6.0. The total iron concentrations are rather high at three sites in Illinois and two sites in Iowa. They range between 47 and 292 mg/l. The sulfate concentrations are also highest at these sites and range from 1700 to 4400 mg/l.

The water quality characteristics are most likely more attributable to the lithological character of the country rocks and to the fact that most of these mines are permanently flooded. It is a present consensus that deep mines of these areas do not significantly affect the surface water quality as do the surface mining wastes.

Repplier, Veith, Otto, and Otto Primrose Mines

Repplier, Veith, Otto, and Otto Primrose are the sites located in the anthracite region of eastern Pennsylvania. Shaft entries in this area were sealed during the Federal Work Projects Administration mine sealing projects which began in 1933.[b] The mine shafts were filled with earth, rock, or a concrete slab was placed over the shaft. The sealing efforts were not designed to stop the mine water overflow through the shaft or slope entries.

Quality of mine effluent from these mines indicates relatively low concentrations of sulfates ranging between 55 and 255 mg/l, and of total iron between 1 and 14 mg/l. Concentrations of alkalinity are invariably higher than those of acidity, with ranges in concentration between 0.3 and 49 mg/l for acidity and 0.0 to 916 mg/l for alkalinity. The pH levels for these mines are between 4.2 and 7.1 .

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[a] L. R. Scott and P. M. Hays, Inactive and Abandoned Mines.

[b] P. A. Fellows, Sealed Projects - Sharply Reduce Stream Pollution From Abandoned Mines, Coal Age 42 (1937): 158-61.

East Diamond, Atkinson, and Pleasant View Mines

East Diamond, Atkinson, and Pleasant View Mines are located in Western Kentucky. They are similar in their physical and mining background to Miami No. 5 and Viking Mines in Indiana, to Burningstar No. 1, Buckhorn, and Ensminger Mines in Illinois, and to Hull, New Lansing and Lost Creek Mines in Iowa.

All of these mines are located in the Eastern Region of the Interior Coal Province. Mean overburden above the coal seam in question is 48m, the average shale to sandstone thickness ratio is 20:1, with exception of the Kentucky mines with the shale-sandstone ratio of 2:3. There are calcareous rocks as well as another coal seam present in the overburden. The strata are mostly horizontal. The total mined area of these mines ranges from 0.13 to 4.34 km^2, the coal seam thickness varies from 1.3 to 1.5m.

There was no drainage from an observation well for sampling waters from the East Diamond Mine. The water quality data for the other two West Kentucky mines, the Atkinson and Pleasant View Mines, indicate relatively high pH levels ranging between 6.2 and 8.4, acidity concentrations ranging between 1.0 and 3.4 mg/l, sulfate between 151 to 810 mg/l, and total iron between 4 and 6 mg/l. The mines were closed by placing a concrete slab over the slope or shaft openings.

The mine discharges from the sites that were studied in Illinois and Indiana show pH levels mostly above 6.0, with acidity always lower than alkalinity. Some of the sites, namely the Burningstar No.1 and Buckhorn Mines, are characterized by sulfate concentrations above 3,000 mg/l and total dissolved solids ranging between 1,440 mg/l and 6,166 mg/l. The mines were closed by a concrete slab placed over the slope openings or by an earth seal.

Hull, New Lansing, and Lost Creek Mines

The Hull, New Lansing, and Lost Creek Mines in Iowa are shaft and slope mines that were earth-sealed approximately 70 years ago when the mines were abandoned. They are supposedly small mines with overburden characterized by a predominance of shale and presence of another coal seam and limestone. No mine maps are available for these mines.

The measured pH levels range between 4.4 and 6.2, acidity concentrations between 121 and 1293 mg/l, sulfates between 91 and 2150 mg/l, and the total iron between 60 and 1840 mg/l.

Arjay Mine

The Arjay No. 4 is a downdip mine in eastern Kentucky which was sealed with a concrete slab in 1973. Overburden thickness is 30m thick and is predominately sandstone. Most of the mine is positioned below the water table.

EARTH SEALS

This type of seal is constructed by bulldozing earth into the mine portal or by simple caving in the mine opening. Earth seals are generally intended to close mines to prevent entry rather than to abate pollution.

Four drift mines in Pennsylvania, two in West Virginia, and one in Eastern Kentucky closed by earth sealing were sampled during this investigation. Pre-sealing water quality data exist for only one of the sites.

Imperial Colliery No. 8, Burnwell, West Virginia

The Imperial Colliery No. 8 is a drift mine of 3.2 km^2 located in the No. 2 Gas coal seam. The average overburden thickness is 164m, of which 60 percent consists of shale, and 40 percent of sandstone. No calcareous rock is present.

The mines were closed in 1972 when production ended. Mine discharge was sampled once before the sealing and twice afterward. Comparison of the chemical analyses of the pre- and post-sealing periods show improvement in drainage quality. The acidity concentrations were reduced by 83 percent from 810 mg/l to 134 mg/l and pH values increased from 2.6 to 4. Alkalinity remained at zero. Sulfate concentrations were reduced from 1100 mg/l to an average of 494 mg/l.

Helen Mine, Helen, West Virginia

The Helen Mine, sealed in 1967 by the Westmoreland Coal Company, was discharging at a rate of 3.00 lpm when measured in October 1975 and March 1976. Alkalinity was slightly higher than acidity (9.4 vs. 9.1 mg/l), total iron and sulfates average 6 mg/l and 188 mg/l, respectively. No pre-sealing analyses were performed on the discharge at this site.

The mine produced in the Pocahontas No. 4 seam (sulfur content of 0.8 percent) from 1957 to 1967. The overburden is primarily shale.

Baker No. 1, near Arjay, Kentucky

This small drift mine (0.16 km^2) is located above drainage and has a predominantly sandstone overburden. It produced in the 4A seam (3.1 percent sulfur) from the 1940's to 1973, when the portals were bulldozed closed.

Neither flow nor quality measurements were made prior to sealing. Average flow for the sampling in October 1975 and March 1976 was one lpm. Alkalinity was greater than acidity (76 mg/l as opposed to 50 mg/l), total iron averaged 0.7 mg/l, and the mean of sulfate in concentration was 114 mg/l.

New Watson, Mills No. 4, and Buskirk Mines, Clearfield, Centre, and Armstrong Counties, Pennsylvania

The New Watson and Mills No. 4 mines are small drifts located above drainage in the Clarion seam. The mines were sealed soon after production ended in the 1950's. Mine discharges are characterized by pH values of 3.7 and 3.6, and ranges in acidity concentrations of 42 mg/l and 96 mg/l, total iron of 2 mg/l and 10 mg/l, and sulfate concentrations of 72 mg/l and 74 mg/l.

The Old Watson mine, located adjacent to the New Watson, is characterized by pH levels of 4.1, acidity of 20 mg/l, total iron of 0.2 mg/l, and sulfate of 5 mg/l. Since this mine is unsealed, it may be assumed that the water quality of its discharge is comparable to that which would emanate from the New Watson, were it unsealed. The implication is that the mine discharge from the New Watson is unaffected or has slightly deteriorated due to the sealing; however, no evaluation based on these conditions is very credible.

The Buskirk Mine, a drift of approximately 0.05 km^2, is located above the drainage in the Upper Freeport seam (sulfur content is 1.6 percent). This mine was abandoned fifty years ago and recently (1974) blew out when an excessive amount of water pressure developed behind the slumped or caved portal. It was resealed in December 1974 by placing an earth seal and a pipe in the portal. The water flows through the pipe at approximately 39 lpm. The water quality is characterized by pH levels of 4.2 and 4.8, an average alkalinity of 0.45 mg/l, an acidity of 10 mg/l, a total iron level of 0.25 mg/l, and a sulfate level of 31 mg/l.

CLAY SEALS

Shaw Mine, SL 118-3, Meyersdale, Pennsylvania

Clay seals are constructed of clay material placed in the mine opening to form a hydraulic seal or to control infiltrating water. The clay is placed in layers and compacted to cause the clay to flow into cracks and voids along the walls and roof of the seal area. Under ideal conditions a clay seal may withstand up to 10 meters of hydrostatic head.[a]

Construction of clay seals at the Shaw Mine complex was performed as part of an extensive reclamation work and was sponsored under the "Operation Scarlift" program, Project SL 118-3.

Clay seals were installed along the high-wall of the box cuts in an attempt to hydrologically isolate sections of the extensive Shaw Mine complex. Overburden above the abandoned mine was excavated and the Redstone and Pittsburgh coal seams removed. The clay barrier seals were constructed in the cut to flood portions of the underground mine.

[a] L. R. Scott and P. M. Hays, Inactive and Abandoned Mines.

Chemical analyses of the mine discharges from the mine in proximity to the clay seal show rather poor water quality. The flow rates were measured up to 95 lpm. There are no water quality and quantity data for the mine discharges before the sealing effort.

GROUT BAG SEAL

Construction of a grout bag seal involves a placement of successive layers of expendable grout containers in an accessible mine opening. Nylon or cotton cloth grout retainers are placed on the floor of the mine and inflated with cement to conform to the shape of the mine entry. After the cement sufficiently hardens and is capable of withstanding a load of about 2,109 kg per square meter, a second row of shorter retainers is placed above it and inflated with cement. This process is repeated until the entire area between the floor and roof of the mine entry is filled by the retainers.[a]

Mine No. 14-042A near Clarksburg, West Virginia

A grout bag seal consisting of four expendable 0.3m long cement grout-filled nylon retainers was constructed in Mine No. 14-042A by the Halliburton Company in May 1967. The mine is located in the Pittsburgh seam and is approximately 0.02 km^2 in size. The mine water discharges to Doll Run, a tributary to West Fork River.

The mine discharge prior to the sealing was reported to be approximately 55 to 60 lpm with a pH level of 2.6, and concentrations of acidity and total iron of 2,750 mg/l and 558 mg/l, respectively.

A leakage around the bag seal, observed immediately after the sealing, was reduced from 5.6 lpm to 1.25 lpm by subsequent remedial work. However, as the water level ascended behind the seal, the flow increased. The additional attempt to stop the leakage made by filling the void space behind the seal with a gel material of bentonite and shredded cane fiber was not successful. The leakage was reported not only through the seal itself, but mainly through the adjacent rocks. Four years later when the seal was inspected, the major leakage was reported to be due to the considerable deterioration of the coal surrounding the seal, which broke the bond between the seal and the rock.[b]

The mine discharges were monitored by the EPA Norton Mine Drainage Field Site from September 1969 to June 1971 in continuation of the project.

Evaluation of the effectiveness of this seal is rather difficult because only one sample each of the acid, total iron, and sulfate concentrations and outputs was available for the pre-sealing period.

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[a] L. R. Scott and P.M. Hays, Inactive and Abandoned Mines.

[b] Robert B. Scott, Bulkhead Seals.

The post-sealing period trends show significant decreases in acid, total iron, and sulfate concentrations. Outputs appear to be decreasing slightly; however, the standard errors of the coefficients suggest that the rates are variable and not significant.

Pollutant concentrations increased immediately after sealing but reached the pre-sealing levels in nearly a year. Flow, on the other hand, decreased immediately upon closure and has continued to average from 1 to 6 lpm.

According to chemical analyses of samples taken in October 1975 and March 1976, flow is averaging 3.5 lpm, and the acidity concentration has decreased to 1130 mg/l. Total iron and sulfate concentrations average about half of the pre-sealing sampling period means. Alkalinity remains at zero.

There is considerable subsidence and slumping in the vicinity of the mine portal and the flow is still seeping through the adjacent rocks with minimal flow through the seal itself.

UNDERGROUND PRECIPITATION SEALING

Driscoll No. 4, Vintondale, Cambria County, Pennsylvania

The Driscol No. 4 Mine was used as a field demonstration site of a project testing an underground sealing by injection of alkaline water slurries behind a rubble barrier, allowing precipitate to flow into the barrier and plug the opening.

The project was sponsored by the U.S. Environmental Protection Agency and the Commonwealth of Pennsylvania and conducted by the Parson-Jurden Corporation at the end of 1970.

The effort to seal the mine was not successful. The injection of the alkaline slurry resulted in immediate increase of pH up to 12.0 level. However, when the injection stopped, pH levels dropped to less than 4.0.

The Driscoll No. 4 Mine is a high flow mine with two measured discharges in October 1975 and March 1976, of 1893 lpm and 4781 lpm. The mine is directly recharged from the Black Lick-North Branch stream. The high flow in the mine may have contributed to the sealing failure.

SHORT-WALL MINING

Short-wall mining is a method of removing a mineral seam in an operation by means of a short-wall or working face. The roof behind the mined face is allowed to break and cave immediately behind the support line. The mined-out space is then filled with the roof material. The reduction of the void space should result in a reduced oxygen-sulfide contact and subsequent control or inhibition of the acid forming processes.

An example of short-wall mining was found at a drift mine (Delta) near Jennerstown, Pennsylvania. Two samples were obtained from this mine. One from a section mined by the room and pillar method (Sample 1), and one from a sectioned mined by the short-wall technique (Sample 2). Water quality of the sample taken from the latter section shows significantly lower concentrations of all the pollutants. The acidity and alkalinity concentration for Sample 1 were measured at 119 mg/l and 0 mg/l, respectively, compared to Sample 2 for which the concentrations were indicated to be 7 mg/l and 2 mg/l, respectively.

STOWING

Stowing or underground mine backfilling was done mainly to prevent surface damage from subsidence or to control mine fires in abandoned anthracite or bituminous coal mines.

Because the reduction of void space within the mine reduces the oxygen-sulfide contact, it can be expected that the oxidation of sulfides within the backfilled mine will be inhibited.

Two sites in the anthracite region of Pennsylvania, Storries and Taylor Mines backfilled with crushed spoil materials, were surveyed on this project. Quality of the mine effluent pumped out of the two mines is characterized by pH levels of 5.4 and 6.2 and acidity concentrations of 130 mg/l and 99 mg/l. There are no other water quality data available from the mines besides the two above samples to allow evaluation of the effect of the backfilling on the effluent quality.

DAYLIGHTING

Daylighting to abate mine drainage pollution entails removal of the mine overburden, extraction of the remaining coal and other potential acid-producing materials, and replacement of the overburden to reclaim the site. The acid-producing materials are buried in such a way as to minimize the possibility of future pollutant generation.[a]

No examples of this procedure as a mine drainage abatement technique were discovered during site selection, although abandoned deep mines have been stripped out and reclaimed as part of the surface mining law requirements in some states.

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[a] L. R. Scott and P. M. Hays, Inactive and Abandoned Mines.

There are plans to demonstrate the technique as a closure method in the Lostland Run watershed of the Upper Potomac River basin near Deer Park, Garret County, Maryland. A complete description of the proposed project is given elsewhere and will not be duplicated in this report.[a]

The Gilman Mine is the principal source (48 percent) of the pollution discharging into the North Branch of the Potomac River. Monitoring of the discharge from this mine from October 1972 to February 1976 shows a mean acid concentration of 799 mg/l and a mean alkalinity concentration of 0.1 mg/l. Total iron and sulfate concentration means are 59 mg/l and 1591 mg/l, respectively. Outputs of acidity, total iron, and sulfate average 327, 37 and 543 kg/day.

Trend analysis done on these data indicates that acid concentrations and outputs are decreasing at 225 mg/l and 373 kg/year. Similarly, total iron concentrations and loads are decreasing at 58 mg/l and 63 kg/year. These trends are significant at the 1 percent level. Sulfate concentrations appear to be decreasing at 32 mg/l/year, however, this rate is variable according to the magnitude of the standard error of the coefficient and thus is not significant. The sulfate output rate is significant, though, and shows outputs decreasing at 430 kg/year.

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[a] H. F. Moomau, M. T. Dougherty, and J. R. Matis, Engineering and Administrative Problems, Deer Park Daylighting Demonstration Project, in Fifth Symposium on Coal Mine Drainage Research, National Coal Association/ Bituminous Coal Research (Washington, 1974).

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APPENDICES

APPENDIX A. FIELD SURVEY PROCEDURES

The following discussion yields technical information on those facets of the field survey relative to sampling techniques, analysis, and measurement, and to sample preservation and handling.

A preliminary field trip was conducted in late August 1975 before the dry season field effort. To familiarize the field crews with the problems anticipated at the mining sites, to understand the objectives of the study, and to assure uniformity in sampling techniques and procedures, all field crew members took part in a training session at actual mine closure sites at Moraine State Park, Pennsylvania, and the Woolridge Mine, Clearfield, Pennsylvania. Another aspect of this preliminary field effort was the collection of water samples, previous water quality data, maps, reports, and field information. The results of this effort were used as an aid in discriminating essential from non-essential information necessary for final site selection.

Water quality tests performed in the field during this trial run included temperature, pH, total iron, acidity, and alkalinity, Flow was also measured. Laboratory analysis included pH, net acidity, specific conductance, sulfates, COD, suspended solids, total solids, ferrous iron, Al, Mg, Mn, Cd, Hg, and total iron.

Sample Collection

To increase the mobility of the sampling operation, all water sampling was conducted manually. In the majority of cases, grab samples were taken of mine discharges, observation boreholes, receiving streams, seeps, and adjacent waters representative of the area.

When more feasible, composite samples were collected manually, as in the case of seep zones and french drains. Bomb samplers were used to collect water from boreholes and other deep, narrow openings.

To insure an adequate volume of sample to perform the chemical tests and an allowance for accidents and errors, approximately twice the amount actually necessary for analysis was collected. Three bottles of sample were filled at each discharge point.

Every sample bottle was identified by means of a tag or bottle marking printed legibly with waterproof pen. Information on the sample label included identification of the site, date and time of collection, and pH. The dry season effort also listed total iron content.

Supplemental information not listed on the label was recorded on the field sheet for the site. Sample site, date, hour of collection, and name of mining community representative or local contact were recorded. In addition, all results of water quality tests and flow measurement done in the field were logged.

Sample Preservation and Handling

Every effort was made to achieve the shortest possible interval between sample collection and analysis. However, in anticipation of unavoidable delays long enough to produce significant changes in the sample, preservation measures were utilized. Water samples used for identification of chemical oxygen demand and mercury were treated with hydrochloric acid, and samples for determination of Fe, Al, Mg, Mn, Ca, Cd, Ni, and Zn, were treated with nitric acid. Laboratory samples for pH, alkalinity, specific conductance, sulfate, suspended solids, and total dissolved solids were collected in 1-liter, unfixed, polyethelene bottles. Since chemical samples often require icing, all sample bottles were transported in styrofoam mailing containers packed with dry and/or cube ice. Samples were then shipped to the laboratory via air freight, bus, or personal delivery.

Flow Measurement

Discharge measurements were calculated through use of Gurley current meters, V-notch weirs, standard equations, and calibrated buckets. Very high or low flows and those physically inaccessible were estimated or determined from previous records.

APPENDIX B. LABORATORY ANALYSES

Laboratory analytical methods utilized during the testing are summarized in Table C-3. Sample acidity was determined according to EPA hot titration and cooling method which incorporates a back titration with sulfuric acid to a pH less than 4.0. This technique employed on a sample with a pH less than or equal to 4.5 results in a total acidity value. If, however, the sample pH is greater than 4.5, the value obtained is termed net acidity (or net alkalinity if the value is negative) which implies that all of the components (except carbon dioxide) which contribute to acidity and alkalinity are encompassed in the analysis. Samples were subsequently analyzed for total alkalinity using a cold titration with sulphuric acid to an endpoint of pH 4.2.

Total metals (unfiltered), excluding ferrous iron and mercury, were analyzed according to Perkin Elmer Atomic Absorption Methodology.

Low concentrations (0.010 to 1.12 mg/1) of ferrous iron were determined utilizing a Spectronic 70 spectrophotometer according to the procedures listed in the ASTM Standards and Standard Methods. High concentrations (greater than 1.12 mg/l) were determined by titration with a standard dichromate solution to a diphenylamine sulfonate endpoint, purple in color.

Mercury analyses were run on a Perkin Elmer Model 50 Mercury Analyzer System using EPA defined methodology.

The COD test utilized in this study proved to be inaccurate in the presence of ferrous iron. We hypothesize that as the procedure involves an inverse colorimetric test, the color interference resulting from the oxidation of iron from the ferrous to the ferric state limits the accuracy of this test. At this time, the method seems to be inapplicable to the determination of COD in ferruginous mine water.

All the methods of sample preservation followed the Environmental Protection Agency guidelines.

Ideally, complete chemical analysis should be performed on water samples upon their arrival at the laboratory. Since this was not possible, the following schedule was arranged. Upon arrival of the samples at the laboratory, analysis for pH, alkalinity, acidity, and specific conductance were initiated and completed in one day. Analysis for suspended and total dissolved solids was completed within one week. The remainder of the one liter unfixed sample was refrigerated at 4° C. Sulfate analysis was performed on this remaining sample within one week of sample receipt. Samples for determination of ferrous iron and COD were stored at 4° C and were analyzed within one to five days from sample arrival. Mercury samples were stored at 4° C and were run within two weeks from date of collection. Samples for determination of metal concentrations were stored at 4° C and analyzed at the completion of each Phase.

TABLE B-1. INFORMATION PERTAINING TO THE SITE CODES, SAMPLE CODES, AND MINE LOCATIONS

Site code	Sample code	Mine name	Mine location
1	49,50,195	Repplier	Darkwater, Pa.
2	51,194	Veith	Phoenix Park, Pa.
3	54,193	Otto Primrose	New Mines, Pa.
4	52,53,191,192	Otto	Branchdale, Pa.
5	6,7,120,121	Argentine	Argentine, Pa.
6	8,9,124	Keystone #6	Boyers, Pa.
7	10,11,12,122,123	Keystone #10	Boyers, Pa.
8	13,14,118,119	Keystone #19	Ferris, Pa.
9	15,16,127,128	Hilliard	Mt. Chestnut, Pa.
10	24,25	Lindey #1	Prospect, Pa.
11	21,22,23,125,126	Isle #1	Prospect, Pa.
12	31,32,142,144	Shaw Elk Lick #1	Meyersdale, Pa.
13	28,33,34,103,104,105,141	Shaw SL-118-3	Meyersdale, Pa.
14	30,143	Shaw SL-118-5	Meyersdale, Pa.
15	106,107,108,110,111,112 136,137,138,139	Salem #2	Keystone State Park, Pa.
16	100,101,102,140	Driscoll #4	Vintondale, Pa.
17	42,46,168,169,170,171,172	Rattlesnake Creek Mine	Brockway, Pa.
18	43,45,173	Buskirk	Brockway, Pa.
19	44	Brandycamp Mine	Brockway, Pa.
20	1	New Watson	Philipsburg, Pa.
21	17,18,174,175	Old Watson	Philipsburg, Pa.
22	3,4,5,176,177	Mills #4	Osceola Mills, Pa.
23	61,158,159	Bullrock Run	Kittanning, Pa.
24	62,163	Mahoning Creek	Kittanning, Pa.
25	63,164,165	Decker #3	Kittanning, Pa.
26	64,166,167	Decker #5	Kittanning, Pa.
27	19,20	Woolridge #1	Clearfield, Pa.
28	113,114,115,116,117	Unknown	Cherry Run Village, Pa.
29	134,135	Delta #1	Jennerstown, Pa
30	188,190	Taylor	Taylor, Pa.
31	85,189	Storries	Dickson City, Pa.
32	65,66,198,199	40-016	Lost Creek, W. Va.
33	56,58,179	Helen-Westmoreland	Helen, W. Va.
34	87,167	RT5-2	Coalton, W. Va.
35	84,161	RT5-2A	Coalton, W. Va.
36	81,160	RT9-11	Elkins, W. Va.
37	89,152	Savage	Bowden, W. Va.
38	79,148,149	Big Knob #1	Bowden, W. Va.
39	88,150	Big Knob #2	Bowden, W. Va.
40	80,151	Big Knob #6	Bowden, W. Va.
41	67,154	14-042A	Clarksburg, W. Va.
42	68,196	62008-3	West Milford, W. Va.
43	69,197	62008-4	West Milford, W. Va.
44		62008-5	West Milford, W. Va.

TABLE B-1 (continued)

Site code	Sample code	Mine name	Mine location
45	70,71,153	Stewartstown	Stewartstown, W. Va.
46	57,178	Imperial Colliery #8	Burnwell, W. Va.
47	55,180	Imperial Colliery #9	Burnwell, W. Va.
48	36,187	Jack's Creek	Wheelwright, Ky.
49	37,182	Arnold's Fork	Wheelwright, Ky.
50		Buckingham	Wheelwright, Ky.
51		Price #2	Lambert, Ky.
52		Arjay #4	Pineville, Ky.
53	38,184,185	Baker #1	Arjay, Ky.
54		East Diamond	Madisonville, Ky.
55	47	Atkinson	Madisonville, Ky.
56	48	Pleasantview	Madisonville, Ky.
57	35,186	Buckingham #5	Wheelwright, Ky.
58		Sayreton	Sayreton, Ala.
59		Lewisburg	Fultondale, Ala.
60		New Castle	New Castle, Ala.
61	72	Ellisonville	Ellisonville, Oh.
62	77	Kelly	Ironton, Oh.
63	96,156	Essex #1	New Straitsville, Oh.
64	97,157	Essex #2	New Straitsville, Oh.
65	73,74,75	Piney Fork	Adena, Oh.
66	76	Florence	Florence, Oh.
67	98	McDaniels	NE. of Lake Hope, Oh.
68	95,155	Buchtel	Buchtel, Oh.
69	40,130	Miami #5	Shepardsville, Ind.
70		Miami #10	Shepardsville, Ind.
71		Viking	Spelterville, Ind.
72	39,129	Bennett	W. Terre Haute, Ind.
73	41	Black Diamond	St. Bernice, Ind.
74	183	Bates	Kite, Ky.
75	90,91,147	Burningstar #1	Desoto, Ill.
76	89	Buckhorn	Johnson City, Ill.
77	83,146	Lake City	Crenshaw Crossing, Ill.
78	86,145	Ensinger	Crab Orchard, Ill.
79	82	Watson	Herrin, Ill.
80	78	Carbon Fuel	Herrin, Ill.
81	92,131,132	Hull	Oskalloosa, Ia.
82	94	New Lanning	Eddyville, Ia.
83	93,133	Lost Creek	Eddyville, Ia.
84	27	Rockhead	Fall Creek, Tenn.
85	26,181	Phifers #1	Fall Creek, Tenn.

TABLE B-2. LISTING OF LABORATORY DERIVED WATER QUALITY DATA, ANALYZED BY THE INSTITUTE FOR RESEARCH ON LAND AND WATER RESOURCES, THE PENNSYLVANIA STATE UNIVERSITY

Sample code	Type	Site code	State	pH	Alkalinity	Net Acidity mg/ℓ	Specific Conductance μmhos/cm	Total Dissolved Solids mg/ℓ	Suspended Solids mg/ℓ	Sulfate mg/ℓ	COD mg/ℓ	Total Iron mg/ℓ	Total Acidity mg/ℓ
1	SE	20	PA	3.33		41.80	691.	312.7	39.2	74.	8.	1.75	41.80
3	OT	22	PA	6.87	6.30	0.55		35.1	2.1	16.	3.	0.15	6.85
4	SE	22	PA	2.83		106.70	513.	132.5	0.7	81.	1.	10.00	106.70
5	OT	22	PA	2.61		282.70	1210.	745.8	2.7	330.	1.	27.75	282.70
6	SO	5	PA	6.48	44.10	-12.50	259.	161.6	666.6	89.	6.	41.00	31.60
7	SE	5	PA	5.01	4.20	55.45	621.	471.0	2.7	120.	1.	30.00	59.65
8	OT	6	PA	4.69	1.05	10.15	104.	63.5	7.3	12.	4.	0.15	11.20
9	SO	6	PA	5.97	28.35	-11.60	122.	73.8	265.2	23.	1.	20.00	16.75
10	OT	7	PA	6.82	31.50	-4.60	1094.	138.5	3.7	82.	8.	0.15	29.90
11	SO	7	PA	6.75	231.00	-219.40		788.5	136.6	300.	1.	14.00	11.60
12	SE	7	PA	6.95	184.80	-179.80		700.1	10.2	240.	3.	2.10	5.00
13	OT	8	PA	4.54	0.12	11.13	169.	101.6	4.5	56.	3.	0.15	11.25
14	SO	8	PA	6.72	95.55	-90.70	351.	229.0	75.6	93.	3.	4.50	4.85
15	SO	9	PA	6.47	35.38	-27.67	85.	33.4	412.1	8.	1.	30.75	7.71
16	SE	9	PA	3.20		89.10	466.	315.5	3.3	177.	1.	7.20	89.10
17	UN	21	PA	4.27		18.46	528.	288.0	3.3	57.	7.	1.00	18.46
18	UN	21	PA	3.60		27.50	511.	305.2	3.0	54.	8.	0.15	27.50
19	SE	27	PA	2.34		305.80	1680.	1122.8	4.1	540.	1.	32.00	305.80
20	SE	27	PA	2.34		334.40	1790.	119.3	4.9	600.	1.	32.50	334.40
21	OT	11	PA	6.37	18.30	-1.18	163.	83.8	34.4	69.	11.	1.75	17.12
22	SO	11	PA	4.75	0.12	10.76	139.	78.2	38.4	46.	1.	7.80	10.88
23	SE	11	PA	5.69	23.18	-3.37	222.	52.5	162.7	89.	2.	9.10	19.77
24	OT	10	PA	4.70	0.12	57.21	627.	120.4	6.9	190.	1.	31.25	57.33
25	SO	10	PA	6.73	24.89	-18.61	54.	0.4	306.4	9.	3.	19.00	6.28
26	UN	85	TN	3.00		84.70	396.	139.9	18.0	69.	1.	11.40	84.70
27	UN	84	TN	2.88		123.20	512.	223.8	51.9	156.	1.	30.00	123.20
28	SE	13	PA	6.10	14.88		1350.	1313.9	30.1	810.	1.	48.00	
30	SE	14	PA	3.36		764.50	2090.	2569.8	36.5	1410.	1.	380.00	764.50
31	OT	12	PA	2.73		523.60	2190.	2402.0	16.9	1450.	1.	100.00	523.60
32	SE	12	PA	2.89		1102.20	2680.	3210.0	16.4	1850.	1.	434.00	1102.20
33	SE	13	PA	2.34		1007.60	2600.	2263.1	11.9	1360.		161.00	1007.60
34	OT	13	PA	4.83	1.71	5.15	251.	122.9	2.9	113.	1.	0.15	6.86
35	SE	50	KY	5.16	21.47	1.53	209.	176.6	13.5	100.		0.15	23.00
36	UN	48	KY	5.64	261.32	-144.18	1074.	816.8	4.0	400.	7.	0.15	117.14
37	SE	49	KY	7.11	388.51	-351.12	1044.	802.9	12.8	270.	9.	1.20	37.39
38	SE	53	KY	6.48	56.48	9.03	234.	159.2	23.2	86.	17.	1.30	65.51
39	SO	72	IN	6.86	158.19	-129.97	888.	805.2	150.6	400.	13.	7.75	28.22
40	SO	69	IN	6.95	272.13	-277.63	721.	595.4	183.4	250.	4.	1.90	.00
41	SO	73	IN	5.42	17.12	-7.59	3820.	3888.1	224.4	2350.	12.	23.00	9.53
42	SO	17	PA	3.46	0.12	277.20	1290.	1215.5	4612.1	540.	1.	47.00	277.20
43	SE	18	PA	4.45		12.22	214.	77.7	5.7	57.	4.	0.15	12.22
44	UN	19	PA	4.35		284.78	1240.	1267.1	11.9	560.	1.	112.50	284.78
45	SE	18	PA	5.17	0.12	9.66	176.	90.3	6.0	64.	4.	0.15	9.78
46	SE	17	PA	3.31		251.90	1240.	1212.0	8.2	550.	1.	26.00	251.90
47	SO	55	KY	8.05	701.49	-723.77	2190.	1568.8	67.3	810.	21.	4.40	.00
48	SO	56	KY	6.22	3.42	6.23	311.	196.0	39.2	151.	3.	6.75	9.65
49	SE	1	PA	6.02	24.45	12.83	635.	496.0	10.4	230.	1.	14.25	37.28
50	SO	1	PA										

SE – Drainages from closed drift mines.
UN – Drainages from abandoned but open drift mines.
SO – Interior mine waters from shaft/slope mines or inundated closed drift mines.
OT – Surface waters in proximity of the mine sites.

TABLE B-2 (continued)

Sample code	Type	Site code	State	Ferrous Iron mg/ℓ	Ferric Iron mg/ℓ	Manganese mg/ℓ	Calcium mg/ℓ	Magnesium mg/ℓ	Aluminum mg/ℓ	Cadmium mg/ℓ	Mercury mg/ℓ	Nickel mg/ℓ	Zinc mg/ℓ
1	SE	20	PA	0.065	1.685	0.72	26.5	3.85	1.0	0.10	0.1	0.10	0.015
3	OT	22	PA	0.015	0.135	0.03	4.7	0.82	0.5	0.05	0.1	0.10	0.015
4	SE	22	PA	0.220	9.780	0.40	3.8	2.78	25.0	0.20	0.1	0.10	0.015
5	OT	22	PA	0.430	27.320	8.55	23.0	31.50	1.0	1.00	0.1	0.32	0.450
6	SO	5	PA	0.005	40.995	0.23	26.5	6.38	1.0	0.20	0.1	0.10	0.075
7	SE	5	PA	29.040	0.960	0.97	52.4	14.49	0.5	0.05	0.1	0.10	0.015
8	OT	6	PA	0.061	0.089	0.09	6.1	2.65	0.5	0.20	0.1	0.10	0.015
9	SO	6	PA	0.350	19.650	0.08	10.1	2.35	0.5	0.05	0.1	0.10	0.015
10	OT	7	PA	0.015	0.135	0.03	30.5	5.10	0.5	0.05	0.3	0.10	0.015
11	SO	7	PA	8.940	5.060	0.78	168.0	27.93	0.5	0.05	0.1	0.10	0.015
12	SE	7	PA	1.110	0.990	0.87	116.0	24.36	0.5	0.05	0.2	0.10	0.015
13	OT	8	PA	0.022	0.128	0.53	11.6	8.27	0.5	0.40	0.1	0.10	0.015
14	SO	8	PA	0.005	4.495	0.14	49.5	8.96	0.5	0.10	0.1	0.10	0.015
15	SO	9	PA	0.325	30.425	0.28	7.4	0.72	0.5	0.05	0.1	0.10	0.015
16	SE	9	PA	4.650	2.550	6.28	25.0	16.54	5.0	1.50	0.1	0.10	0.300
17	UN	21	PA	0.185	0.815	1.00	12.0	4.99	1.5	0.40	0.1	0.10	0.050
18	UN	21	PA	0.010	0.140	1.15	13.4	4.71	1.5	0.50	0.1	0.10	0.060
19	SE	27	PA	0.097	31.903	6.97	125.0	45.78	8.0	0.70	0.1	0.28	0.595
20	SE	27	PA	10.050	22.450	7.85	123.0	48.72	8.0	1.40	0.1	0.28	0.645
21	OT	11	PA	0.005	1.745	0.34	16.5	6.68	0.5	0.05	0.1	0.10	0.015
22	SO	11	PA	4.400	3.400	0.65	8.8	5.65	0.5	0.05	0.1	0.10	0.015
23	SE	11	PA	10.050		0.48	18.2	9.57	0.5	0.05	0.1	0.10	0.015
24	OT	10	PA	27.920	3.330	2.13	58.4	23.52	0.5	0.05	0.1	0.10	0.080
25	SO	10	PA	0.005	18.995	0.22	6.0	0.77	0.5	0.05	0.1	0.10	0.015
26	UN	85	TN	0.265	11.135	1.18	7.9	5.37	3.0	0.20	0.1	0.10	0.015
27	UN	84	TN	12.290	17.710	1.50	8.1	8.07	1.5	0.05	0.1	0.10	0.015
28	SE	13	PA	60.320		9.40	202.0	53.76	0.5	0.40	0.1	0.26	0.245
30	SE	14	PA	335.100	44.900	14.85	202.0	80.85	7.5	1.40	0.1	0.54	0.735
31	OT	12	PA	31.280	68.720	19.25	237.0	128.31	18.5	3.90	0.1	0.73	1.200
32	SE	12	PA	367.490	66.510	19.58	207.0	131.88	22.0	2.30	0.1	0.76	1.250
33	SE	13	PA	71.490	89.510	13.53	122.0	90.93	31.0	6.00	0.1	0.83	1.500
34	OT	13	PA	0.265		6.05	25.0	7.45	0.5	0.30	0.1	0.10	0.015
35	SE	50	KY	0.018	0.132	0.03	19.1	8.61	0.5	0.20	0.1	0.10	0.015
36	UN	48	KY	0.025	0.125	0.03	42.4	15.12	0.5	0.05	0.1	0.10	0.015
37	SE	49	KY	0.030	1.170	0.22	32.3	11.76	0.5	0.40	0.1	0.10	0.015
38	SE	53	KY	0.327	0.973	0.38	29.8	11.13	0.5	0.05	0.1	0.10	0.015
39	SO	72	IN	0.700	7.050	0.68	142.0	18.48	0.5	0.05	0.1	0.10	0.015
40	SO	69	IN	0.075	1.825	0.03	63.0	18.06	0.5	0.05	0.1	0.10	0.015
41	SO	73	IN	26.810		9.38	139.0	60.48	0.5	0.70	0.1	0.10	0.110
42	SO	17	PA	51.380		13.64	168.0	45.78	6.5	2.30	0.1	0.81	0.650
43	SE	18	PA	0.075	0.075	0.31	148.0	6.32	0.5	0.10	0.1	0.10	0.015
44	UN	19	PA	132.920		9.95	129.0	46.62	3.5	0.10	0.1	0.23	0.290
45	SE	18	PA	0.045	0.105	0.31	20.1	6.45	0.5	0.05	0.1	0.10	0.015
46	SE	17	PA	39.100		14.52	136.0	59.43	8.5	0.60	0.1	0.31	0.515
47	SO	55	KY	0.005	4.395	0.20	45.0	39.27	0.5	0.40	0.1	0.10	0.015
48	SO	56	KY	14.520		4.28	40.6	4.50	0.5	0.05	0.1	0.10	0.015
49	SE	1	PA	14.520		6.25	53.0	47.67	0.5	0.30	0.1	0.19	0.370
50	SO	1	PA			0.61	9.9	3.10	0.5	2.60		0.10	0.015

SE – Drainages from closed drift mines.
UN – Drainages from abandoned but open drift mines.
SO – Interior mine waters from shaft/slope mines or inundated closed drift mines.
OT – Surface waters in proximity of the mine sites.

TABLE B-2 (continued)

Sample code	Type	Site code	State	pH	Alkalinity	Net Acidity mg/ℓ	Specific Conductance µmhos/cm	Total Dissolved Solids mg/ℓ	Suspended Solids mg/ℓ	Sulfate mg/ℓ	COD mg/ℓ	Total Iron mg/ℓ	Total Acidity mg/ℓ
51	SO	2	PA	7.23	916.56	-763.54	1340.	905.0	32.1	22.	10.	10.00	153.02
52	SO	4	PA	6.23	10.51	-4.40	366.	316.0	8.5	20.	4.	1.90	6.11
53	SE	4	PA	4.88	1.47	72.84	732.	575.0	16.6	200.	1.	27.50	74.31
54	SO	3	PA	6.17	14.18	-3.55	308.	204.0	10.1	54.	5.	1.70	10.63
55	SE	47	WV	6.49	106.60	-62.61	1170.	1047.0	12.7	460.	3.	4.25	43.99
56	SE	33	WV	5.79	10.76	18.09	704.	621.0	154.7	240.	1.	12.75	28.85
57	SE	46	WV	3.23		180.40	1690.	1551.0	8.0	730.	1.	19.00	180.40
58	OT	33	WV	4.73	0.12	58.42	2510.	2604.0	104.4	1480.	1.	11.75	58.54
61	SE	24	PA	7.50	321.60	-279.19	974.	688.0	4.0	170.	4.	0.15	42.41
62	UN	24	PA	8.22	235.17	-277.62	849.	617.0	5.9	150.	1.	1.40	.00
63	SE	25	PA	5.82	26.16	-8.56	698.	580.0	12.4	210.	1.	6.50	17.60
64	SE	26	PA	3.20		178.20	1130.	923.0	3.4	360.	1.	40.00	178.20
65	SE	32	WV	6.26	151.39	-53.68	1760.	1808.0	45.1	920.	1.	22.50	97.71
66	SE	32	WV	6.30	168.71	-112.73	1730.	1884.0	39.1	1080.	1.	35.00	55.98
67	SE	41	WV	2.91		1546.60	2770.	3715.0	35.7	1625.	1.	350.00	1546.60
68	SE	42	WV	6.74	313.56	-260.68	2890.	3280.0	52.9	1900.	1.	30.00	52.88
69	SE	43	WV	6.14	100.73	80.88	2440.	2823.0	139.9	1800.	1.	52.00	181.61
70	SE	45	WV	6.70	307.53	-286.02	2290.	2692.0	26.6	1560.	8.	14.50	21.51
71	SO	45	WV	2.52		1633.50	3090.	4159.0	18.8	2100.	1.	470.00	1633.50
72	SE	61	OH	2.54		1221.00	2340.	2015.0	11.9	1070.	1.	150.00	1221.00
73	SO	65	OH	7.08	438.18	-394.67	1240.	931.0	6.2	470.	1.	0.30	43.51
74	UN	65	OH	7.46	568.83	-566.36	1150.	846.0	303.7	270.	4.	0.30	2.47
75	UN	65	OH	7.82	343.71	-324.27	948.	852.0	90.8	370.	2.	2.00	19.44
76	SE	66	OH	6.76	507.57	-238.78	7220.	7439.0	315.2	3500.	1.	227.50	268.79
77	SE	62	OH	3.04		585.20	1480.	1391.0	11.7	610.	7.	7.75	585.20
78	SE	80	IL	5.73	103.42	-59.67	1620.	1422.0	78.9	820.	4.	6.25	43.75
79	SE	38	WV	3.19		107.80	317.	169.8	0.4	73.	2.	0.15	107.80
80	SE	40	WV	3.96		28.60	103.	61.3	0.4	37.	2.	0.15	28.60
81	SE	36	WV	3.18		171.60	737.	655.6	23.9	250.	1.	19.60	171.60
82	SE	79	IL	5.54	50.37	116.34	1830.	2505.1	50.5	1420.	1.	52.50	166.71
83	SE	77	IL	6.28	261.30	-0.67	2940.	3729.9	76.3	2150.	1.	60.00	260.63
84	SE	35	WV	2.68		1078.00	1360.	1339.6	118.7	480.	1.	105.00	1078.00
85	SE	37	WV	4.44		20.65	105.	80.8	21.7	43.	6.	4.25	20.65
86	UN	78	IL	3.02		409.20	2000.	2157.4	94.5	1240.	1.	35.00	409.20
87	SE	34	WV	2.75		1194.60	1240.	1134.4	4.1	460.	1.	82.00	1194.60
88	SE	39	WV	4.05		22.98	98.	72.0	2.5	37.		0.15	22.98
89	SO	76	IL	8.15	249.24	-279.50	1490.	1477.2	262.5	840.	1.	3.75	.00
90	SE	75	IL	6.34	366.83	177.89	4990.	6000.2	281.3	3000.	22.	270.00	544.72
91	OT	75	IL	7.30	426.12	-432.26	4150.	5056.6	42.4	3050.	1.	1.00	.00
92	SE	81	IA	4.00		1293.36	2690.	4144.4	10.9	2150.	1.	335.00	1293.36
93	UN	83	IA								1.	54.00	
94	SE	82	IA								4.	150.00	
95	UN	68	OH	6.05	66.56	-56.46	974.	935.3	0.4	540.		0.15	10.10
96	SE	63	OH	6.91	210.05	-206.33	35000.	35599.4	83.3	39.		5.50	3.72
97	UN	64	OH	3.55		292.60	1170.	1285.1	68.6	310.		42.50	292.60
98	UN	67	OH	3.18		246.40	347.	228.7	0.4	83.	2.	0.90	246.40
100	OT	36	WV	4.20		52.90	852.	763.9	16.5	480.	1.	33.00	52.90

SE – Drainages from closed drift mines.
UN – Drainages from abandoned but open drift mines.
SO – Interior mine waters from shaft/slope mines or inundated closed drift mines.
OT – Surface waters in proximity of the mine sites.

TABLE B-2 (continued)

Sample code	Type	Site code	State	Ferrous Iron mg/ℓ	Ferric Iron mg/ℓ	Manganese mg/ℓ	Calcium mg/ℓ	Magnesium mg/ℓ	Aluminum mg/ℓ	Cadmium mg/ℓ	Mercury mg/ℓ	Nickel mg/ℓ	Zinc mg/ℓ
51	SO	2	PA	8.940	1.060	0.18	44.4	29.82	0.5	0.05	0.1	0.10	0.015
52	SO	4	PA	0.205	1.695	1.46	33.9	25.62	0.5	0.05	0.1	0.10	0.015
53	SE	4	PA	25.690	1.810	4.55	43.9	49.77	4.0	1.90	0.1	0.24	0.645
54	SO	3	PA	0.290	1.410	0.84	19.6	11.13	0.5	0.20	0.1	0.10	0.015
55	SE	47	WV	3.500	0.750	0.73	46.4	20.58	0.5	0.05	0.1	0.10	0.015
56	SE	33	WV	4.000	8.750	0.39	40.4	20.16	0.5	1.30	0.1	0.10	1.050
57	SE	46	WV	0.250	18.750	1.35	52.0	39.06	4.0	2.00	0.1	0.10	0.400
58	OT	33	WV	2.500	9.250	9.40	112.0	154.35	10.0	1.20	0.1	0.40	0.860
61	SE	24	PA	0.025	0.125	0.65	56.1	18.27	0.5	0.05	0.1	0.10	0.145
62	UN	24	PA	0.465	0.935	0.03	3.3	0.56	1.0	0.20	0.1	0.10	0.015
63	SE	25	PA	7.820		0.42	72.0	26.88	1.0	0.10	0.1	0.10	0.015
64	SE	26	PA	51.380		1.90	84.0	39.48	0.5	0.20	0.1	0.22	0.165
65	SE	32	WV	25.690		5.01	409.0	116.55	0.5	0.50	0.5	0.10	0.015
66	SE	32	WV	25.690	9.310	2.22	258.0	75.60	0.5	0.10	0.1	0.10	0.015
67	SE	41	WV	215.580	134.420	2.73	323.0	109.83	28.0	3.40	0.1	0.69	1.340
68	SE	42	WV	0.290	29.710	1.26	323.0	44.31	0.5	0.30	0.1	0.10	0.015
69	SE	43	WV	48.030	3.970	1.93	317.0	65.10	0.5	0.80	0.1	0.10	0.015
70	SE	45	WV	0.170	14.330	9.90	472.0	78.96	0.5	0.30	0.1	0.54	0.480
71	SO	45	WV	213.350	256.650	15.29	366.0	127.47	27.0	6.40	0.1	1.37	3.650
72	SE	61	OH	52.490	97.510	7.00	121.0	46.62	16.0	1.20	0.1	0.46	1.015
73	SO	65	OH	0.105	0.195	0.03	141.0	57.75	0.5	0.05	0.1	0.10	0.015
74	UN	65	OH	0.260	0.040	0.03	42.1	16.38	0.5	0.20	0.1	0.10	0.015
75	UN	65	OH	0.465	1.535	0.03	149.0	53.55	0.5	0.05	0.1	0.10	0.015
76	SE	66	OH	174.250	53.250	1.00	316.0	147.21	0.5	3.30	0.1	0.10	0.015
77	SE	62	OH	1.250	6.500	9.80	102.0	52.08	28.5	2.20	0.1	0.87	1.340
78	SE	80	IL	8.940		0.91	88.0	49.77	0.5	0.80	0.1	0.10	0.015
79	SE	38	WV	0.475		0.33	1.8	4.07	2.0	0.30	0.1	0.10	0.070
80	SE	40	WV	0.040	0.110	0.03	2.6	3.42	0.5	0.10	0.1	0.10	0.015
81	SE	36	WV	13.400	6.200	8.64		18.69	8.6	3.00	0.2	0.10	11.400
82	SE	79	IL	56.790		2.95	298.0	52.92	0.5	0.70	0.1	0.10	8.600
83	SE	77	IL	64.790		10.56	306.0	242.25	0.5	0.60	0.1	0.10	0.240
84	SE	35	WV	0.510	104.490	1.53	35.4	16.80	15.5	2.00	0.1	0.33	2.250
85	SE	37	WV	0.020	4.230	0.34	4.2	3.67	0.5	0.05	0.3	0.10	0.150
86	UN	78	IL	2.000	33.000	11.40	227.0	117.60	18.5	8.40	0.2	0.62	1.100
87	SE	34	WV	44.680	37.320	2.51	50.9	21.84	18.5	1.50	0.2	0.75	0.920
88	SE	39	WV	0.020	0.130	0.03	3.1	2.53	0.5	0.30	0.1	0.10	2.650
89	SO	76	IL	0.040	3.710	0.13	9.4	49.98	0.5	0.40	0.2	0.10	0.150
90	SE	75	IL	239.040	30.960	3.80	303.0	207.79	0.5	2.00	0.1	0.10	0.150
91	OT	75	IL	0.200	0.800	7.63	364.0	252.96	0.5	1.40	0.1	0.10	0.150
92	SE	81	IA	289.300	45.700	32.12	452.0	150.36	13.0	3.80	0.3	1.03	1.800
93	UN	83	IA	53.620	0.380	3.88	50.0	83.58	0.5	0.20	0.2	0.10	0.345
94	SE	82	IA	140.720	9.280	26.95	242.0	39.80	0.5	0.20	0.1	0.10	0.150
95	UN	68	OH	0.015	0.135	0.03	113.0	38.00	0.5	0.05	0.1	0.10	0.150
96	SE	63	OH	6.700		0.14	1026.0	364.65	0.5		0.1	0.33	0.150
97	UN	64	OH	42.500		4.90	74.0	62.79	11.0	0.50	0.1	0.26	0.345
98	UN	67	OH	0.025	0.875	1.64	10.7	7.62	0.5	0.05	0.1	0.10	0.080
100	OT	36	WV	0.220	32.780	0.89	110.0	10.08	4.0	0.30	0.7	0.10	0.050

SE – Drainages from closed drift mines.
UN – Drainages from abandoned but open drift mines.
SO – Interior mine waters from shaft/slope mines or inundated closed drift mines.
OT – Surface waters in proximity of the mine sites.

TABLE B-2 (continued)

Sample code	Type	Site code	State	pH	Alkalinity	Net Acidity mg/ℓ	Specific Conductance μmhos/cm	Total Dissolved Solids mg/ℓ	Suspended Solids mg/ℓ	Sulfate mg/ℓ	COD mg/ℓ	Total Iron mg/ℓ	Total Acidity mg/ℓ
101	SE	16	PA	3.56		999.93	2600.	3495.5	24.2	1900.	1.	612.50	999.93
102	OT	16	PA	3.15		178.53	1120.	981.7	35.8	530.	1.	62.50	178.53
103	SO	13	PA	4.40		1037.37	2370.			1750.	1.	587.50	1037.37
104	SO	13	PA	2.47		1337.55	2500.	3029.9	227.6	1700.	1.	504.00	1337.55
105	SE	13	PA	6.39	110.50	-59.52	602.	509.9	195.6	380.	17.	9.00	50.98
106	SO	15	PA	6.14	18.98	1.30	59.	50.9	27.0	230.	8.	9.00	20.28
107	SE	15	PA	3.09		315.27	1500.	1439.4	24.0	610.	1.	107.50	315.27
108	SO	15	PA	6.27	50.96	-18.54	237.	162.3	58.6	81.	15.	75.00	32.42
110	SO	15	PA	8.04	300.30	-281.10	443.	336.6	413.4	38.	8.	10.90	19.20
111	SO	15	PA	7.83	241.02	-111.36	350.	236.6	151.2	5.	7.	19.60	129.66
112	OT	15	PA	7.75	28.34	-27.79	109.	100.9	4.0	5.	17.	0.15	.55
113	SE	28	PA	2.66		676.87	1980.	1937.2	6.1		1.	22.00	676.87
114	SE	28	PA	2.96		292.67	1420.	465.8	15.3		1.	93.00	292.67
115	SE	28	PA	3.55		56.50	515.	404.1	3.3		1.	0.18	56.50
116	SE	28	PA	2.65		827.16	2170.	2221.3	6.2		1.	89.00	827.16
117	OT	28	PA	3.47		72.32	405.	278.5	5.9		2.	2.65	72.32
118	SE	8	PA	5.99	7.16	-0.07	82.	77.8	110.0	30.	1.	2.60	7.09
119	SO	8	PA	6.08	27.75	-22.45	455.	460.8	406.5	225.	11.	1.00	5.30
120	SE	5	PA	4.41		9.77	335.	282.0	5.0	148.	1.	3.05	9.77
121	SO	5	PA	5.04	5.37	1.72	258.	203.5	158.0	105.	1.	7.60	7.09
122	SE	7	PA	6.52	147.68	-138.94	688.	645.0	52.8	303.	1.	26.00	8.74
123	SO	6	PA	6.46	163.79	-150.98	605.	582.1	177.0	243.	1.	15.00	12.81
124	SO	6	PA	5.73	16.11	-9.26	88.	82.9	170.1	15.	1.	18.00	6.85
125	SO	11	PA	5.15	2.69	8.47	101.	93.5	532.7	25.	1.	41.50	11.16
126	SE	11	PA	5.22	9.85	0.99	162.	139.6	0.4	53.	1.	4.45	10.84
127	SO	9	PA	6.22	24.17	-15.10	78.	88.1	1444.3	12.	1.	46.00	9.07
128	SE	9	PA	5.41	7.16	66.46	454.	574.3	19.8	300.	1.	28.50	73.62
129	SO	72	IN	5.63	59.07	-43.75	686.	602.4	146.1	300.	22.	15.00	15.32
130	SO	69	IN	6.16	255.97	-248.66	808.	620.3	88.1	207.	1.	11.80	7.31
131	SE	81	IA	4.41		674.92	2880.	3859.8	85.9	2090.	1.	250.00	674.92
132	OT	81	IA	5.03	2.86	6.81	621.	538.6	22.1	297.	1.	2.20	9.67
133	UN	83	IA	6.24	285.51	-121.89	2590.	2872.6	38.7	1840.	1.	91.00	163.62
134	SE	29	PA	5.22	2.69	4.40	671.	617.9	7.3	315.	1.	2.30	7.09
135	UN	29	PA	3.08		119.26	1770.	1684.5	103.8	850.	1.	34.00	119.26
136	SE	15	PA	3.18		356.00	1530.	1471.3	8.9	700.	1.	80.00	356.00
137	SE	15	PA	3.18		296.37	1550.	1457.0	30.2	740.	1.	87.00	296.37
138	SO	15	PA	6.15	17.90	-13.50	226.	183.0	20.6	95.	1.	6.85	4.40
139	SO	15	PA	8.68	102.03	-96.73	225.	156.5	11.6	47.	1.	7.40	5.30
140	SE	16	PA	3.24		974.55	2370.	2830.6	27.3	1540.	1.	370.00	974.55
141	SE	13	PA	2.60		936.28	2700.	2856.2	13.0	1400.	1.	185.00	936.28
142	SE	12	PA	3.25		966.54	2380.	3038.4	15.9	1450.	1.	354.00	966.54
143	SE	14	PA	2.87		698.65	2130.	2147.8	1435.1	1970.	1.	200.00	698.65
144	OT	12	PA	3.01		554.47	1960.	2041.5	34.5	1150.	1.	98.00	554.47
145	UN	78	IL	3.22		243.86	2040.	2191.4	24.0	1330.	1.	45.00	243.86
146	SE	77	IL	6.28	179.89	-90.12	3150.	3846.5	32.7	2330.	1.	74.00	89.77
147	SE	75	IL	6.32	249.71	-23.78	5270.	6166.9	131.1	3050.	1.	273.00	225.93
148	SE	38	WV	4.10		18.68	77.	51.7	4.9	7.	4.	0.45	18.68
149	SE	38	WV	3.99		40.94	100.	71.5	243.8	7.	28.	0.75	40.94
150	SE	39	WV	3.27		84.55	390.	169.3	3.9	59.	8.	1.80	84.55

SE – Drainages from closed drift mines.
UN – Drainages from abandoned but open drift mines.
SO – Interior mine waters from shaft/slope mines or inundated closed drift mines.
OT – Surface waters in proximity of the mine sites.

TABLE B-2 (continued)

Sample code	Type	Site code	State	Ferrous iron mg/ℓ	Ferric iron mg/ℓ	Manganese mg/ℓ	Calcium mg/ℓ	Magnesium mg/ℓ	Aluminum mg/ℓ	Cadmium mg/ℓ	Mercury mg/ℓ	Nickel mg/ℓ	Zinc mg/ℓ
101	SE	16	PA	543.980	68.520	6.78	152.0	75.60	20.0	0.90	0.3	0.63	0.830
102	OT	16	PA	36.860	25.640	1.59	121.0	11.76	14.0	0.80	0.5	0.10	0.165
103	SO	13	PA		587.500	18.70	205.0	124.95	29.0	5.60	0.7	2.03	3.000
104	SO	13	PA	167.550	336.450	7.07	93.0	43.89	35.0	6.40	2.8	9.70	1.700
105	SE	13	PA	1.210	7.790	0.53	39.3	25.62	0.5	2.10	0.5	0.10	0.610
106	SO	15	PA	0.720	8.280	0.20	4.6	2.97	0.5	1.00	1.2	0.10	0.400
107	SE	15	PA	94.940	12.560	6.30	208.0	42.00	3.0	0.60	0.7	0.36	0.400
108	SO	15	PA	81.540		1.54	17.9	5.58	0.5	1.10	0.7	0.10	0.150
110	SO	15	PA	5.000	5.900	0.12	4.5	0.75	0.5	0.20	0.3	0.10	0.150
111	SO	15	PA	0.700	18.900	0.08	28.5	8.22	0.5	0.30	0.7	0.10	0.150
112	OT	15	PA	0.050	0.100	0.10	14.0	3.60	0.5	0.05	0.1	0.10	0.150
113	SE	28	PA	1.000	21.000	29.00	114.0	117.00		10.00		1.60	3.270
114	SE	28	PA	75.000	18.000	24.00	100.0	97.00		2.10		0.74	1.200
115	SE	28	PA	0.190		5.45	36.3	37.00		2.40		0.19	0.520
116	SE	28	PA	17.000	72.000	31.00	152.0	126.00		8.30		1.80	3.500
117	OT	28	PA	0.510	2.140	4.80	18.1	19.00		2.10		0.22	0.100
118	SE	8	PA	0.150	2.450	0.45	91.0	18.40	1.5	0.05	0.5	0.15	0.015
119	SO	8	PA	0.350	0.650	0.03	8.1	2.40	0.5	0.05	0.5	0.15	0.015
120	SE	5	PA	5.590		0.90	30.5	12.60	0.5	0.05	0.5	0.15	0.015
121	SO	5	PA	0.450	7.150	0.50	25.0	8.40	3.1	0.30	0.5	0.15	0.100
122	SE	7	PA	4.470	21.530	2.10	155.0	21.80	1.1	0.05	0.5	0.15	0.015
123	SO	6	PA	11.170	3.830	0.62	90.0	18.80	1.7	0.60	0.5	0.15	0.015
124	SO	6	PA	1.170	16.830	0.13	10.9	2.64	2.6	0.05	0.5	0.15	0.015
125	SO	11	PA	4.100	37.400	0.34	7.5	4.60	5.6	0.05	0.5	0.15	0.015
126	SE	11	PA	6.700		0.32	5.5	6.70	0.5	0.05	0.5	0.15	0.015
127	SO	9	PA	14.520	31.480	0.90	10.5	2.56	16.0	0.40	0.5	0.15	0.130
128	SE	9	PA	33.510		8.20	88.0	25.60	2.0	0.05	0.5	0.30	0.160
129	SO	72	IN	13.400	1.600	0.38	112.0	16.10	2.2	0.40	0.5	0.15	0.450
130	SO	69	IN	0.170	11.630	0.15	114.0	42.00	2.0	0.05	0.5	0.15	0.015
131	SE	81	IA	272.410		31.60	505.0	194.00	15.5	2.30	0.5	0.75	1.390
132	OT	81	IA	3.350		2.51	72.0	27.60	0.5	0.20	0.5	0.15	0.015
133	UN	83	IA	22.900	68.100	4.50	505.0	113.00	0.5	0.05	0.5	0.15	0.015
134	SE	29	PA	0.220	2.080	1.31	90.0	35.80	0.5	0.70	0.5	0.15	0.180
135	UN	29	PA	6.700	27.300	5.80	296.0	93.60	3.2	2.40	0.5	0.65	0.930
136	SE	15	PA	78.190	1.810	12.00	204.0	48.60	8.3	1.20	0.5	0.45	0.540
137	SE	15	PA	75.960	11.040	8.40	236.0	45.40	6.1	0.60	0.5	0.45	0.400
138	SO	15	PA	2.230	4.620	1.77	37.0	6.80	0.5	0.60	0.5	0.15	0.015
139	SO	15	PA	0.550	6.850	0.03	31.0	6.70	0.5	0.05	0.5	0.15	0.015
140	SE	16	PA	406.590		5.70	120.0	70.00	35.0	0.30	0.5	0.45	0.700
141	SE	13	PA	101.650	83.350	22.40	136.0	126.40	77.0	3.00	0.5	0.95	1.900
142	SE	12	PA	323.930	30.070	20.40	226.0	127.00	51.0	1.60	0.5	0.70	1.100
143	SE	14	PA	156.400	43.600	18.20	218.0	91.40	27.0	1.00	0.5	0.55	0.710
144	OT	12	PA	53.620	44.380	18.40	256.0	109.40	35.0	2.00	0.5	0.50	0.930
145	UN	78	IL	44.680	0.320	13.40	274.0	131.80	33.0	6.00	0.5	0.50	0.870
146	SE	77	IL	73.720	0.280	14.70	465.0	270.00	0.5	0.50	0.5	0.15	0.300
147	SE	75	IL	259.140	13.860	4.20	455.0	247.50	0.5	0.05	0.5	0.15	0.015
148	SE	38	WV	0.160	0.290	0.22	2.1	1.63	0.5	0.05	0.5	0.15	0.015
149	SE	38	WV	0.005	0.745	0.24	3.1	2.67	1.2	0.05	0.5	0.15	0.015
150	SE	39	WV	1.780	0.020	0.77	6.1	7.10	4.6	0.50	0.5	0.30	0.220

SE – Drainages from closed drift mines.
UN – Drainages from abandoned but open drift mines.
SO – Interior mine waters from shaft/slope mines or inundated closed drift mines.
OT – Surface waters in proximity of the mine sites.

TABLE B-2 (continued)

Sample code	Type	Site code	State	pH	Alkalinity	Net Acidity mg/ℓ	Specific Conductance µmhos/cm	Total Dissolved Solids mg/ℓ	Suspended Solids mg/ℓ	Sulfate mg/ℓ	COD mg/ℓ	Total Iron mg/ℓ	Total Acidity mg/ℓ
151	SE	40	WV	4.01		17.80	121.	74.0	3.1	31.	1.	0.15	17.80
152	SE	37	WV	4.90	0.45	7.97	81.	55.1	5.1	28.	1.	0.35	8.42
153	SE	45	WV	3.00		406.73	1570.	1412.3	6.3	600.	1.	61.00	406.73
154	SE	41	WV	2.90		713.78	2710.	3231.9	116.3	1520.	1.	204.00	713.78
155	UN	68	OH	6.50	50.12	-44.84	1030.	889.2	8.4	530.	5.	0.15	5.28
156	SE	63	OH	7.00	218.38	-202.40	38600.	35439.2	178.6	31.		3.70	15.98
157	UN	64	OH	3.81		177.11	1040.	987.0	24.1	500.		35.50	177.11
158	SE	24	PA	7.40	297.14	-284.77	970.	722.1	41.6	278.	1.	1.80	12.37
159	OT	24	PA	7.56	124.41	-119.11	450.	294.5	23.1	108.	1.	1.40	5.30
160	SE	36	WV	3.14		101.46	775.	501.0	8.7	270.	1.	16.40	101.46
161	SE	35	WV	2.69		536.67	1430.	872.3	5.2	318.	1.	85.00	536.67
162	SE	34	WV	2.77		461.02	1170.	699.7	17.1	326.	1.	80.50	461.02
163	UN	24	PA	7.97	214.80	-216.66	849.	612.5	7.3	288.	1.	0.55	.00
164	SE	25	PA	5.58	10.74	1.68	588.	476.5	16.5	285.	1.	4.10	1.68
165	OT	25	PA	3.76		64.97	762.	591.6	42.8	307.	1.	16.15	64.97
166	SE	26	PA	3.23		48.95	767.	542.6	8.0	307.	1.	8.85	48.95
167	OT	26	PA	5.28	0.45	14.21	597.	497.7	121.7	305.	1.	6.80	14.66
168	SE	17	PA	3.23		97.90	1020.	862.4	7.1	311.	1.	13.00	97.90
169	SE	17	PA	3.40		64.97	840.	709.0	10.8	243.	1.	8.55	64.97
170	OT	17	PA	6.92	7.16	-0.65	84.	40.0	3.8	5.	1.	0.30	6.51
171	SO	17	PA	3.21		101.46	1010.	879.0	17.5	252.	1.	16.05	101.46
172	SO	17	PA	5.35	7.16	13.27	980.	1089.1	399.2	258.	1.	30.00	20.43
173	SE	18	PA	4.83	0.45	8.87	159.	97.4	0.4	5.	3.	0.15	9.32
174	UN	21	PA	4.18		20.46	653.	405.5	6.6	5.	4.	0.15	20.46
175	OT	21	PA	4.39		17.78	773.	477.8	3.4	5.	7.	0.15	17.78
176	SE	22	PA	2.98		85.44	431.	155.1	3.4	64.	1.	9.80	85.44
177	OT	22	PA	7.11	4.48	-0.06	50.	49.2	2.4	5.	1.	0.15	4.42
178	SE	46	WV	3.21		89.89	1460.	1342.3	315.1	258.	1.	9.55	89.89
179	SE	33	WV	6.05	8.06	-0.07	452.	379.0	6.4	167.	1.	0.15	7.99
180	SE	47	WV	6.46	39.38	-30.53	1070.	992.2	8.3	243.	1.	4.45	8.85
181	SO	85	TN	7.44	132.46	-161.14	386.	318.1	422.5	48.	3.	10.40	.00
182	SE	49	KY	7.91	341.89	-332.18	702.	706.3	2.2	119.	2.	1.00	9.71
183	UN	74	KY	7.50	51.91	-43.95	708.	964.5	14.8	245.	1.	4.45	7.96
184	SE	53	KY	7.80	95.77	-91.36	453.	441.2	21.3	142.	3.	0.15	4.41
186	SE	57	WV	6.86	21.48	-14.40	167.	157.6	4.3	5.	9.	0.15	7.08
187	UN	48	WV	7.46	241.65	-241.73	847.	737.6	0.4	207.	4.	0.15	.00
188	SO	30	PA	6.24	111.88	-45.19	1330.	1595.6	14.2	255.	1.	27.00	66.69
189	SE	31	PA	5.44	8.95	121.84	710.	814.9	2.4	288.	1.	54.00	130.79
190	SE	30	PA	6.18	56.39	75.28	1370.	1730.0	7.5	350.	1.	59.00	131.67
191	SE	4	PA	4.97	2.69	34.66	485.	507.6	12.0	255.	1.	15.40	34.66
192	SO	4	PA	4.55	0.45	41.80	517.	513.4	10.4	248.	1.	13.00	41.80
193	SO	3	PA	4.21		49.83	318.	268.0	8.5	90.	1.	1.45	49.83
194	SO	2	PA	7.09	744.18	-746.77	882.	905.8	23.3	5.	6.	7.60	.00
195	SE	1	PA	5.91	28.64	-1.98	376.	513.2	3.9	226.	1.	10.20	26.66
196	SE	42	WV	6.92	196.90	-158.76	2970.						38.14
197	SE	43	WV	5.50	16.11	26.52	2690.						42.63
198	SE	32	WV	7.59	110.09	-100.36	1520.						9.73
199	SE	32	WV	6.92	102.93	-50.51	1570.						52.54

SE – Drainages from closed drift mines.
UN – Drainages from abandoned but open drift mines.
SO – Interior mine waters from shaft/slope mines or inundated closed drift mines.
OT – Surface waters in proximity of the mine sites.

TABLE B-2 (continued)

Sample code	Type	Site code	State	Ferrous Iron mg/ℓ	Ferric Iron mg/ℓ	Manganese mg/ℓ	Calcium mg/ℓ	Magnesium mg/ℓ	Aluminum mg/ℓ	Cadmium mg/ℓ	Mercury mg/ℓ	Nickel mg/ℓ	Zinc mg/ℓ
151	SE	40	WV	0.130	0.020	0.41	23.0	3.70	0.5	0.20	0.5	0.15	0.015
152	SE	37	WV	0.060	0.290	0.03	0.8	0.89	0.5	0.05	0.5	0.15	0.015
153	SE	45	WV	11.'70	49.830	10.40	164.0	62.80	13.3	1.10	0.5	0.40	0.750
154	SE	41	WV	109.470	94.530	2.63	472.6	97.60	56.0	0.05	0.5	1.65	1.100
155	UN	68	OH	0.020	0.130	0.06	98.0	38.80	1.0	0.05	0.5	0.15	0.015
156	SE	63	OH	4.470		0.16	1056.0	370.00	0.5	2.20	0.5	0.15	0.015
157	UN	64	OH	14.520	20.980	4.80	68.0	61.40	13.7	0.30	0.5	0.15	0.330
158	SE	24	PA	0.830	0.970	0.82	60.0	23.00	2.9	0.05	0.5	0.15	0.015
159	OT	24	PA	0.150	1.250	0.32	38.0	10.40	1.0	0.05	0.5	0.15	0.015
160	SE	36	WV	10.050	6.350	11.20	28.0	23.60	5.7	0.60	0.5	0.30	0.370
161	SE	35	WV	52.500	32.500	1.56	40.0	20.60	25.0	1.20	0.5	0.54	0.780
162	SE	34	WV	35.740	44.760	1.30	22.0	16.40	13.7	1.00	0.5	0.40	0.620
163	UN	24	PA	0.160	0.390	0.03	4.3	0.49	2.5	0.05	0.5	0.15	0.015
164	SE	25	PA	4.470		0.43	58.0	24.80	2.2	0.05	0.5	0.15	0.015
165	OT	25	PA	14.520	1.630	4.80	28.0	24.20	5.4	0.50	0.5	0.15	0.150
166	SE	26	PA	5.590	3.260	1.13	74.0	27.20	1.3	0.20	0.5	0.15	0.070
167	OT	26	PA	6.700	0.100	2.69	76.0	29.40	2.3	0.50	0.5	0.15	0.120
168	SE	17	PA	8.940	4.060	13.80	106.0	47.00	7.5	0.50	0.5	0.35	0.350
169	SE	17	PA	7.820	0.730	1.12	132.0	40.00	4.2	0.60	0.5	0.30	0.300
170	OT	17	PA	0.180	0.120	0.27	8.4	2.95	0.5	0.05	0.5	0.15	0.015
171	SO	17	PA	14.520	1.530	11.10	130.0	41.00	6.1	0.90	0.5	0.65	0.430
172	SO	17	PA	26.810	3.190	10.60	214.0	59.80	3.5	0.20	0.5	0.30	0.150
173	SE	18	PA	0.040	0.110	0.26	17.0	5.60	0.5	0.05	0.5	0.15	0.015
174	UN	21	PA	0.105	0.045	1.12	24.0	5.40	2.2	0.60	0.5	0.15	0.100
175	OT	21	PA	0.035	0.115	1.34	25.0	5.10	2.6	0.60	0.5	0.15	0.120
176	SE	22	PA	0.985	8.815	0.46	3.8	2.45	3.1	0.20	0.5	0.15	0.015
177	OT	22	PA	0.050	0.100	0.03	5.1	0.97	0.5	0.05	0.5	0.15	0.015
178	SE	46	WV	8.940	0.610	1.69	134.0	82.40	7.7	0.30	0.5	0.15	0.150
179	SE	33	WV	0.055	0.095	0.03	48.0	34.00	0.5	0.05	0.5	0.15	0.015
180	SE	47	WV	4.470		0.85	94.0	56.00	0.5	0.05	0.5	0.15	0.015
181	SO	85	TN	4.470	5.930	0.72	164.0	12.20	7.4	0.40	0.5	0.15	0.015
182	SE	49	KY	0.130	0.870	0.11	41.0	14.00	0.5	0.05	0.5	0.15	0.015
183	UN	74	KY	0.750	3.700	0.72	114.0	55.00	0.5	0.50	0.5	0.15	0.015
184	SE	53	KY	0.440		0.03	44.0	40.20	0.5	0.05	0.5	0.15	0.015
186	SE	57	WV	0.150		0.03	33.0	11.60	0.5	0.05	0.5	0.15	0.015
187	UN	48	WV	0.020	0.130	0.03	96.0	29.80	0.5	0.05	0.5	0.15	0.015
188	SO	30	PA	25.690	1.310	19.20	298.0	130.00	0.5	0.70	0.5	0.30	0.200
189	SE	31	PA	58.080		4.60	108.0	49.60	0.5	0.20	0.5	0.15	0.130
190	SE	30	PA	62.550		9.90	220.0	149.20	1.0	0.20	0.5	0.15	0.130
191	SE	4	PA	17.870		3.50	22.0	47.80	4.6	0.60	0.5	0.15	0.520
192	SO	4	PA	12.290	0.710	3.80	26.0	49.80	4.2	0.90	0.5	0.15	0.530
193	SO	3	PA	0.165	1.285	2.80	32.0	21.20	2.8	0.50	0.5	0.15	0.180
194	SO	2	PA	11.170		0.14	42.0	35.20	0.5	0.05	0.5	0.15	0.015
195	SE	1	PA	12.290		5.30	32.0	50.00	0.5	0.20	0.5	0.15	0.280
196	SE	42	WV	33.510					0.5	0.05			
197	SE	43	WV	78.190					1.0	0.05			
198	SE	32	WV	0.560									
199	SE	32	WV	29.040									

SE – Drainages from closed drift mines.
UN – Drainages from abandoned but open drift mines.
SO – Interior mine waters from shaft/slope mines or inundated closed drift mines.
OT – Surface waters in proximity of the mine sites.

TABLE B-3. LABORATORY METHODS

Parameter	Methodology	Equipment	Preservation	Holding
pH	Standard Methods (Potentiometric)†	Orion 801 Ionanalyzer Serial #8001	Refrigerate at 4°C	6 hours
Alkalinity	Standard Methods (Potentiometric)†	Orion 801 Ionanalyzer Serial #8001	Refrigerate at 4°C	24 hours
Acidity	EPA (Potentiometric)+	Orion 801 Ionanalyzer Serial #8001	Refrigerate at 4°C	24 hours
Specific Conductance	EPA (Wheatstone Bridge)+	Barnstead Wheatstone Bridge PM-70CB	Refrigerate at 4°C	24 hours
Total Dissolved Solids (Nonfilterable)	EPA+		Refrigerate at 4°C	7 days
Suspended Solids (Nonfilterable)	EPA+		Refrigerate at 4°C	7 days
Sulfate	Technicon Method 118-71W Modified*	Technicon Autoanalyzer II	Refrigerate at 4°C	7 days
Chemical Oxygen Demand	Technicon Method 137-71W*	Technicon Autoanalyzer II	Acidify with H_2SO_4 to pH 2.00; 4°C	7 days
Total Iron	Perkin Elmer§	Perkin Elmer Atomic Absorption 306, Serial #54229	Acidify with HNO_3 to pH 2.00; 4°C	6 months
Ferrous Iron	Standard Methods (Phenantroline)† ASTM (D-1068-A)# Lovell (Titration)**	Bausch & Lomb Spectronic 70, Serial #1488TK Bausch & Lomb Spectronic 70, Serial #1488TK	Acidify with HCl to pH 1.00; 4°C	7 days
Ferric Iron	Calculated			
Manganese	Perkin Elmer§	Perkin Elmer Atomic Absorption 306, Serial #54229	Acidify with HNO_3 to pH 2.00; 4°C	6 months
Calcium	Perkin Elmer§	Perkin Elmer Atomic Absorption 306, Serial #54229	Acidify with HNO_3 to pH 2.00; 4°C	6 months
Magnesium	Perkin Elmer§	Perkin Elmer Atomic Absorption 306, Serial #54229	Acidify with HNO_3 to pH 2.00; 4°C	6 months
Aluminum	Perkin Elmer§	Perkin Elmer Atomic Absorption 306, Serial #54229	Acidify with HNO_3 to pH 2.00; 4°C	6 months
Cadmium	Perkin Elmer§	Perkin Elmer Atomic Absorption 306 with Graphite Furnace Model 2000, Serial #54229	Acidify with HNO_3 to pH 2.00; 4°C	6 months
Mercury	EPA+	Perkin Elmer Model 50 Mercury Analyzer System	Acidify with H_2SO_4 to pH 2.00; 4°C	13 days
Nickel	Perkin Elmer§	Perkin Elmer Atomic Absorption 306, Serial #54229	Acidify with HNO_3 to pH 2.00; 4°C	6 months
Zinc	Perkin Elmer§	Perkin Elmer Atomic Absorption 306, Serial #54229	Acidify with HNO_3 to pH 2.00; 4°C	6 months
Hardness	Calculated			

* Technicon Autoanalyzer II Industrial Methodologies.
† Standard Methods for the Examination of Water and Wastewater, 13th edition, New York, 1971.
+ EPA-Methods for Chemical Analysis of Water and Wastes, 1974.
§ Perkin Elmer Atomic Absorption Methodologies.
# 1973 Annual Book of ASTM Standards, Part 23.
** Procedures of Analysis of Coal Mine Drainage, H.L. Lovell, The Pennsylvania State University, College of Earth and Mineral Sciences.

APPENDIX C. STATISTICAL SUMMARY OF WATER QUALITY DATA FOR 85 MINES IN THE EASTERN COAL MINING REGIONS

TABLE C-1. WATER QUALITY PARAMETERS: PHASE 1, DRY SAMPLING SEASON, SEALED MINES

Parameter	Number of samples	Mean	Range ±1 Standard Deviation	Range (Low-High)
Drainages from closed drift mines:				
pH: -log $[H^+]$*	55	4.59	2.95-6.22	2.34-7.50
Alkalinity, mg $CaCO_3$/l*	26	147.56	2.78-294.34	<.24-507.57
Net Acidity, mg $CaCO_3$/l	54	159.73	-151.76-629.55	-351.12-1546.60
Total Acidity, mg $CaCO_3$	54	126.97	---	0.001-1546.60
Specific Conductance, µmhos/cm	53	927.	273.-3153.	98.0-7220.0
Total Dissolved Solids, mg/l	54	794.7	217.7-2901.6	52.5-7439.0
Suspended Solids, mg/l	55	15.8	3.5-71.2	<0.8-315.2
Sulfate, mg SO_4/l	51	385.	104.-1427.	37.-3500.
Chemical Oxygen Demand, mg O/l	52	2.	<2.-4.	<2.-22.
Total Iron, mg Fe/l	56	14.11	1.31-152.48	<0.30-612.50
Ferrous Iron, mg Fe/l	56	4.39	0.197-98.00	0.018-543.98
Manganese, mg Mn/l	56	2.03	0.34-12.19	<0.05-32.12
Calcium, mg Ca/l	55	76.4	18.8-309.8	1.8-1026.0
Magnesium, mg Mg/l	56	33.08	9.94-110.06	2.53-364.65
Aluminum, mg Al/l	52	1.7	<1.0-7.9	<1.0-31.0
Cadmium, µg Cd/l	55	0.5	0.1-2.5	<0.1-10.0
Mercury, µg Hg/l	52	0.1	<0.2-0.2	<0.2-0.7
Nickel, mg Ni/l	56	0.20	<0.20-0.48	<0.20-1.80
Zinc, mg Zn/l	56	0.186	<0.030-1.443	<0.030-11.400
Interior mine waters from shaft/slope mines or inundated closed drift mines:				
pH: -log $[H^+]$*	25	6.13	4.58-7.68	2.47-8.15
Alkalinity, mg $CaCO_3$/l*	22	175.08	---	0.24-916.56
Net Acidity, mg $CaCO_3$/l	25	-236.59	-646.27 to 1592.12	-763.54 to 1633.50
Total Acidity, mg $CaCO_3$/l	25	53.70	---	0.001-1633.50
Specific Conductance, µmhos/cm	24	522.	147.-1858.	54.-3820.
Total Dissolved Solids, mg/l	24	316.7	45.0-2230.5	0.8-4159.0
Suspended Solids, mg/l	24	101.0	21.6-472.5	6.2-4612.1
Sulfate, mg SO_4/l	25	142.	22.-896.	10.-2350.
Chemical Oxygen Demand, mg O/l	25	3.	2.-9.	2.-21.
Total Iron, mg Fe/l	25	14.34	2.34-87.88	0.30-587.50
Ferrous Iron, mg Fe/l	24	0.881	0.030-25.94	0.010-213.35
Manganese, mg Mn/l	26	0.58	0.09-3.87	0.05-18.70
Calcium, mg Ca/l	26	34.5	9.37-126.9	4.5-366.0
Magnesium, mg Mg/l	26	11.95	2.61-54.76	0.72-127.47
Aluminum, mg Al/l	26	0.9	1.0-3.7	1.0-35.0
Cadmium, µg Cd/l	26	0.3	0.1-1.4	0.1-6.4
Mercury, µg Hg/l	25	0.2	0.2-0.5	0.2-2.8
Nickel, mg Ni/l	26	0.16	0.20-0.53	0.20-9.70
Zinc, mg Zn/l	26	0.059	0.030-0.371	0.030-3.650

*Values listed are arithmetic means: All other values are geometric means.

TABLE C-2. WATER QUALITY PARAMETERS: PHASE 1, DRY SAMPLING SEASON, UNSEALED MINES AND SURFACE WATERS

Parameter	Number of samples	Mean	Range ±1 Standard Deviation	Range (Low-High)
Drainages from abandoned and unsealed drift mines:				
pH: $-\log [H^+]$*	12	4.90	2.86-6.94	2.88-8.22
Alkalinity, mg $CaCO_3$/l	5	295.12	111.91-478.32	66.56-568.83
Net Acidity, mg $CaCO_3$/l	12	-69.09	-339.75 to 400.37	-566.36 to 409.20
Total Acidity, mg $CaCO_3$/l	13	75.86	---	0.001-409.20
Specific Conductance, μmhos/cm	12	826.	488.-1399.	347.-2000.
Total Dissolved Solids, mg/l	12	609.1	262.6-1412.9	139.9-2157.4
Suspended Solids, mg/l	12	13.0	1.5-111.3	<0.8-303.7
Sulfate, mg SO_4/l	12	238.	92.-616.	54.-1240.
Chemical Oxygen Demand, mg O/l	11	2.	<2.-4.	<2.-8.
Total Iron mg Fe/l	13	3.39	0.30-41.93	<0.30-112.50
Ferrous Iron, mg Fe/l	13	0.704	0.026-38.10	0.010-132.92
Manganese, mg Mn/l	13	0.51	0.05-5.93	<0.05-11.40
Calcium, mg Ca/l	13	34.5	9.0-132.3	3.3-227.0
Magnesium, mg Mg/l	13	17.32	3.89-77.17	0.56-117.60
Aluminum, mg Al/l	13	1.4	<1.0-4.9	<1.0-18.5
Cadmium, μg Cd/l	13	0.2	<0.1-0.7	<0.1-8.4
Mercury, μg Hg/l	13	0.1	<0.1-0.2	<0.2-0.2
Nickel, mg Ni/l	13	0.13	<0.20-0.23	<0.20-0.62
Zinc, mg Zn/l	13	0.064	<0.030-0.307	<0.030-1.100
Surface waters in proximity of studied mines:				
pH: $-\log [H^+]$*	16	4.94	3.31-6.57	2.61-7.75
Alkalinity, mg $CaCO_3$/l	10	51.37	---	0.24-426.12
Net Acidity, mg $CaCO_3$/l	16	25.43	-163.30 to 273.41	-432.26 to 523.60
Total Acidity, mg $CaCO_3$/l	15	41.69	---	0.001-523.60
Specific Conductance, μmhos/cm	16	498.	109.-2271.	104.-4150.
Total Dissolved Solids, mg/l	16	304.9	68.7-1352.9	35.1-5056.6
Suspended Solids, mg/l	16	8.9	2.7-29.1	2.1-104.4
Sulfate, mg SO_4/l	15	143.	22.-925.	-10.-3050.
Chemical Oxygen Demand, mg O/l	16	2.	<2.-6.	<2.-17.
Total Iron, mg Fe/l	16	2.07	<0.30-25.23	<0.30-100.00
Ferrous Iron, mg Fe/l	16	0.293	0.018-4.84	<0.010-36.86
Manganese, mg Mn/l	16	1.03	0.13-8.40	<0.05-19.25
Calcium, mg Ca/l	16	33.2	9.1-124.6	4.7-364.0
Magnesium, mg Mg/l	16	13.03	2.76-61.44	0.82-252.96
Aluminum, mg Al/l	15	1.3	<1.0-5.0	<1.0-18.5
Cadmium, μg Cd/l	16	0.3	<0.1-1.4	<0.1-3.9
Mercury, μg Hg/l	15	0.1	<0.2-0.26	<0.2-0.7
Nickel, mg Ni/l	16	0.14	<0.20-0.26	<0.20-0.73
Zinc, mg Zn/l	16	0.071	<0.30-0.321	<0.030-1.200

*Values listed are arithmetic means: All other values are geometric means.

TABLE C-3. WATER QUALITY PARAMETERS: PHASE 2, WET SAMPLING SEASON, SEALED MINES

Parameter	Number of samples	Mean	Range ∓1 Standard Deviation	Range (Low-High)
Drainages from closed drift mines:				
pH: -log $[H^+]$*	47	4.86	3.22-6.50	2.60-7.91
Alkalinity, mg $CaCO_3$/l*	25	26.55	3.81-185.12	<0.90-341.89
Net Acidity, mg $CaCO_3$/l	47	93.80	-135.87 to 407.38	-332.18 to 974.53
Total Acidity, mg $CaCO_3$/l	47	52.48	---	1.68-974.55
Specific Conductance, μmhos/cm	46	750.	248.-2264.	77.-5270.
Total Dissolved Solids, mg/l	46	457.6	102.9-2034.5	51.7-6166.9
Suspended Solids, mg/l	47	13.1	1.0-65.5	<0.8-1435.1
Sulfate, mg SO_4/l	43	204.	39.-1074.	<10.-3050.
Chemical Oxygen Demand, mg O/l	42	1.3	<2.0-2.8	<2.0-28.0
Total Iron, mg Fe/l	43	9.54	0.86-105.53	<0.30-370.00
Ferrous Iron, mg Fe/l	47	5.75	0.343-96.45	<0.010-406.59
Manganese, mg Mn/l	43	1.42	0.20-10.09	<0.05-31.60
Calcium, mg Ca/l	43	59.2	12.3-284.6	0.8-1056.0
Magnesium, mg Mg/l	43	29.31	7.35-116.98	0.89-370.00
Aluminum, mg Al/l	45	2.3	<1.0-11.3	<1.0-77.0
Cadmium , μg Cd/l	45	0.2	<0.1-0.8	<0.1-3.0
Mercury, μg Hg/l**	43	---	---	---
Nickel, mg Ni/l	43	0.23	<0.30-0.44	<0.30-1.65
Zinc, mg Zn/l	43	0.093	<0.030-0.544	<0.030-1.900
Interior mine waters from shaft/slope mines or inundated closed drift mines:				
pH: -log $[H^+]$*	17	5.85	4.58-7.12	3.21-8.68
Alkalinity, mg $CaCO_3$/l	15	31.13	4.46-217.24	<0.90-744.18
Net Acidity, mg $CaCO_3$/l	17	580.56	---	-746.77 to 107.46
Total Acidity, mg $CaCO_3$/l	17	4.68	---	0.001-107.46
Specific Conductance, μmhos/cm	17	388.	160.-940.	78.-1330.
Total Dissolved Solids, mg/l	17	356.4	141.7-896.1	82.9-1595.6
Suspended Solids, mg/l	17	82.7	15.9-430.5	8.5-1444.3
Sulfate, mg SO_4/l	17	85.	24.-306.	<10.-300.
Chemical Oxygen Demand, mg O/l	17	1.6	<2.0-4.4	<2.-22.
Total Iron, mg Fe/l	17	11.19	4.02-31.13	1.00-46.00
Ferrous Iron, mg Fe/l	17	3.18	0.534-18.95	0.165-26.81
Manganese, mg Mn/l	17	0.71	0.10-4.93	<0.05-19.20
Calcium, mg Ca/l	17	44.6	13.7-144.8	7.5-298.0
Magnesium, mg Mg/l	17	14.45	4.30-48.57	2.40-130.00
Aluminum, mg Al/l	17	2.1	<1.0-6.3	<1.0-16.0
Cadmium, μg Cd/l	17	0.2	<0.1-0.7	<0.1-0.9
Mercury, μg Hg/l**	17	---	---	---
Nickel, mg Ni/l	17	0.18	<0.30-<0.30	<0.30-0.65
Zinc, mg Zn/l	17	0.054	<0.030-0.233	<0.030-0.530

*Values listed are arithmetic means: All other values are geometric means.

**All values were less than the detection limit of the test (0.2μg Hg/l).

TABLE C-4. WATER QUALITY PARAMETERS: PHASE 2, WET SAMPLING SEASON, UNSEALED MINES

Parameter	Number of samples	Mean	Range ∓1 Standard Deviation	Range (Low-High)
Drainage from unsealed drift mines:				
pH: -log $[H^+]$*	9	5.55	3.58-7.52	3.08-7.97
Alkalinity, mg $CaCO_3$/1*	5	130.97	55.04-311.66	50.12-285.51
Net Acidity, mg $CaCO_3$/1	9	-29.44	-180.33 to 160.1	-241.73 to 243.86
Total Acidity, mg $CaCO_3$/1	9	4.48	---	0.001-243.86
Specific Conductance, μmhos/cm	9	1143.	669.-1869.	653.-2590.
Total Dissolved Solids, mg/1	9	1056.8	565.0-1976.5	405.5-2872.6
Suspended Solids, mg/1	9	12.1	2.6-57.3	<0.8-103.8
Sulfate, mg SO_4/1	9	325.	57.-1839.	<10.-1840.
Chemical Oxygen Demand, mg O/1	8	1.7	<2.0-3.7	<2.0-5.0
Total Iron, mg Fe/1	9	3.25	<0.30-51.32	<0.30-91.00
Ferrous Iron, mg Fe/1	9	0.926	0.044-19.42	0.020-44.68
Manganese, mg Mn/1	9	0.75	0.07-8.32	0.05-13.40
Calcium, mg Ca/1	9	87.7	20.6-373.2	4.3-505.0
Magnesium, mg Mg/1	9	28.96	4.76-176.09	0.49-131.80
Aluminum, mg Al/1	9	2.2	<1.0-9.7	<1.0-33.0
Cadmium, μg Cd/1	9	0.3	<0.1-1.7	<0.1-6.0
Mercury, μg Hg/1**	9	---	---	---
Nickel, mg Ni/1	9	0.20	<0.30-0.37	<0.30-0.65
Zinc, mg Zn/1	9	0.065	<0.030-0.413	<0.030-0.930
Surface waters in proximity of studied mines:				
pH: -log $[H^+]$*	8	5.38	3.71-7.05	3.01-7.56
Alkalinity, mg $CaCO_3$/1	5	5.52	0.72-42.18	0.90-124.41
Net Acidity, mg $CaCO_3$/1	8	50.31	-102.45 to 238.31	-119.01 to 554.47
Total Acidity, mg $CaCO_3$/1	8	4.68	---	4.42-554.47
Specific Conductance, μmhos/cm	8	411.	121.-1397.	50.-1960.
Total Dissolved Solids, mg/1	8	312.2	83.0-1172.6	40.0-2041.5
Suspended Solids, mg/1	8	15.2	3.7-62.4	2.4-121.7
Sulfate, mg SO_4/1	8	68.	<10.-638.	<10.-1150.
Chemical Oxygen Demand, mg O/1	8	1.3	<2.0-2.5	<2.-7.
Total Iron, mg Fe/1	8	1.97	<0.30-20.31	<0.30-98.00
Ferrous Iron, mg Fe/1	8	0.976	0.059-16.04	0.035-53.62
Manganese, mg Mn/1	8	1.10	0.15-8.12	<0.05-18.40
Calcium, mg Ca/1	8	33.5	9.6-117.3	5.1-256.0
Magnesium, mg Mg/1	8	11.59	2.57-52.35	0.97-109.40
Aluminum, mg Al/1	8	1.9	<1.0-8.2	<1.0-35.0
Cadmium, μg Cd/1	8	0.2	<0.1-0.9	<0.1-2.0
Mercury, μg Mg/1**	8	---	---	---
Nickel, mg Ni/1	8	0.17	0.12-0.27	<0.30-0.50
Zinc, mg Zn/1	8	0.056	0.012-0.267	<0.030-0.930

*Values listed are arithmetic means: All other values are geometric means.

**All values were less than the detection limit of the test (0.2 μg Hg/1).

TABLE C-5. SUMMARY OF CLUSTER ANALYSIS; SITE SAMPLES FOR PHASE 1

Sample Code*	Parameter	Range	Mean	Standard deviation
Group 1:				
32, 33, 36, 37, 42, 46, 49,	pH: -log $[H^+]$	2.34-8.22	4.92	1.75
51, 53, 55, 56, 57, 61, 62,	Acidity mg $CaCO_3$/1	-764.54-1546.60	277.8	536.2
63, 64, 65, 66, 67, 68, 69,	Specific Conductance μmhos/cm	466.-4990.	---	---
70, 81, 83, 84, 86, 87, 90,	Total Dissolved Solids mg/1	316.2-6025.6	---	---
92, 93, 95, 97, 101, 107	Suspended Solids mg/1	<0.8-4570.9	---	---
	Sulfate mg SO_4/1	22.-2138.	588.9	---
	Total Iron mg Fe/1	0.30-616.59	22.4	---
	Ferrous mg Fe^{+2}/1	0.020-549.54	8.1	---
	% Sulfur	0.80-3.1	1.96	0.83
Group 2				
4, 6, 7, 9, 11, 12, 14	pH: -log $[H^+]$	2.83-7.83	5.55	1.37
15, 16, 18, 22, 23, 35,	Acidity mg $CaCO_3$/1	-277.63-106.70	-28.64	94.60
38, 39, 40, 43, 52, 54,	Specific Conductance μmhos/cm	85.-888.	64.6	---
79, 80, 85, 88, 108, 111	Total Dissolved Solids mg/1	33.1-812.8	---	---
	Suspended Solids mg/1	<0.8-416.9	---	---
	Sulfate mg SO_4/1	<10.-398.1	---	---
	Total Iron mg Fe/1	<0.30-75.85	3.10	---
	Ferrous mg Fe^{+2}/1	0.010-81.28	0.35	---
	% Sulfur	0.60-4.2	2.05	1.11

*For conversion of sample code to site number, see Appendix B, Table B-2.

TABLE C-6. SUMMARY OF CLUSTER ANALYSIS; SITE SAMPLES FOR PHASE 2

Sample code*	Parameter	Range	Mean	Standard deviation
Group 1:				
120, 126, 131, 137, 140, 141,	pH: -log $[H^+]$	2.60-7.91	4.35	1.46
142, 145, 148, 150, 151, 152,	Acidity mg $CaCO_3$/1	-332.18-974.55	184.15	325.72
153, 154, 155, 157, 160, 161,	Specific Conductance µmhos/cm	77.1-2880.	---	---
162, 164, 166, 168, 173, 174,	Total Dissolved Solids mg/1	51.3-3890.5	---	---
176, 178, 179, 180, 182, 186,	Suspended Solids mg/1	<0.8-316.2	---	---
187, 191, 192, 193, 195	Sulfate mg SO_4/1	<10.-2089.	179.9	---
	Total Iron mg Fe/1	<0.30-371.54	12.94	---
	Ferrous mg Fe^{+2}/1	0.030-407.38	3.14	---
	% Sulfur	0.60-3.1	1.59	0.79
Group 2:				
119, 121, 122, 123, 124, 125,	pH: -log $[H^+]$	5.04-8.68	6.14	1.41
127, 128, 129, 130, 133, 138,	Acidity mg $CaCO_3$/1	-746.77-66.64	-104.49	163.51
139, 146, 147, 158, 163, 172,	Specific Conductance µmhos/cm	78.3-5271.	---	---
184, 194, 196, 197, 198, 199	Total Dissolved Solids mg/1	83.2-6166.0	---	---
	Suspended Solids mg/1	7.2-1445.4	---	---
	Sulfate mg SO_4/1	<10.-3020.	227.5	---
	Total Iron mg Fe/1	<0.30-275.42	20.59	---
	Ferrous mg Fe^{+2}/1	0.17-257.42	4.78	---
	% Sulfur	0.75-4.2	2.58	0.86

*For conversion of sample code to site number, see Appendix B, Table B-2.

TABLE C-7. SUMMARY OF CLUSTER ANALYSIS; SITE SAMPLE FOR PHASE 1 AND 2

Sample code*	Parameter	Range	Mean	Standard deviation
Group 1:				
032, 033, 036, 037, 042, 046,	pH: -log [H^+]	2.34-8.22	4.68	1.63
049, 051, 053, 055, 056, 057,	Acidity mg $CaCO_3$/l	-763.54-1546.60	209.0	447.0
061, 062, 063, 064, 065, 066,	Specific Conductance μmhos/cm	77.0-4990.	---	---
067, 068, 069, 070, 081, 083,	Total Dissolved Solids mg/l	51.3-6025.6	---	---
084, 086, 087, 090, 092, 093,	Suspended Solids mg/l	<0.8-4570.9	---	---
095, 097, 101, 107, 120, 126,	Sulfate mg SO_4/l	<10.-3020.	323.5	---
131, 137, 140, 141, 142, 145,	Total Iron mg Fe/l	<0.30-612.35	11.7	---
148, 150, 151, 152, 153, 154,	Ferrous mg Fe^{+2}/l	0.025-544.02	5.1	---
155, 157, 160, 161, 162, 164,	% Sulfur	0.6-3.1	1.76	0.82
166, 168, 173, 174, 176, 178,				
179, 180, 182, 186, 187, 191,				
192, 193, 195				
Group 2:				
004, 006, 007, 009, 011, 012,	pH: -log [H^+]	2.83-8.68	5.49	1.30
014, 015, 016, 018, 022, 023,	Acidity mg $CaCO_3$/l	-746.77-107.80	-63.70	139.4
035, 038, 039, 040, 043, 052,	Specific Conductance μmhos/cm	78.3-5271.	---	---
054, 079, 080, 085, 088, 108,	Total Dissolved Solids mg/l	33.1-6166.0	---	---
111, 119, 121, 122, 123, 124,	Suspended Solids mg/l	<0.8-1445.4	---	---
125, 127, 128, 129, 130, 133,	Sulfate mg SO_4/l	<10.-3020.	112.2	---
138, 139, 146, 147, 158, 163,	Total Iron mg Fe/l	<0.30-272.89	6.5	---
172, 184, 194, 196, 197, 198,	Ferrous mg Fe^{+2}/l	0.015-259.42	1.32	---
199	% Sulfur	0.6-4.2	2.3	1.02

* For conversion of sample code to site number, see Appendix B, Table B-2.

TABLE C-8. MINE DISCHARGES FROM CLOSED AND OPEN ABANDONED UNDERGROUND COAL MINES THAT EXCEEDED THE EPA PRELIMINARY MINE WATER EFFLUENT GUIDELINES ∞

Mine name	Sample code	pH	Total iron mg/1	Aluminum mg/1	Manganese mg/1	Nickel mg/1	Zinc mg/1	Suspended solids mg/1
Repplier	49	+	*	+	*	+	*	+
	195	*	*	+	*	†	*	+
Otto	53	*	*	*	*	*	*	+
	191	*	*	*	*	†	*	+
Argentines	7	*	*	+	+	†	+	+
	120	*	+	+	+	+	+	+
Keystone	12	+	+	+	+	+	+	+
No. 10	122	+	*	+	*	†	+	*
Keystone	118	*	+	+	+	†	+	*
No. 19								
Hilliard	16	*	*	*	*	+	*	+
	128	*	*	+	*	*	+	+
Isle No. 7	23	*	*	+	+	+	+	*
	126	*	*	+	+	†	+	+
Shaw-Elk	32	*	*	*	*	*	*	+
Lick No. 1	142	*	*	*	*	*	*	+
Shaw-SL-	28	+	*	+	*	*	*	+
118-3	33	*	*	*	*	*	*	+
	105	+	*	+	+	+	*	*
	141	*	*	*	*	*	*	+
Shaw-SL-	30	*	*	*	*	*	*	*
118-5	143	*	*	*	*	*	*	*
Salem No. 2	107	*	*	*	*	*	*	+
	136	*	*	*	*	*	*	+
	137	*	*	*	*	*	*	+
Driscoll	101	*	*	*	*	*	*	+
No. 4	140	*	*	*	*	*	*	+
Rattlesnake	46	*	*	*	*	*	*	+
Creek	163	*	*	*	*	*	*	+
	169	*	*	*	*	*	*	+
Buskirk	43	*	+	+	+	+	+	+
	45	*	+	+	+	+	+	+
	173	*	+	+	+	†	+	+
Brandy Camp	44	*	*	*	*	*	*	+
New Watson	1	*	+	+	+	+	+	*
Old Watson	18	*	+	+	+	+	+	+
	174	*	+	*	+	†	+	+
Mills No. 4	4	*	*	*	+	+	+	+
	176	*	*	*	+	†	+	+
Bullrock	61	+	+	+	+	+	+	+
Run	158	+	+	*	+	†	+	*
Mahoning	62	+	+	+	+	+	+	+
Creek	163	+	+	*	+	†	+	+
Decker	63	*	*	+	+	+	+	+
No. 3	164	*	*	*	+	†	+	+

TABLE C-8 (continued)

Mine name	Sample code	pH	Total iron mg/l	Aluminum mg/l	Manganese mg/l	Nickel mg/l	Zinc mg/l	Suspended solids mg/l
Decker	64	*	*	+	+	*	+	+
No. 5	166	*	*	+	+	†	+	+
Woolridge	19	*	*	*	*	*	*	+
	20	*	*	*	*	*	*	+
Unknown	113	*	*	§	*	*	*	+
	114	*	*	§	*	*	*	+
	115	*	+	§	*	+	*	+
	116	*	*	§	*	*	*	+
Delta	134	*	+	+	+	†	+	+
	135	*	*	*	*	*	*	*
Taylor	190	+	*	+	*	†	+	+
Storries	189	*	*	+	*	†	+	+
40-016	65	+	*	+	*	+	+	*
	66	+	*	+	*	+	+	*
	198	+	§	§	§	§	§	+
	199	+	§	§	§	§	§	*
Helen	56	*	*	+	+	+	*	*
	179	+	+	+	+	†	+	+
RT 5-2	87	*	*	*	*	*	*	+
	162	*	*	*	+	*	*	+
RT 5-2A	84	*	*	*	+	*	*	*
	161	*	*	*	+	*	*	+
RT 9-11	81	*	*	*	*	+	*	+
	160	*	*	*	*	*	*	+
Savage	85	*	*	+	+	+	+	+
	152	*	+	+	+	†	+	+
Big Knob 1	79	*	+	+	+	+	+	+
	148	*	+	+	+	†	+	+
Big Knob 2	88	*	+	+	+	+	*	+
	150	*	+	*	+	*	*	+
Big Knob 6	80	*	+	+	+	+	+	+
	151	*	+	+	+	†	+	+
14-042	67	*	*	*	*	*	*	*
	154	*	*	*	*	*	*	*
62-008-3	68	+	*	+	+	+	+	*
	196	+	§	+	§	§	§	*
62-008-4	69	+	*	+	+	+	+	*
	197	*	§	+	§	§	§	*
Stewartstown	70	+	*	+	*	*	*	+
	153	*	*	*	*	*	*	+
Imperial Colliery No. 8	57	*	*	*	+	+	*	+
	178	*	*	*	+	†	+	*
Imperial Colliery No. 9	55	+	*	+	+	+	+	+
	180	+	*	+	+	†	+	+
Jack's Creek	36	*	+	+	+	+	+	+
	187	+	+	+	+	†	+	+

TABLE C-8 (continued)

Mine name	Sample code	pH	Total iron mg/l	Aluminum mg/l	Manganese mg/l	Nickel mg/l	Zinc mg/l	Suspended solids mg/l
Arnold	37	+	+	+	+	+	+	+
Fork	182	+	+	+	+	†	+	+
Baker No. 1	38	+	+	+	+	+	+	+
	184	+	+	+	+	†	+	+
Buckingham	35	*	+	+	+	+	+	+
No. 5	186	+	+	+	+	†	+	+
Ellisonville	72	*	*	*	*	*	*	+
Kelly	77	*	*	*	*	*	*	+
Essex No. 1	96	+	*	+	*	+	*	+
	156	+	*	+	+	†	+	*
Essex No. 2	97	*	*	*	*	*	*	*
	157	*	*	*	*	†	*	+
Piney Fork	74	+	+	+	+	+	+	*
	75	+	+	+	+	+	+	*
Florence	76	+	*	+	+	+	+	*
McDaniels	98	*	+	+	+	+	+	+
Buchtel	95	+	+	+	+	+	+	+
	155	+	+	+	+	†	+	+
Bates	183	+	*	+	+	†	+	+
Burningstar	90	+	*	+	*	+	+	*
No. 7	147	+	*	+	*	†	+	*
Lake City	83	+	*	+	*	+	*	*
	146	+	*	+	*	†	*	+
Ensminger	86	*	*	*	*	*	*	*
	145	*	*	*	*	*	*	+
Watson	82	*	*	+	*	+	*	*
Carbon Fuel	78	*	*	+	+	+	+	*
Hall	92	*	*	*	*	*	*	+
	131	*	*	*	*	*	*	*
New Lanning	94	§	*	+	*	+	+	§
Lost Creek	93	§	*	+	*	+	*	§
	133	+	*	+	*	†	+	*
Rock Head	27	*	*	+	+	+	+	*
Phifers No. 1	26	*	*	*	+	+	+	*

∞The U.S. EPA preliminary effluent guidelines for mine drainages (Skelly and Loy, 1975), are given as follows:

Parameter:	30- day average	Parameter:	30-day average
pH: $-\log [H^+]$	6 - 9	Nickel mg Ni/l	0.20 mg Ni/l
Total Iron mg Fe/l	3.5 mg Fe/l	Zinc mg Zn/l	0.20 mg Zn/l
Aluminum mg Al/l	2.0 mg Al/l	Total Suspended Solids	35 mg/l
Manganese mg Mn/l	2.0 mg Mn/l		

+The chemical parameter that met the effluent guidelines.
*The chemical parameter that exceeded the effluent guidelines.
†Detection limit of test greater than the effluent guidelines.
§Not analyzed.

APPENDIX D. SUMMARY OF WATER QUALITY AND QUANTITY DATA FOR PRE- AND POST-CLOSURE PERIODS IN AIR-,SINGLE AND DOUBLE BULKHEAD-, AND PERMEABLE (LIMESTONE) BULKHEAD-SEALED MINES

TABLE D-1. PRE- AND POST-CLOSURE MEANS OF ACIDITY AND ALKALINITY CONCENTRATIONS AND STANDARD DEVIATIONS; AIR-SEALED MINES

Mine name	Before closure B	After closure A	Standard deviation B	Number observ. B	Standard deviation A	Number observ. A
Acidity (mg/1):						
Decker No. 3	486	209	171	343	61	173
RT 9-11	570	315	89	33	62	110
Imperial Colliery No. 9	68	137	*	1	121	8
Big Knob No. 1	119	120	52	31	54	28
Big Knob No. 2	76	83	27	33	35	29
Big Knob No. 6	*	25	*	0	21	26
Savage	24	12	16	29	5	27
Essex No. 1	*	10	*	0	8	2
Kelly	*	585	*	0	*	1
McDaniels	*	151	36	15	61	18
Elk Lick No. 1	*	1057	*	0	78	3
Alkalinity (mg/1):						
Decker No. 3	*	18	*	0	10	2
RT 9-11	*	0	*	0	0	3
Imperial Colliery No. 9	38	61	*	1	30	7
Big Knob No. 1	*	5	*	0	7	2
Big Knob No. 2	4	10	*	1	14	2
Big Knob No. 6	*	0	*	0	*	1
Savage	6	5	5	11	6	2
Essex No. 1	*	214	*	0	5	2
Kelly	*	0	*	0	*	1
McDaniels	*	*	*	0	*	0
Elk Lick No. 1	*	0	*	0	*	1

* No data available.

TABLE D-2. PRE- AND POST-CLOSURE MEANS OF SULFATE AND TOTAL IRON CONCENTRATIONS AND STANDARD DEVIATIONS; AIR-SEALED MINES

Mine name	Before closure B	After closure A	Standard deviation B	Number observ. B	Standard deviation A	Number observ. A
Sulfate (mg/l):						
Decker No. 3	1282	889	317	331	182	173
RT 9-11	666	790	605	51	916	110
Imperial Colliery No. 9	705	556	*	1	205	7
Big Knob No. 1	204	234	93	14	184	25
Big Knob No. 2	120	131	46	14	93	24
Big Knob No. 6	*	45	*	0	16	24
Savage	46	43	21	15	18	23
Essex No. 1	*	35	*	0	5	2
Kelly	*	610	*	0	*	1
McDaniels	*	221	*	0	60	12
Elk Lick No. 1	*	1856	*	0	110	3
Total Iron (mg/l):						
Decker No. 3	142	58	70	343	27	173
RT 9-11	94	70	29	32	40	110
Imperial Colliery No. 9	2	5	*	1	4	12
Big Knob No. 1	4	10	4	14	11	28
Big Knob No. 2	8	3	22	14	2	29
Savage	0.5	1	0.7	14	0.8	27
Essex No. 1	*	4	*	0	1	2
Kelly	*	7	*	0	*	1
McDaniels	*	0.9	*	0	*	1
Elk Lick No. 1	*	323	*	0	*	2

* No data available.

TABLE D-3. PRE- AND POST-CLOSURE MEANS OF POLLUTANT OUTPUTS AND STANDARD DEVIATIONS; AIR-SEALED MINES

Mine name	Before closure B	After closure A	Standard deviation B	Number observ. A	Standard deviation B	Number observ. B
Acidity (kg/day):						
Decker No. 3	264.4	50.2	612.6	343	99.7	135
RT 9-11	28.7	34.7	49.6	25	21.9	79
Imperial Colliery No. 9	*	1.6	*	0	*	2
Big Knob No. 1	2.4	2.3	1.0	23	2.4	23
Big Knob No. 2	2.1	1.2	1.1	23	1.3	22
Big Knob No. 6	*	1.9	*	0	1.6	23
Savage	1.9	0.8	*	0	1.3	22
Sulfate (kg/day):						
Decker No. 3	544.4	165.6	1370.4	331	261.3	135
RT 9-11	43.0	73.6	69.1	26	48.1	79
Imperial Colliery No. 9	*	22.5	*	0	3.7	2
Big Knob No. 1	4.6	4.4	1.6	8	5.2	23
Big Knob No. 2	3.1	2.2	1.7	9	2.6	22
Big Knob No. 6	*	3.9	*	0	3.3	23
Savage	3.5	2.6	1.8	10	3.2	22
Total Iron (kg/day):						
Decker No. 3	83.3	15.9	203.2	343	34.2	135
RT 9-11	4.8	7.8	8.5	25	5.9	79
Imperial Colliery No. 9	*	0.3	*	0	*	2
Big Knob No. 1	0.1	0.2	0.1	9	0.3	23
Big Knob No. 2	0.2	0.1	0.4	9	0.1	22
Big Knob No. 6	*	0.1	*	0	0.3	23
Savage	0.1	0.1	0.1	9	0.2	22

* No data available.

TABLE D-4. PRE- AND POST-CLOSURE MEANS OF ACIDITY CONCENTRATIONS AND STANDARD DEVIATIONS; DOUBLE BULKHEAD-SEALED MINES

Mine name	Before closure B	After closure A	Standard deviation B	Number observ. B	Standard deviation A	Number observ. A
Acidity (mg/l):						
Argentine	69	34	10	12	35	2
Argentine OB*	69	19	10	12	17	2
Keystone No. 6	104	NF+	41	12	NF	2
Keystone No. 6 OB	104	14	41	12	2	2
Keystone No. 10	16	6	8	11	2	2
Keystone No. 10 OB	16	2	8	11	2	2
Keystone No. 19	102	7†	19	11	§	1
Keystone No. 19 OB	102	5	19	11	1	2
Hilliard	70	81	95	8	10	2
Hilliard OB	70	2	95	8	4	7
Lindey No. 1	432	NF	160	26	NF	1
Lindey No. 1 OB	432	6	160	26	§	1
Shaw SL-118-5	1505	989	523	103	212	5
Shaw SL-118-5 CD#	954	763	326	62	251	15
Salem No. 2	494	335	151	35	28	2
Salem No. 2 OB	494	14	151	35	15	3
RT 5-2	683	794	160	68	371	3
RT 5-2 OB	683	1107	160	68	276	29
Phifers No. 1	83	NF	18	3	NF	1
Phifers No. 1 OB	83	0	18	3	§	1
Isle No. 1	32	15	19	22	6	2
Isle No. 1 OB	32	4	19	22	5	7
62008-5	2260	1090	§	1	§	1

* Samples taken from observation borings.
\+ No flow.
† Observation value for March 1976; no flow observed in October 1975.
§ No calculations made.
\# Combined drainage from several mine openings.

TABLE D-5. PRE- AND POST-CLOSURE MEANS OF ALKALINITY CONCENTRATIONS AND STANDARD DEVIATIONS; DOUBLE BULKHEAD-SEALED MINES

Mine name	Before closure B	After closure A	Standard deviation B	Number observ. B	Standard deviation A	Number observ. A
Alkalinity (mg/1):						
Argentine	0.2	4.3	0.1	12	4.4	3
Argentine OB*	0.2	24.7	0.1	12	27.3	2
Keystone No. 6	0.0	NF+	0.0	12	NF	2
Keystone No. 6 OB	0.0	96.0	0.0	12	95.7	2
Keystone No. 10	4.3	166.2	3.3	11	26.2	2
Keystone No. 10 OB	4.3	123.5	3.3	11	151.9	2
Keystone No. 19	0.0	7.1†	0.0	11	§	1
Keystone No. 19 OB	0.0	6.4	0.0	11	.4	2
Hilliard	0.5	3.5	1.4	8	5.0	2
Hilliard OB	0.5	49.6	1.4	8	35.0	7
Lindey No. 1	0.0	NF	0.3	26	NF	1
Lindey No. 1 OB	0.0	24.8	0.3	26	§	1
Shaw SL-118-5	#	0.0	#	0	§	1
Shaw SL-118-5 CD **	#	#	#	0	#	0
Salem No. 2	0.0	0.0	0.0	3	§	1
Salem No. 2 OB	0.0	57.0	0.0	3	42.5	3
RT 5-2	#	0.0	#	0	0.0	2
RT 5-2 OB	#	0.0	#	0	§	1
Phifers No. 1	#	NF	#	0	NF	1
Phifers No. 1 OB	#	132.4	#	0	§	1
Isle No. 1	3.2	16.5	5.1	22	9.4	2
Isle No. 1 OB	3.2	15.5	5.1	22	13.0	7
62008-5	#	#	#	0	#	0

* Samples taken from observation borings.
\+ No flow.
† Observation value for March 1976; no flow observed in October 1975.
§ No calculations made.
\# No data available.
** Combined drainage from several mine openings.

TABLE D-6. PRE- AND POST-CLOSURE MEANS OF SULFATE CONCENTRATIONS AND STANDARD DEVIATIONS; DOUBLE BULKHEAD-SEALED MINES

Mine name	Before closure B	After closure A	Standard deviation B	Number observ. B	Standard deviation A	Number observ. A
Sulfate (mg/l):						
Argentine	248	114	60	12	36	3
Argentine OB*	248	569	60	12	679	2
Keystone No. 6	381	NF	139	12	NF	2
Keystone No. 6 OB	381	133	139	12	155	2
Keystone No. 10	80	271	45	11	44	2
Keystone No. 10 OB	80	157	45	11	201	2
Keystone No. 19	364	30†	66	11	§	1
Keystone No. 19 OB	364	159	66	11	93	2
Hilliard	#	238	#	0	86	2
Hilliard OB	#	10	#	0	2	2
Lindey No. 1	#	#	#	0	#	0
Lindey No. 1 OB	#	9	#	0	§	1
Shaw SL-118-5	2915	1580	1274	3	297	5
Shaw SL-118-5 CD**	2492	1657	1037	72	434	15
Salem No. 2	1176	610	533	35	127	2
Salem No. 2 OB	1176	74	533	35	24	3
RT 5-2	660	568	439	92	311	3
RT 5-2 OB	660	1438	439	92	708	32
Phifers No. 1	109	NF	36	3	NF	1
Phifers No. 1 OB	109	48	36	3	§	1
Isle No. 1	#	71	#	0	25	2
Isle No. 1 OB	#	40	#	0	13	3
62008-5	4160	3610	§	1	§	1

* Samples taken from observation borings.
+ No flow.
† Observation value for March 1976; no flow observed in October 1975.
§ No calculations made.
# No data available.
** Combined drainage from several mine openings.

TABLE D-7. PRE- AND POST-CLOSURE MEANS OF TOTAL IRON CONCENTRATIONS AND STANDARD DEVIATIONS; DOUBLE BULKHEAD-SEALED MINES

Mine name	Before closure B	After closure A	Standard deviation B	Number observ. B	Standard deviation A	Number observ. A
Total Iron (mg/l):						
Argentine	26	18	7	12	13	3
Argentine OB*	26	24	7	12	23	2
Keystone No. 6	5	NF	4	12	NF	2
Keystone No. 6 OB	5	17	4	12	3	2
Keystone No. 10	2	14	1	11	16	2
Keystone No. 10 OB	2	16	1	11	2	2
Keystone No. 19	2	2†	1	11	§	1
Keystone No. 19 OB	2	2	1	11	2	2
Hilliard	4	17	4	8	15	2
Hilliard OB	4	34	4	8	28	7
Lindey No. 1	20	NF	13	26	NF	1
Lindey No. 1 OB	20	19	13	26	§	1
Shaw SL-118-5	459	298	197	103	59	5
Shaw SL-118-5 CD#	189	72	73	72	26	15
Salem No. 2	94	48	69	35	44	2
Salem No. 2 OB	94	29	69	35	39	3
RT 5-2	212	124	86	67	74	3
RT 5-2 OB	212	502	86	67	200	29
Phifers No. 1	14	NF	9	3	NF	1
Phifers No. 1 OB	14	10	9	3	§	1
Isle No. 1	12	6	7	22	3	2
Isle No. 1 OB	12	20	7	22	20	7
62008-5	600	716	§	1	§	1

* Samples taken from observation borings.
+ No flow.
† Observation value for March 1976; no flow observed in October 1975.
§ No calculations made.
# Combined drainage from several mine openings.

TABLE D-8. PRE- AND POST-CLOSURE MEANS OF POLLUTANT OUTPUTS AND STANDARD DEVIATIONS; DOUBLE BULKHEAD-SEALED MINES

Mine name	Before closure B	After closure A	Standard deviation B	Number observ. B	Standard deviation A	Number observ. A
Acidity (kg/day):						
Argentine	68.9	13.3	17.2	12	11.5	2
Keystone No. 6	46.2	NF*	30.7	12	NF	2
Keystone No. 10	0.3	1.2	0.3	11	.9	2
Keystone No. 19	4.0	.1	5.0	11	+	1
Hilliard	.9	2.7	1.2	8	3.1	2
Lindey No. 1	11.4	NF	4.4	26	NF	1
Shaw SL-118-5	†	185.1	†	0	+	1
Shaw SL-118-5 CD	†	856.5	†	0	+	1
Salem No. 2	162.3	3.5	136.1	23	3.0	2
RT 5-2	365.8	87.1	465.7	54	14.0	3
Isle No. 1	0.9	.4	.7	22	.3	2
62008-5	30.9	1.2	+	1	+	1
Alkalinity (kg/day):						
Argentine	0.3	0.2	0.1	12	0.3	2
Keystone No. 6	0.0	NF	0.0	12	NF	2
Keystone No. 10	0.2	26.6	0.3	11	6.8	2
Keystone No. 19	0.0	0.1	0.0	11	+	1
Hilliard	0.1	0.3	0.1	8	0.3	2
Lindey No. 1	0.1	NF	0.1	26	NF	1
Shaw SL-118-5	†	0.0	†	0	+	1
Shaw SL-118-5 CD	†	†	†	0	†	0
Salem No. 2	†	0.0	†	0	+	1
RT5-2	†	0.0	†	0	0.0	2
Isle No. 1	0.1	0.4	0.2	22	0.2	2
62008-5	†	†	†	0	†	0

* No flow.
\+ No calculations made.
† No data available.
§ Combined drainage from several mine openings.

TABLE D-9. PRE- AND POST-CLOSURE MEANS OF POLLUTANT OUTPUTS AND STANDARD DEVIATIONS; DOUBLE BULKHEAD-SEALED MINES

Mine name	Before closure B	After closure A	Standard deviation B	Number observ. B	Standard deviation A	Number observ. A
Sulfate (kg/day):						
Argentine	244.8	167.7	63.9	12	222.3	2
Keystone No. 6	171.3	NF*	122.9	12	NF	2
Keystone No. 10	1.5	46.4	1.5	11	25.6	2
Keystone No. 19	12.4	0.0	10.9	11	+	1
Hilliard	†	10.6	†	0	13.6	2
Lindey No. 1	†	NF	+	0	NF	1
Shaw SL-118-5	†	277.7	†	0	+	1
Shaw SL-118-CD§	†	2371.9	†	0	+	1
Salem No. 2	401.4	6.6	320.0	23	6.2	2
RT 5-2	472.1	70.4	530.8	54	43.4	3
Isle No. 1	†	1.9	†	0	1.3	2
6.2008-5	56.9	4.1	+	1	+	1
Total Iron (kg/day):						
Argentine	26.7	4.7	10.9	12	2.9	2
Keystone No. 6	2.0	NF	1.8	12	NF	2
Keystone No. 10	0.0	2.9	0.1	11	3.7	2
Keystone No. 19	0.0	0.0	0.0	11	+	1
Hilliard	0.0	0.9	0.0	8	1.3	2
Lindey No. 1	0.6	NF	0.7	26	NF	1
Shaw SL-118-5	†	67.8	†	0	+	1
Shaw SL-118-5 CD§	†	163.5	†	0	+	1
Salem No. 2	33.6	0.6	33.4	23	0.8	2
RT 5-2	125.8	16.0	185.3	53	10.4	3
Isle No. 1	0.3	0.1	0.3	22	0.1	2
62008-5	8.2	0.8	+	1	+	1

* No flow.
\+ No calculations made.
† No data available.
§ Combined drainage from several mine openings.

TABLE D-10. PRE- AND POST-CLOSURE MEANS OF ACIDITY AND ALKALINITY CONCENTRATIONS AND STANDARD DEVIATIONS; SINGLE BULKHEAD-SEALED MINES

Mine name	Before closure B	After closure A	Standard deviation B	Number observ. B	Standard deviation A	Number observ. A
Acidity (mg/l):						
62008-4	1170	446	*	1	421	4
Decker No. 5	+	105	+	0	65	3
Woolridge No. 1	+	305	+	0	*	1
Bullrock Run	10	27	*	1	*	2
Buckingham	+	NF§	+	0	NF	2
Price No. 2	+	NF	+	0	NF	2
Ellisonville	+	1221	+	0	*	1
Piney Fork	+	2	+	0	+	0
Florence	+	268	+	0	*	1
Rattlesnake Creek	120	65	37	6	*	1
Rattlesnake Creek CD§	+	211	+	0	52	9
Rattlesnake Creek	7	6	3	8	5	9
40-016	350	170	*	1	143	56
Alkalinity (mg/l):						
62008-4	0	58	*	1	59	3
Decker No. 5	+	0	+	0	0	2
Woolridge No. 1	+	+	+	0	+	0
Bullrock Run	225	309	*	1	17	2
Buckingham	+	NF	+	0	NF	2
Price No. 2	+	NF	+	0	NF	2
Ellisonville	+	0	+	0	+	0
Piney Fork	+	568	+	0	+	0
Florence	+	507	+	0	*	1
Rattlesnake Creek	0	0	0	3	*	1
Rattlesnake Creek CD§	+	0	+	0	0	7
Rattlesnake Creek	11	11	6	8	6	9
40-016	*	40	*	0	39	56

* No calculations made.
\+ No data available.
† No flow.
§ Combined drainage from several mine openings.

TABLE D-11. PRE- AND POST-CLOSURE MEANS OF SULFATE AND TOTAL IRON CONCENTRATIONS AND STANDARD DEVIATIONS; SINGLE BULKHEAD-SEALED MINES

Mine name	Before closure B	After closure A	Standard deviation B	Number observ. B	Standard deviation A	Number observ. A
Sulfate (mg/l):						
62008-4	3016	2433	*	1	571	3
Decker No. 5	+	247	+	0	151	3
Woolridge No. 1	+	540	+	0	*	1
Bullrock Run	206	224	+	1	76	2
Buckingham	+	NF†	+	0	*	2
Price No. 2	+	NF	+	0	*	2
Ellisonville	+	1020	+	0	*	1
Piney Fork	+	270	+	0	+	0
Florence	+	3050	+	0	*	1
Rattlesnake Creek	252	243	155	6	*	1
Rattlesnake Creek CD§	+	677	+	0	239	9
Rattlesnake Creek	62	170	56	8	142	9
40-016	+	1560	*	1	213	54
Total Iron (mg/l):						
62008-4	246	231	*	1	167	3
Decker No. 5	+	19	+	0	17	3
Woolridge No. 1	+	28	+	0	*	1
Bullrock Run	16	1	*	1	1	2
Buckingham	+	NF	+	0	NF	2
Price No. 2	+	NF	+	0	NF	2
Ellisonville	+	150	+	0	*	1
Piney Fork	+	1	+	0	+	0
Florence	+	227	+	0	*	1
Rattlesnake Creek	7	8	1	3	*	1
Rattlesnake Creek CD	+	38	+	0	55	8
Rattlesnake Creek	1	1	1	7	1	9
40-016	160	99	*	1	42	56

* No calculations made.
+ No data available.
† No flow.
§ Combined drainage from several mine openings.

TABLE D-12. PRE- AND POST-CLOSURE MEANS OF ACIDITY AND ALKALINITY OUTPUTS AND STANDARD DEVIATIONS; SINGLE BULKHEAD-SEALED MINES

Mine name	Before closure B	After closure A	Standard deviation B	Number observ. B	Standard deviation A	Number observ. A
Acidity (kg/day):						
62008-4	18.5	30.1	*	1	12.8	3
Decker No. 5	+	1.5	+	0	1.7	2
Woolridge No. 1	+	3.5	+	0	*	1
Bullrock Run	+	0.2	+	0	0.1	2
Buckingham	+	NF†	+	0	NF	0
Price No. 2	+	NF	+	0	NF	0
Ellisonville	*	26.3	+	0	*	1
Piney Fork	+	+	+	0	+	0
Forence	+	268	+	0	*	1
Rattlesnake Creek	289.1	+	186.7	6	+	0
Rattlesnake Creek CD§	+	57.443	+	0	22.0	8
40-016	71.0	2.879	*	1	2.6	54
Alkalinity (kg/day):						
62008-4	0.0	9.7	*	1	*	1
Decker No. 5	+	0.0	+	0	*	1
Woolridge No. 1	+	+	+	0	+	0
Bullrock Run	+	3.101	+	0	0.4	2
Buckingham	+	NF	+	0	NF	0
Price No. 2	+	NF	+	0	+	0
Ellisonville	+	+	+	0	+	0
Piney Fork	+	507.8	+	0	*	1
Rattlesnake Creek	0.0	+	0	3	+	0
Rattlesnake Creek CD	+	0.0	+	0	0.0	7
40-016	+	0.5	+	0	0.5	52

* No calculations made.
\+ No data available.
† No flow.
§ Combined drainage from several mine openings.

TABLE D-13. PRE- AND POST-CLOSURE MEANS OF SULFATE AND TOTAL IRON LOADS AND STANDARD DEVIATIONS; SINGLE BULKHEAD-SEALED MINES

Mine name	Before closure B	After closure A	Standard deviation B	Number observ. B	Standard deviation A	Number observ. A
Sulfate (kg/day):						
62008-4	47.7	150.9	*	1	61.0	3
Decker No. 5	+	3.7	+	0	2.7	2
Woolridge No. 1	+	6.2	+	0	*	1
Bullrock Run	+	2.3	+	0	1.2	2
Buckingham	+	NF †	+	0	*	0
Price No. 2	+	NF	+	0	*	0
Ellisonville	+	22.0	+	0	*	1
Piney Fork	+	+	+	0	+	0
Florence	+	1993.9	+	0	*	1
Rattlesnake Creek	724.3	+	547.4	6	+	0
Rattlesnake Creek CD§	+	194.5	+	0	91.8	8
40-016	+	26.6	+	0	17.1	53
Total Iron (kg/day):						
62008-4	3.8	13.1	*	1	11.5	3
Decker No. 5	+	0.3	+	0	0.4	2
Woolridge No. 1	+	0.3	+	0	*	1
Bullrock Run	+	0.1	+	0	0.1	2
Buckingham	+	NF	+	0	*	0
Price No. 2	+	NF	+	0	*	0
Ellisonville	+	3.2	+	0	*	1
Piney Fork	+	+	+	0	+	0
Florence	+	148.7	+	0	*	1
Rattlesnake Creek	19.4	+	12.1	3	+	0
Rattlesnake Creek CD	+	10.8	+	0	16.3	7
40-016	32.4	1.7	*	1	1.8	53

* No calculations made.
\+ No data available.
† No flow.
§ Combined drainage from several mine openings.

TABLE D-14. PRE- AND POST-CLOSURE MEANS OF POLLUTANT CONCENTRATIONS AND STANDARD DEVIATIONS; PERMEABLE (LIMESTONE) BULKHEAD-SEALED MINES

Mine name	Before closure B	After closure A	Standard deviation B	Number observ. B	Standard deviation A	Number observ. A
Acidity (mg/l):						
62008-3	200	111	141	2	104	17
Stewartstown	595	224	359	13	240	20
Stewartstown OB	595	627	359	13	640	6
RT 5-2A	683	107	160	68	215	42
RT 5-2A OB*	683	1093	160	68	399	22
Alkalinity (mg/l):						
62008-3	0	234	0	2	48	17
Stewartstown	+	205	+	0	143	10
Stewartstown OB	+	463	+	0	681	3
RT 5-2A	+	15	+	0	34	5
RT 5-2A OB	+	0	+	0	*	1
Sulfate (mg/l):						
62008-3	2220	2441	749	2	255	16
Stewartstown	1316	1208	494	13	590	20
Stewartstown OB	1316	2007	494	13	882	6
RT 5-2A	660	887	439	92	362	42
RT 5-2A OB	660	1543	439	92	701	24
Total Iron (mg/l):						
62008-3	55	45	27	2	53	16
Stewartstown	117	42	68	13	52	20
Stewartstown OB	117	214	68	13	186	6
RT 5-2A	212	160	86	67	115	42
RT 5-2A OB	212	482	86	67	199	22

* Samples taken from observation borings.
\+ No data available.
† No calculations made.

TABLE D-15. PRE- AND POST-CLOSURE MEANS OF POLLUTANT OUTPUTS AND STANDARD DEVIATIONS; PERMEABLE (LIMESTONE) BULKHEAD-SEALED MINES

Mine name	Before closure B	After closure A	Standard deviation B	Number observ. B	Standard deviation A	Number observ. A
Acidity (kg/day):						
62008-3	1.5	1.8	*	1	1.5	16
Stewartstown	22.0	2.3	13.3	13	1.5	6
RT 5-2A	365.8	2.9	465.7	54	8.2	41
Alkalinity (kg/day):						
62008-3	0.0	3.8	*	1	2.2	16
Stewartstown	+	2.2	+	0	3.2	2
RT 5-2A	+	2.1	+	0	4.7	5
Sulfate (kg/day):						
62008-3	26.7	37.8	*	1	11.6	16
Stewartstown	51.4	10.6	15.9	13	9.0	6
RT 5-2A	472.1	18.0	70.4	54	15.7	41
Total Iron (kg/day):						
62008-3	0.5	0.7	*	1	0.7	16
Stewartstown	4.2	0.4	2.2	13	0.2	6
RT 5-2A	125.8	2.8	185.3	53	1.7	41

* No calculations made.

+ No data available.

APPENDIX E. REGRESSION COEFFICIENTS FOR POLLUTANT CONCENTRATIONS AND OUTPUTS

TABLE E-1. REGRESSION COEFFICIENTS FOR ACIDITY CONCENTRATION

Mine name	Before closure: Regression coefficient	Before closure: Standard error	Before closure: Degree of freedom	After closure: Regression coefficient	After closure: Standard error	After closure: Degree of freedom
Decker No. 3	-108.2*	7.56	864	-75.84*	1.38	642
RT 9-11	-17.96+	12.08	48	-24.70†	3.83	107
Big Knob No. 1	-25.53†	27.17	31	-12.44	4.65	26
Big Knob No. 2	-12.77†	14.19	32	-7.77	3.14	26
Savage	-5.38	8.11	30	-1.27†	.52	25
Argentine	28.10+	6.53	9	#	#	§
Keystone No. 6	101.17*	27.71	9	§	§	§
Keystone No. 10	-8.27†	8.90	9	§	§	§
Keystone No. 19	-10.42	32.86	8	§	§	§
Isle No. 1	-3.03	16.18	19	§	§	§
Lindey No. 1	-206.32*	117.25	23	§	§	§
RT 5-2	.08	.75	87	§	§	§
Salem No. 2	-22.99+	13.81	32	§	§	§
SL-118-5 Shaw Complex	126.38*	52.18	93	-14.66	54.64	10
Stewartstown	103.73	586.69	12	-179.13+	137.65	16
62008-3	§	§	§	-4.91	12.53	15
RT 5-2A	.08	10.35	87	2.77	19.74	32
40-016	§	§	§	-21.96*	11.82	53
14-042A	§	§	§	-443.41*	70.62	49
Gilman	-225.41*	33.51	87	§	§	§
Imperial Colliery No. 9	§	§	§	-80.51	27.88	10

* Significant at 0.05.
\+ Significant at 0.10.
† Significant at 0.20.
\# Essentially constant.
§ Less than three observations.

TABLE E-2. REGRESSION COEFFICIENTS FOR ACIDITY OUTPUT

Mine name	Before closure Regression coefficient	Before closure Standard error	Before closure Degree of freedom	After closure Regression coefficient	After closure Standard error	After closure Degree of freedom
Decker No. 3	-277.08*	28.60	864	-34.29*	5.17	642
RT 9-11	5.82	5.50	48	-5.28*	1.49	107
Big Knob No. 1	.06	.64	31	-.02	.23	26
Big Knob No. 2	.30	.60	32	-.02	.12	26
Savage	-.85	.81	30	-.02	.08	25
Argentine	§	§	§	§	§	§
Keystone No. 6	§	§	§	§	§	§
Keystone No. 10	§	§	§	§	§	§
Keystone No. 19	§	§	§	§	§	§
Isle No. 1	-1.30*	.51	19	§	§	§
Lindey No. 1	-4.01†	3.34	23	§	§	§
RT 5-2	44.36+	26.64	87	§	§	§
Salem No. 2	-7.93	12.88	32	§	§	§
SL-118-5 Shaw Complex	§	§	§	§	§	§
Stewartstown	12.12	27.61	10	-.63	.85	18
62008-3	§	§	§	-.16†	.20	15
RT 5-2A	44.36*	26.64	87	.05	.32	32
40-016	§	§	§	§	§	§
14-042A	§	§	§	-1.87+	1.23	49
Gilman	-373.90*	86.93	87	§	§	§
Imperial Colliery No. 9	§	§	§	§	§	§

* Significant at 0.05.
§ Less than three observations.
† Significant at 0.20.
+ Significant at 0.10.

TABLE E-3. REGRESSION COEFFICIENTS FOR TOTAL IRON CONCENTRATION

	Before closure			After closure		
Mine name	Regression coefficient	Standard error	Degree of freedom	Regression coefficient	Standard error	Degree of freedom
Decker No. 3	-29.29*	3.30	864	-24.35*	1.13	642
RT 9-11	3.36†	1.18	48	-2.22†	2.85	107
Big Knob No. 1	-8.75+	1.43	31	-1.93	1.08	26
Big Knob No. 2	-13.22*	11.10	32	-.49*	.24	26
Savage	.98	.31	30	.21*	.07	25
Argentine	-.32	7.97	9	-40.89†	23.52	1
Keystone No. 6	7.73*	3.66	9	§	§	§
Keystone No. 10	-3.45*	1.21	9	§	§	§
Keystone No. 19	3.63*	1.64	8	§	§	§
Isle No. 1	3.86	5.93	19	§	§	§
Lindey No. 1	35.97*	7.42	23	§	§	§
RT 5-2	8.79+	5.33	87	§	§	§
Salem No. 2	-5.77†	6.52	32	§	§	§
SL-118-5 Shaw Complex	-32.61+	19.93	93	-22.01	45.75	10
Stewartstown	-26.27	115.59	12	-29.33†	29.57	16
62008-3	§	§	§	.08	2.63	15
RT 5-2A	8.79*	5.33	87	6.64	48.00	32
40-016	§	§	§	-5.75*	3.41	53
14-042A	§	§	§	-82.18*	20.16	49
Gilman	-58.04*	7.03	87	§	§	§
Imperial Colliery No. 9	§	§	§	-2.53*	1.16	10

* Significant at 0.05.
† Significant at 0.20.
+ Significant at 0.10.
§ Less than three observations.

TABLE E-4. REGRESSION COEFFICIENTS FOR TOTAL IRON OUTPUT

	Before closure			After closure		
Mine name	Regression coefficient	Standard error	Degree of freedom	Regression coefficient	Standard error	Degree of freedom
Decker No. 3	-88.50*	9.53	864	-11.70*	1.77	642
RT 9-11	.87+	.93	48	-.96*	.42	107
Big Knob No. 1	.02*	.03	31	-.03*	.03	26
Big Knob No. 2	-.10	.17	32	-.003	.01	26
Savage	.05+	.04	30	.07*	.02	25
Argentine	§	§	§	§	§	§
Keystone No. 6	§	§	§	§	§	§
Keystone No. 10	§	§	§	§	§	§
Keystone No. 19	§	§	§	§	§	§
Isle No. 1	-.19	.26	19	§	§	§
Lindey No. 1	1.92*	.40	23	§	§	§
RT 5-2	17.71*	10.36	87	§	§	§
Salem No. 2	-1.98	3.17	32	§	§	§
SL-118-5 Shaw Complex	§	§	§	§	§	§
Stewartstown	.03	.05	10	-.10	.16	18
62008-3	§	§	§	.01	.05	15
RT 5-2A	17.71*	10.36	87	.11	.70	32
40-016	§	§	§	§	§	§
14-042A	§	§	§	-.34+	.25	49
Gilman	-63.54*	12.90	87	§	§	§
Imperial Colliery No. 9	§	§	§	§	§	§

* Significant at 0.05.
+ Significant at 0.10.
§ Less than three observations.

TABLE E-5. REGRESSION COEFFICIENTS FOR SULFATE CONCENTRATION

	Before closure			After closure		
Mine name	Regression coefficient	Standard error	Degree of freedom	Regression coefficient	Standard error	Degree of freedom
Decker No. 3	-150.08*	14.75	864	-176.10*	6.84	642
RT 9-11	90.65*	82.90	48	-86.77†	65.05	107
Big Knob No. 1	-59.58*	47.57	31	-42.01	15.63	26
Big Knob No. 2	-47.42†	22.27	32	-20.78	7.99	26
Savage	6.18	10.95	30	-2.68†	1.72	25
Argentine	103.66*	54.60	9	113.11†	57.47	1
Keystone No. 6	320.07*	107.29	9	§	§	§
Keystone No. 10	-11.54	48.38	9	§	§	§
Keystone No. 19	124.10+	69.51	8	§	§	§
Isle No. 1	#	#	§	§	§	§
Lindey No. 1	#	#	§	§	§	§
RT 5-2	74.81*	27.12	87	§	§	§
Salem No. 2	-123.40	46.02	22	§	§	§
SL-118-5 Shaw Complex	-289.46*	127.58	93	-164.00	221.19	10
Stewartstown	645.60	771.27	12	-473.98†	341.61	16
62008-3	§	§	§	-55.10	28.69	15
RT 5-2A	74.81*	27.12	87	13.85	150.95	32
40-016	§	§	§	44.91*	17.05	53
14-042A	§	§	§	-530.56*	86.75	49
Gilman	-32.07	63.13	87	§	§	§
Imperial Colliery No. 9	§	§	§	-164.24*	35.69	10

* Significant at 0.05.
† Significant at 0.20.
§ Less than three observations.
+ Significant at 0.10.

TABLE E-6. REGRESSION COEFFICIENTS FOR SULFATE OUTPUT

Mine name	Before closure: Regression coefficient	Before closure: Standard error	Before closure: Degree of freedom	After closure: Regression coefficient	After closure: Standard error	After closure: Degree of freedom
Decker No. 3	-527.10*	64.94	864	-79.01*	13.64	642
RT 9-11	8.65	7.86	48	-10.66*	3.29	107
Big Knob No. 1	3.95*	1.18	31	-.11†	.48	26
Big Knob No. 2	2.35*	.95	32	.10	.24	25
Savage	2.54*	1.03	30	.61*	.27	25
Argentine	§	§	§	§	§	§
Keystone No. 6	§	§	§	§	§	§
Keystone No. 10	§	§	§	§	§	§
Keystone No. 19	§	§	§	§	§	§
Isle No. 1	#	#	§	§	§	§
Lindey No. 1	#	#	§	§	§	§
RT 5-2	56.28*	30.95	87	§	§	§
Salem No. 2	-19.59	30.26	32	§	§	§
SL-118-5 Shaw Complex	§	§	§	§	§	§
Stewartstown	11.53	33.08	10	-10.73*	4.17	18
62008-3	§	§	§	-.26+	.18	15
RT 5-2A	56.28*	30.95	87	.08	2.09	32
40-016	§	§	§	§	§	§
14-042A	§	§	§	-2.42	1.48	49
Gilman	-430.77*	131.20	87	§	§	§
Imperial Colliery No. 9	§	§	§	§	§	§

* Significant at 0.05.
† Significant at 0.20.
§ Less than three observations.
# Essentially constant.
+ Significant at 0.10.

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(Please read Instructions on the reverse before completing)

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16. ABSTRACT

The objective of the research project was to prepare an up-to-date document on deep mine closures that have been or are planned to be implemented in the eastern coal mining regions. The project was also to provide an initial overview of the effectiveness of the closure methods and the factors to which their effectiveness can be attributed. The effectiveness was evaluated in terms of a closure effect on mine drainage quality and quantity.

The trend analyses of the pollutant concentrations and outputs for the pre- and post-closure periods show that the closures for more than half of the sites reversed or reduced increasing pollutant trends, augmented the already decreasing trends, and reduced variability in fluctuations of the water quality. The effectiveness of the mine closures with respect to the mine effluent quality by comparison with the preliminary mine effluent guidelines was observed to be usually less than 50 percent effective. The degree of closure effectiveness with respect to the mine water quality improvement was found to be predominantly determined by the physical and mining framework of the sites and less by the closure technology.

17. KEY WORDS AND DOCUMENT ANALYSIS

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