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ACID MINE WATER IN THE ANTHRACITE REGION OF PENNSYLVANIA

By

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ACID MINE WATER IN THE ANTHRACITE REGION OF PENNSYLVANIA[1]

By E. W. FELEGY,[2] L. H. JOHNSON,[3] AND J. WESTFIELD [4]

INTRODUCTION

Acid drainage from mining operations in the anthracite region of Pennsylvania is a problem in stream sanitation confronting communities situated along the banks of the receiving streams and scattered over their drainage basins both in and outside the anthracite region. It is therefore one of the principal factors to be considered in the conduct of any anthracite mine-flood-prevention program (*1*, *2*, *3*, *4*, *7*, *10*, *18*, *21*).[5]

Complaints have been directed against the anthracite-mining industry concerning the effects of acid mine drainage on the receiving streams. The data available have been too limited either to support or to refute the validity of the complaints, because no previous detailed investigation relating to acid mine drainage in the anthracite region of Pennsylvania has been made. Furthermore, no practicable means for removing the polluting properties of acid mine drainage are known (*6*, *9*).

The object of this study was to determine the effect of acid mine drainage on the receiving streams at the present time and to indicate the effect on the streams if any program for mine-flood prevention or control is undertaken in the future.

The investigation was conducted under the direction of D. Harrington, chief, Health and Safety Division, and S. H. Ash, chief, Safety Branch, Bureau of Mines, Washington, D. C.

This report includes analyses of water samples collected by Bureau of Mines personnel in 1941 and 1946. In some instances samples from one sampling point were collected at intervals over an extended period of time. At least one sample was collected from every known mine-drainage discharge in the four anthracite fields. Many samples were collected from the main rivers and tributaries in the Susquehanna River Basin and the Delaware River Basin. The sampling points of these streams are both upstream and downstream from the coal measures as well as in them.

The volume of flow at several gaging stations was obtained from the Pennsylvania Hydrographic Service, Department of Forests and

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[5] Italic numbers in parentheses refer to items in the bibliography at the end of this report.

Waters, and the United States Department of the Interior, Geological Survey, Water Resources Branch. The volumes of the drainage from most of the mines were obtained from the mining companies in the region. Both weirs and current meters were used for measuring the rate of flow. Where it was impracticable or impossible to measure the volume of flow accurately, the figure reported is marked "estimated."

ACKNOWLEDGMENTS

The authors acknowledge their indebtedness for aid in the collection of data for this report to: Numerous officials of mining companies in the anthracite region; the Pennsylvania Hydrographic Service, Department of Forests and Waters; the Pennsylvania Department of Mines; the United States Department of the Interior, Geological Survey, Water Resources Branch; the Anthracite Flood Prevention Section, Bureau of Mines; R. D. Leitch, safety engineer, Bureau of Mines, Washington, D. C.; and E. W. Lyon, mining engineer, Bureau of Mines, Pittsburgh, Pa.

DEFINITIONS AND EXPLANATION OF TERMS

Total acidity of mine water.—Total acidity indicates the complete capacity of water to produce chemical change by acid reaction. It is the total amount of acid held in solution or the sum of the quantities of both the ionized and the un-ionized portions of actual acid and the potential quantity of acid that can be formed from mineral salts held in solution. Total acidity is customarily reported in equivalent parts per million (p. p. m.) by weight of calcium carbonate. The indicated total acidity of mine water found by currently accepted methods of analysis generally is greater than the actual total acidity. Total acidity as used in this report is "acidity to phenolphthalein."

Free acidity of mine water.—Free acidity is considered to be that portion of the total acidity that exists in the form of acid, both ionized and un-ionized. It is a measure of the aggressiveness with which the water will enter into chemical reaction. It indicates the rate at which chemical reaction will occur but does not define the total capacity of the water to produce chemical change. Currently accepted methods of mine-water analysis, which were employed in this survey, always yielded higher values of free acidity than the actual free acidity, principally because of the influence of aluminum sulfates in the water. Free acidity as used in this report is defined as "acidity to methyl red."

Total and free alkalinity of mine water.—These terms are analogous in concept to total and free acidity and are determined and reported in a similar manner.

Chemically, acid mine water is a comparatively weak solution of acid and is almost completely ionized. Only 2 to 5 percent or less of the acid exists in the un-ionized state.

Hydrogen-ion concentration.—Hydrogen-ion concentration is an accurate method of expressing the intensity of free acidity or of free alkalinity of mine water. The symbol pH is used to express hydrogen-ion concentration. It is defined by Sørensen (*5, 19, 20*) as the negative logarithm of the number of moles (gram-atoms) of ionized hydrogen per liter of water. The *p*H scale ranges from 0 to 14, a *p*H of 0.0 expressing the hydrogen-ion concentration of 1.0 normal completely dissociated acid and a *p*H of 14.0 expressing the hydrogen-ion concentration of 1.0 normal completely dissociated base (*17*). Each unit of the *p*H scale (by whole numbers) represents a hydrogen-ion concentration 10 times greater than the *p*H unit below and one-tenth as great as the *p*H unit above. Hydrogen-ion concentrations that are uneven decimal fractions of moles per liter also can be expressed in *p*H units.

Pure water is chemically neutral and theoretically has a *p*H of 7. Solutions having a *p*H of 0 to 7 are acid, and those having a *p*H of 7 to 14 are alkaline. The *p*H of distilled water is about 5.7; distilled water always is acid because it absorbs CO_2 from the air (*13*).

Tables 1 and 2 clarify the foregoing discussion.

TABLE 1.—*Scale indicating acidity and alkalinity*

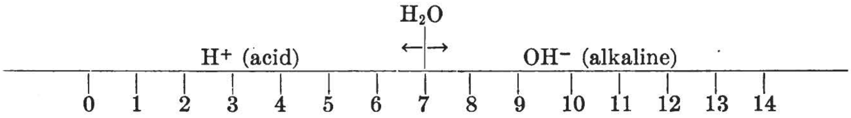


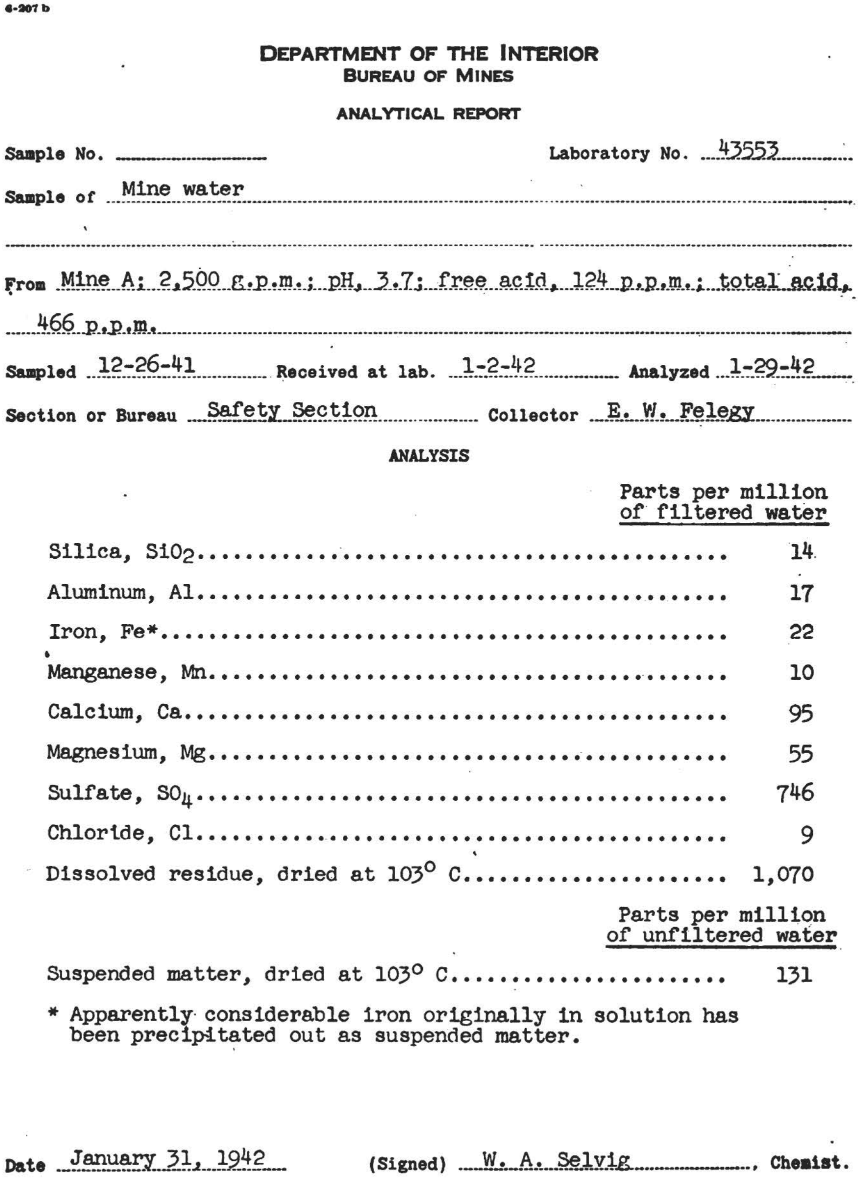
TABLE 2.—*Hydrogen-ion concentration*

*p*H	Intensity of acidity and alkalinity	Ionizable H per liter, grams
0	10,000,000	10^{-0}=1.0
1	1,000,000	10^{-1}= .1
2	100,000	10^{-2}= .01
3	10,000	10^{-3}= .001
4	1,000	10^{-4}= .0001
5	100	10^{-5}= .00001
6	10	10^{-6}= .000001
7	1	10^{-7}= .0000001
8	10	10^{-8}= .00000001
9	100	10^{-9}= .000000001
10	1,000	10^{-10}= .0000000001
11	10,000	10^{-11}= .00000000001
12	100,000	10^{-12}= .000000000001
13	1,000,000	10^{-13}= .0000000000001
14	10,000,000	10^{-14}= .00000000000001

ANALYTICAL REPORTS

Because of the inherent characteristics of acid mine waters and the methods of analyzing them, samples containing free mineral acids normally have a *p*H less than 4.5. In only a few instances in this investigation did slightly acid waters have a *p*H of more than 4.5.

Figures 1 and 2 show a complete analysis of two samples of mine water, one fairly acid with a *p*H of 3.7 and one near the neutral point with a *p*H of 6.2. The sample with the higher acid content contains more silica, aluminum, iron, manganese, calcium, magnesium, sulfate, chloride, and dissolved and suspended residue than the neutral sample.



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DEPARTMENT OF THE INTERIOR
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ANALYTICAL REPORT

Sample No. ____ Laboratory No. 43553

Sample of Mine water

From Mine A; 2,500 g.p.m.; pH, 3.7; free acid, 124 p.p.m.; total acid, 466 p.p.m.

Sampled 12-26-41 Received at lab. 1-2-42 Analyzed 1-29-42

Section or Bureau Safety Section Collector E. W. Felegy

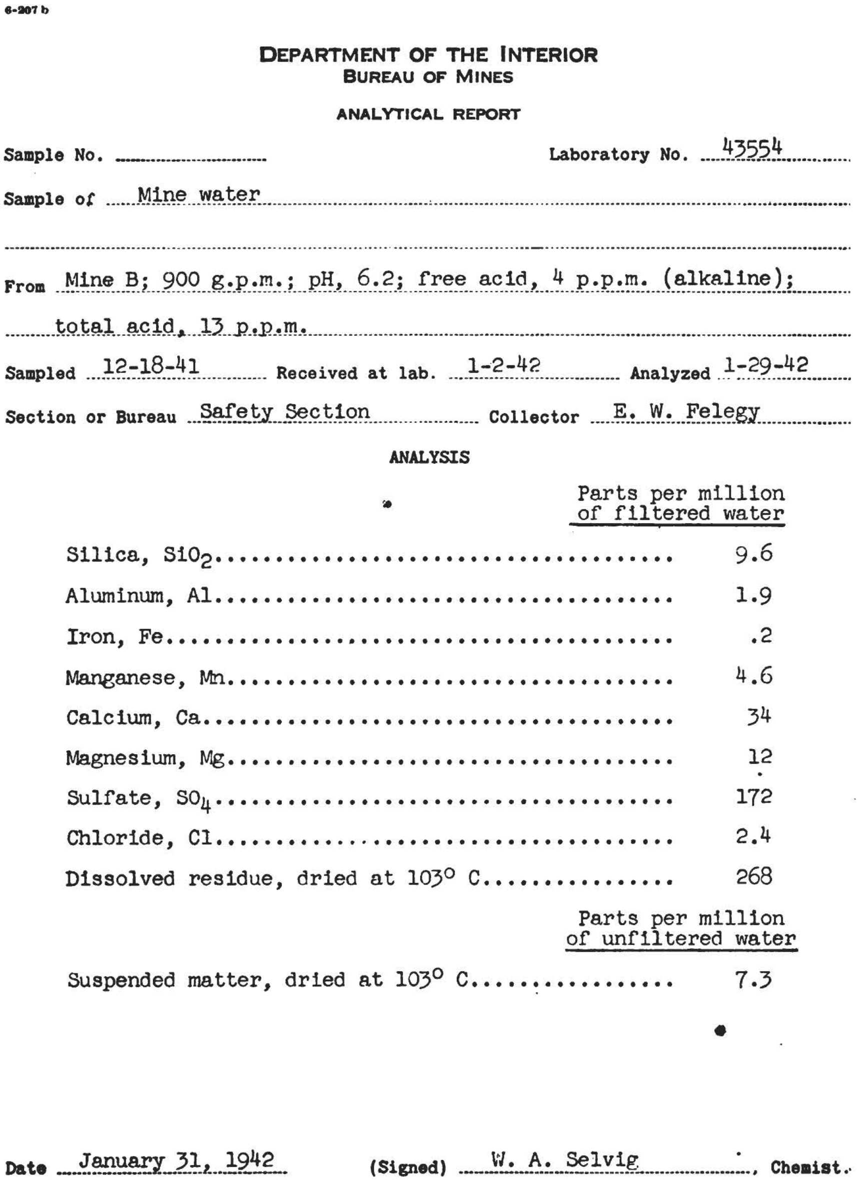
ANALYSIS

	Parts per million of filtered water
Silica, SiO_2	14
Aluminum, Al	17
Iron, Fe*	22
Manganese, Mn	10
Calcium, Ca	95
Magnesium, Mg	55
Sulfate, SO_4	746
Chloride, Cl	9
Dissolved residue, dried at 103° C	1,070
	Parts per million of unfiltered water
Suspended matter, dried at 103° C	131

* Apparently considerable iron originally in solution has been precipitated out as suspended matter.

Date January 31, 1942 (Signed) W. A. Selvig, Chemist.

FIGURE 1.—Analytical report.



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ANALYTICAL REPORT

Sample No. .... Laboratory No. 43554

Sample of Mine water

From Mine B; 900 g.p.m.; pH, 6.2; free acid, 4 p.p.m. (alkaline); total acid, 13 p.p.m.

Sampled 12-18-41 Received at lab. 1-2-42 Analyzed 1-29-42

Section or Bureau Safety Section Collector E. W. Felegy

ANALYSIS

	Parts per million of filtered water
Silica, SiO_2	9.6
Aluminum, Al	1.9
Iron, Fe	.2
Manganese, Mn	4.6
Calcium, Ca	34
Magnesium, Mg	12
Sulfate, SO_4	172
Chloride, Cl	2.4
Dissolved residue, dried at 103° C	268
	Parts per million of unfiltered water
Suspended matter, dried at 103° C	7.3

Date January 31, 1942 (Signed) W. A. Selvig, Chemist.

FIGURE 2.—Analytical report.

DESCRIPTION OF LABORATORY EQUIPMENT

Either the *p*H tester utilizing a glass electrode or the common colorimetric method using colorimetric-slide comparator sets may be employed to determine the *p*H of mine water. A glass-electrode tester yields more-accurate results within the *p*H range of 1 to 9 (*16*) and may be used with less difficulty when the sample of mine water is turbid or discolored.

A glass-electrode *p*H tester was used in this investigation. It had a range of 0 to 13 *p*H, a sensitivity of 0.01 *p*H, and an over-all accuracy of 0.05 *p*H. It was standardized before each set of samples was analyzed. When several samples were analyzed or highly acid results were obtained, the *p*H tester was restandardized several times during the analytical procedure.

Fifty-milliliter (50-ml.) burettes with side-filling tubes were erected so that the supply of standard solution in the burette could be replenished conveniently by means of glass- and rubber-tube connections to stock solution bottles set on shelves above the laboratory table. A gasoline camp stove with two burners was placed near the burettes. Additional equipment comprised pipettes that accurately delivered 1, 2, 5, and 10 ml., 50- or 100-ml. graduated cylinders, glass stirring rods, 125-ml. white porcelain casseroles, tongs, china marking pencils, and labels.

REAGENTS REQUIRED

Reagents required are:

1. *Caustic soda* (NaOH).—A 0.05 N (normal) solution can be purchased from a chemical supply house or is prepared in the laboratory by dissolving 2 grams of chemically pure (c. p.) NaOH in enough distilled water to make 1 liter of solution.
2. *Sulfuric acid* (H_2SO_4).—A 0.05 N solution can be purchased from a chemical supply house or is prepared in the laboratory by adding 2.45 grams c. p. H_2SO_4 to enough distilled water to make 1 liter of solution.
3. *Phenolphthalein indicator.*—A 0.5-percent solution in 50-percent neutral alcohol is prepared by mixing 50 ml. of alcohol with the same volume of distilled water and dissolving 0.5 gram of phenolphthalein in the solution.
4. *Methyl-red indicator.*—A 0.2-percent solution in 70-percent neutral alcohol is prepared by mixing 70 ml. of alcohol with 30 ml. of distilled water and dissolving 0.2 gram of methyl-red salt in the solution.
5. *Potassium iodide* (KI).—A 10-percent solution is made by dissolving 100 grams of the dry salt in a liter of distilled water.
6. *Sodium thiosulfate* ($Na_2S_2O_3.5H_2O$).—A 10-percent solution is made by dissolving 100 grams of the dry salt in a liter of distilled water.

The solutions employed as indicators and the sodium thiosulfate solution may be used most conveniently from small dropping bottles, as only a few drops are required in each sample.

ANALYTICAL PROCEDURE

Previous analyses of acid mine waters indicate that modifications of the standard methods employed by the American Public Health Association to analyze water are advisable and necessary when analyzing mine water. These differences, as set forth by R. D. Leitch in an unpublished paper, Methods of Analysis for Mine Water, are principally the substitution of N/20 caustic solution for N/50 caustic solution and methyl-red indicator for methyl-orange indicator to determine free acidity, the reduction of ferric sulfates by potassium iodide solution before determining free acidity, and the determination of total acidity at boiling point rather than at room temperature.

The procedure for analyzing mine waters is as follows:

1. *Free acidity.*—To 50 ml. or less of the sample in a white porcelain casserole add 5 ml. of the potassium iodide solution and let stand 3 minutes. Add a few drops of sodium thiosulfate solution to discharge the color of free iodine that usually appears. Dilute to 50 ml. by adding distilled water if less than that volume of sample is taken; add 4 drops of methyl-red indicator, and at room temperature titrate with the standard caustic solution to a yellow color. When titration is started it should be completed as rapidly as possible, and the addition of caustic solution should be stopped immediately on the appearance of the first distinct yellow color. The appearance of small flocs of iron hydrate indicates that the true end point has been overrun and that a more-dilute sample should be used. The addition of potassium iodide to the sample reduces the ferric sulfates to ferrous sulfates. If the potassium iodide is not added, ferric sulfate hydrolizes during titration to liberate free sulfuric acid, and abnormally high results will be obtained in the determination of free acid in the original sample.

To obtain free acidity in parts per million by weight of calcium carbonate, multiply the milliliters of standard caustic used by 50 if N/20 caustic is used and 50-ml. samples are taken.

The factor of 50 is derived as follows:

A normal solution of calcium carbonate ($CaCO_3$) contains in 1 liter of solution ½ of the molal weight of calcium carbonate in grams, or $\frac{1}{2}[40+12+(3\times16)]=50$. A N/20 solution contains 1/20 of that amount, or 2.5 grams in 1 liter of solution, or 0.0025 gram of calcium carbonate in each milliliter.

The basic reason for the use of normal solutions is to establish equivalency between equal volumes of solutions of different substances. Thus, 1 ml. of any normal caustic solution used in titration to determine free acidity is equivalent to 1 ml. of a normal calcium carbonate solution. Similarly, 1 ml. of N/20 caustic solution also is equivalent to 1 ml. of N/20 calcium carbonate solution.

Assume that the free acidity of a given sample is to be determined. When 50 ml. of this sample is used 1 ml. of N/20 caustic solution is required to titrate to the final end point. As shown above, the equivalent milliliter of N/20 calcium carbonate solution contains 0.0025 gram of calcium carbonate. A 50-ml. sample of mine water weighs approximately 50 grams. One million grams of mine water contains the equivalent of $\frac{1000000}{50}\times 0.0025$ gram, or 50 grams of calcium carbonate; therefore, a million parts of water contains an equivalent of 50 parts of calcium carbonate by weight, and each milliliter of N/20 caustic solution used in titration should be multiplied by 50 to express the free acidity in parts per million.

The pertinent factor to be applied with a titrating solution of any strength and with any volume of a given sample may be calculated in the same manner. In the foregoing determination of free acidity and in the following determinations of total acidity or total alkalinity the factor of 50 is applied when standard 50-ml. samples are used. If the volume of the sample is less than 50 ml., it is diluted to 50 ml. and the factor of 50 is corrected accordingly.

2. *Total acidity.*—To 50 ml. or less of the sample in a white porcelain casserole add 6 drops of phenolphthalein indicator. If less than 50 ml. of sample is taken, dilute with distilled water to 50 ml. Boil for 3 minutes and titrate at boiling temperature with the standard caustic solution to the first permanent pink color.

To obtain the total acidity in parts per million by weight of calcium carbonate, multiply the number of milliliters of standard caustic used by 50 if N/20 caustic is used and a 50-ml. sample is taken.

3. *Free alkalinity.*—To 50 ml. of the sample in a white porcelain casserole or to a smaller volume diluted with distilled water to 50 ml. add 4 drops of methyl-red indicator. Titrate with N/20 sulfuric acid to a pink color. The alkalinity to methyl red, expressed as parts per million, equals the number of milliliters of standard sulfuric acid used multiplied by 50, again assuming that 50 ml. of sample is used.

Samples that are alkaline to methyl red may or may not contain ferrous sulfate or other acid-forming salts, but they usually do not. To determine whether or not the sample is potentially acid, the following procedure is employed:

4. *Total alkalinity.*—To 50 ml. of the sample in a white porcelain casserole add 6 drops of phenolphthalein indicator. Boil the solution for 3 minutes. Samples that are alkaline to methyl red usually change to a pale to deep pink in less time. If the change occurs, discharge the pink with a few drops of N/20 sulfuric acid and continue boiling. As the pink reappears, continue to add acid and to rinse the casserole after each addition of acid until the colorless end point is reached. It is frequently necessary to boil the sample almost to dryness before a permanent end point is reached. The sum of the successive amounts of standard sulfuric acid in milliliters, multiplied by 50 when N/20 sulfuric acid is used, is the equivalent alkalinity to phenolphthalein in parts per million of calcium carbonate.

METHODS OF SAMPLING

Samples of water were collected in 8-ounce narrow-mouthed rectangular bottles having molded resin screw caps. A composition liner in the cap acted as a gasket for tight sealing and protected the liquid from chemical action.

Samples of surface water usually were collected from rivers that are too wide and too deep to wade, except near the headwaters at very low water periods, and it was necessary to "fish" for the samples from predetermined places on bridges spanning the rivers. The sampling bottle was attached to a heavy cord by means of a large rubber band and was weighted with a 10-pound weight. The bottle was allowed to submerge to the bottom of the river and was then drawn to the surface. As the neck of the bottle was small, two or more submersions were required to fill it with a representative sample at each sampling point.

Cross-section sampling of the rivers was conducted at each gaging station during the initial stages of the investigation, and the analytical results at any one sampling point were analogous for all lateral points; consequently, only one sample from the middle of the river at each gaging station was deemed necessary. Where highly acid mine drainage is discharged into the receiving stream just above a sampling point, cross-section sampling might conceivably indicate widely different results; however, all the sampling points in this investigation were selected in areas where the river water was well-mixed to avoid false indications from purely local effects of acid mine drainage on the receiving streams.

Samples of mine-water discharges were collected at drainage-tunnel portals and at pump-discharge points by means of grab samples in 8-ounce bottles. The sampling areas were small in comparison with those of the rivers, and a representative sample could be collected by this method at each discharge point.

Although it is desirable to analyze samples of mine water at the time they are collected, this was not feasible in the anthracite region because transportation of laboratory apparatus was impracticable.

Tests were made on both acid and alkaline water to determine whether or not the *p*H changes when a sample of water is allowed to stand for several days. The data shown in table 3 indicate that (1) samples that are alkaline remain more stable than samples that are acid and (2) if any delay in analysis is necessary, all samples should be analyzed the day following their collection.

TABLE 3.—*Results of tests to determine change in acidity or alkalinity of samples after different intervals of time*

Sample location	Date collected	Date analyzed	*p*H	Change
Lackawanna River at Archbald	Aug. 4	Aug. 5	3.40	
Do.	do.	Aug. 7	3.25	−0.15
Do.	do.	Aug. 9	3.00	−.40
Lackawanna River at Scranton	do.	Aug. 5	3.60	
Do.	do.	Aug. 7	3.30	−.30
Do.	do.	Aug. 9	3.00	−.60
Lackawanna River at Old Forge	do.	Aug. 5	3.40	
Do.	do.	Aug. 7	3.25	−.15
Do.	do.	Aug. 9	2.95	−.45
Susquehanna River at Towanda	July 29	July 30	8.60	
Do.	do.	Aug. 1	8.55	−.05
Do.	do.	Aug. 5	8.35	−.25
Susquehanna River at Wilkes-Barre	do.	July 30	7.40	
Do.	do.	Aug. 1	7.40	None
Do.	do.	Aug. 5	7.90	+.50
Susquehanna River at Shickshinny	do.	July 30	7.10	
Do.	do.	Aug. 1	7.20	+.10
Do.	do.	Aug. 5	7.70	+.60
Susquehanna River at Danville	do.	July 30	7.10	
Do.	do.	Aug. 1	7.00	−.10
Do.	do.	Aug. 5	7.20	+.10

In this investigation the samples were not analyzed immediately after they were collected. Because some samples were collected within a mile of headquarters and others from points as far distant as 150 miles, considerable time would have elapsed between the collection and the analysis of certain samples or of groups of samples, and only a short time would have elapsed between the collection and analysis of other samples. Inasmuch as the *p*H of a sample of mine water changes after it is collected, analyses of samples from widely separated points, made at different intervals of time after the samples were collected, would not be strictly comparable.

It was decided that samples collected one day should be analyzed the following day, regardless of the distance between headquarters and the sampling point. This plan resulted in a uniform lapse of time (approximately 24 hours) between the collection and analysis of each sample. The results, though not indicating the exact conditions at the time of collection, are comparable.

CHEMICAL ANALYSIS OF SURFACE WATER

The most significant findings of the acid mine-drainage investigation are the indications concerning the acidity or alkalinity of the major streams in the anthracite region. Sampling of streams was confined to the Susquehanna, Lackawanna, Lehigh, Schuylkill, and Little Schuylkill Rivers. Water from these rivers was sampled several times along the course of the streams at sampling points both upstream and downstream from the coal measures as well as in them. Figure 3 is a vicinity map showing the major rivers affected by mine drainage in the anthracite region.

Although many mine-drainage discharges flow directly into comparatively small streams, all the mine drainage in the region eventually finds its way into the Susquehanna River, Lehigh River, or Schuylkill River.

The North Branch of the Susquehanna River flows through Towanda, Wilkes-Barre, and Danville, Pa., and joins the West Branch at Northumberland, Pa. It receives mine drainage directly or indirectly from mines and tunnels in the Northern, Eastern Middle, and Western Middle fields.

The Susquehanna River below the confluence of North and West Branches at Northumberland flows through Harrisburg and Columbia, Pa., and thence into Chesapeake Bay; it receives mine drainage from the Western Middle field and the Southern field. Mine drainage enters the Susquehanna River as far downstream as Middletown, Pa., 15 miles below Harrisburg.

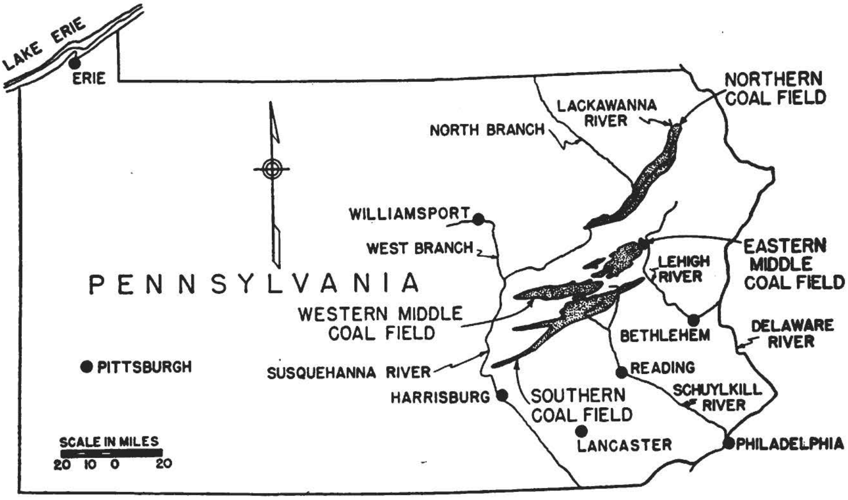

FIGURE 3.—Vicinity map showing the major rivers affected by mine drainage in the anthracite region.

The Lackawanna River flows through Uniondale, Carbondale, Scranton, and Old Forge, Pa. It is one of the main tributaries of the North Branch of the Susquehanna River.

The Lehigh River flows through Lehigh Tannery, Bethlehem, and thence to Easton, Pa., where it joins the Delaware River. It receives mine drainage from the Eastern Middle field and the southeastern part of the Southern field.

The Schuylkill River flows through Pottsville, Port Clinton, Hamburg, Pottstown, and Philadelphia, Pa.; it receives mine drainage from the Southern field. The Little Schuylkill River is a major tributary of the Schuylkill River.

The major streams in the anthracite region also receive sewage and industrial wastes from large and small towns along their banks and in their drainage basins. It became obvious early in the investigation that isolation of the effects of acid drainage from any particular mine or from any particular group of mines on the receiving streams would be impossible. The only practicable procedure by which such effects could be ascertained was (1) to collect and analyze samples of water from different sampling points along each of the rivers and (2) to determine how the *p*H of the water changed without attempting to fix the responsibility for such changes on any particular mine or group of mines. Sampling points were selected where the Commonwealth of Pennsylvania maintains gaging stations along these rivers; because of their interest, several sampling points also were selected where no gaging stations exist.

Surface waters were sampled by the Bureau of Mines in 1941 and 1946. The State Planning Board, Pennsylvania Department of Commerce, in cooperation with the Pennsylvania Department of Forests and Waters and the United States Geological Survey has been analyzing surface waters in the State since June 1, 1944, to ascertain both the quantity and quality of surface waters—a dominating factor in the establishment and expansion of industries throughout the State.

The *p*H and the free and total acidity or free and total alkalinity of each river sample are shown in table 4. The table includes results of Bureau of Mines tests made in 1941 and 1946 and the results of tests made by the Commonwealth of Pennsylvania and the United States Geological Survey during high- and low-water periods from July 1, 1944, to May 31, 1945.

TABLE 4.—*Comparison of stream conditions of major rivers affected by acid mine-water drainage in the anthracite region*

Date of collection	Discharge		*p*H	Free acidity or free alkalinity as $CaCO_3$, p. p. m. (methyl-red indicator)	Total acidity or total alkalinity as $CaCO_3$, p. p. m. (phenolphthalein indicator)
	Sec.-ft.	G. p. m.			
Lackawarna River at Uniondale, Pa.:					
July 11, 1941	No gaging station		7.60	16 alk.	18 alk.
Oct. 8, 1941			5.60	28 alk.	30 alk.
Dec. 2, 1941			6.90	17 alk.	17 alk.
Aug. 5, 1946			7.40	40 alk.	38 alk.
Aug. 16, 1946			7.20	15 alk.	20 alk.
Average	----	----	6.25	23.2 akl.	24.6 alk.
Lackawanna River at Archbald, Pa.:					
July 20, 1944 (low)[1]	48.1	21,587	3.50	----	----
Mar. 31, 1945 (high)[1]	199	89,311	4.00	----	----
Aug. 5, 1946	120	53,856	4.20	15 acid	35 acid
Aug. 16, 1946	56	25,132	3.70	45 acid	80 acid
Average	----	----	3.90	24.5 acid	46.0 acid
Lackawanna River at Dickson City, Pa.:					
Aug. 5, 1946	----	----	3.60	60 acid	120 acid
Aug. 16, 1946	----	----	3.60	60 acid	130 acid
Average	----	----	3.60	60 acid	125.0 acid
Lackawanna River at Old Forge, Pa.:					
July 11, 1941	265	118,932	2.60	96 acid	243 acid
Oct. 8, 1941	114	----	3.30	129 acid	424 acid
Dec. 2, 1941	120	----	3.50	40 acid	219 acid
Aug. 5, 1946	481	215,872	3.40	75 acid	130 acid
Aug. 16, 1946	336	150,797	3.20	75 acid	205 acid
Average	----	----	3.05	83.0 acid	244.0 acid
Susquehanna River at Towanda, Pa.:					
June 5, 1941	3,060	1,373,328	8.10	43 alk.	45 alk.
July 14, 1941	996	447,005	7.70	48 alk.	41 alk.
Oct. 2, 1941	468	210,038	7.50	75 alk.	66 alk.
Nov. 23, 1941	1,510	677,688	8.10	56 alk.	51 alk.
July 21, 1944 (low)[1]	1,570	704,616	7.70	----	----
Mar. 28, 1945 (high)[1]	26,000	11,668,800	6.60	----	----
July 29, 1946	3,630	1,629,144	8.60	70 alk.	65 alk.
Aug. 12, 1946	4,700	2,109,360	7.80	55 alk.	55 alk.
Aug. 21, 1946	3,700	1,660,560	7.70	60 alk.	65 alk.
Average	----	----	6.85	52.5 alk.	52.3 alk.

See footnotes at end of table.

TABLE 4.—*Comparison of stream conditions of major rivers affected by acid mine-water drainage in the anthracite region*—Continued

Date of collection	Discharge		*p*H	Free acidity or free alkalinity as $CaCO_3$, p. p. m. (methyl-red indicator)	Total acidity or total alkalinity, as $CaCO_3$ p. p. m. (phenolphthalein indicator)
	Sec.-ft.	G. p. m.			
Susquehanna River at Wilkes-Barre, Pa.:					
June 6, 1941	6,300	2,827,440	7.30	30 alk.	34 alk.
July 15, 1941	1,600	718,080	6.70	19 alk.	17 alk.
Oct. 3, 1941	693	311,018	6.80	15 alk.	19 alk.
Nov. 24, 1941	2,020	906,576	7.30	36 alk.	41 alk.
July 29, 1944 (low)[1]	2,010	902,088	6.70	-----------	-----------
Aug. 4, 1945 (high)[1]	22,900	10,277,520	7.10	-----------	-----------
July 29, 1946	5,770	2,589,576	7.40	40 alk.	40 alk.
Aug. 12, 1946	6,840	3,069,792	7.00	30 alk.	25 alk.
Aug. 21, 1946	6,300	2,827,440	6.90	25 alk.	30 alk.
Average	-----------	-----------	7.05	30.3 alk.	31.4 alk.
Susquehanna River at Danville, Pa.:					
June 6, 1941	5,850	2,625,480	7.20	9 alk.	11 alk.
July 15, 1941	2,100	942,480	6.30	Neutral	5 acid
Oct. 3, 1941	1,010	453,288	4.70	13 acid	45 acid
Nov. 24, 1941	2,380	1,068,144	7.50	17 alk.	24 alk.
July 29, 1946	7,140	3,204,432	7.10	15 alk.	5 alk.
Aug. 12, 1946	8,740	3,922,512	7.10	10 alk.	10 alk.
Aug. 21, 1946	7,900	3,545,520	7.10	15 alk.	15 alk.
Nov. 19, 1946	5,070	2,275,416	7.50	35 alk.	40 alk.
Average	-----------	-----------	6.10	14.2 alk.	12.7 alk.
Susquehanna River (West Branch) at Northumberland Pa.:					
Nov. 19, 1946	[2] 3,490	[2] 1,566,312	6.60	5 alk.	15 alk.
Susquehanna River at Sunbury, Pa.:					
Aug. 8, 1944 (low)[1]	3,350	1,503,480	5.70	-----------	-----------
Mar. 16, 1945 (high)[1]	76,900	34,512,720	6.80	-----------	-----------
Nov. 19, 1946	8,900	3,949,320	7.20	40 alk.	35 alk.
Average	-----------	-----------	6.70	40.0 alk.	35.0 alk.
Susquehanna River at Harrisburg, Pa.:					
July 22, 1941	6,480	2,908,224	6.50	Neutral	5 acid
Oct. 5, 1941	2,580	1,157,904	6.30	41 alk.	47 alk.
Nov. 25, 1941	6,350	2,849,880	7.70	32 alk.	36 alk.
Oct. 11–20, 1944 (low)[1]	7,490	3,361,512	7.00	-----------	-----------
Mar. 21–31, 1945 (high)[1]	125,000	56,100,000	6.70	-----------	-----------
July 31, 1946	10,100	4,532,880	6.70	15 alk.	5 alk.
Aug. 14, 1946	14,400	6,462,720	7.20	15 alk.	10 alk.
Aug. 27, 1946	8,680	3,888,640	6.90	10 alk.	10 alk.
Average	-----------	-----------	6.75	15.7 alk.	12.3 alk.
Susquehanna River at Columbia, Pa.:					
Nov. 21, 1946	[2] 12,300	[2] 5,520,240	7.40	35 alk.	45 alk.
Lehigh River at Lehigh Tannery, Pa.:					
July 16, 1941	342	153,490	5.00	Neutral	5 acid
Oct. 22, 1941	119	53,407	7.30	2 alk.	2 alk.
Nov. 26, 1941	201	90,209	6.70	2 alk.	2 alk.
July 29, 1944 (low)[1]	158	70,910	6.60	-----------	-----------
Apr. 2, 1945 (high)[1]	770	345,576	5.90	-----------	-----------
Aug. 6, 1946	148	66,422	7.00	5 alk.	5 acid
Aug. 19, 1946	420	188,496	6.90	5 alk.	2 acid
Average	-----------	-----------	5.65	2.85 alk.	2.13 acid
Lehigh River at Catasauqua, Pa.:					
Oct. 11–20, 1944 (low)[1]	426	191,189	7.10	-----------	-----------
Mar. 21–31, 1945 (high)[1]	2,680	1,202,784	5.90	-----------	-----------
Average	-----------	-----------	5.95	-----------	-----------
Lehigh River at Bethlehem, Pa.:					
July 16, 1941	1,270	569,976	6.80	2 alk.	4 alk.
Oct. 22, 1941	476	213,629	7.00	36 alk.	43 alk.
Nov. 26, 1941	685	307,428	7.60	15 alk.	11 alk.
Aug. 6, 1946	1,040	466,752	7.40	30 alk.	35 alk.
Aug. 19, 1946	2,850	1,279,080	7.20	25 alk.	20 alk.
Average	-----------	-----------	7.10	20.9 alk.	22.7 alk.
Schuylkill River at Tuscarora, Pa.:					
July 31, 1946	-----------	-----------	3.70	55 acid	80 acid
Aug 27, 1946	-----------	-----------	3.80	105 acid	170 acid
Average	-----------	-----------	3.75	80.0 acid	125.0 acid
Schuylkill River at Port Clinton, Pa.					
July 24, 1941	No gaging station		3.70	24 acid	76 acid
Oct. 21, 1941			4.60	16 acid	90 acid
Dec. 1, 1941			4.30	11 acid	47 acid
July 31, 1946			4.30	40 acid	80 acid
Aug. 14, 1946			4.30	25 acid	65 acid
Aug. 27, 1946			4.60	30 acid	60 acid
Average	-----------	-----------	4.20	24.0 acid	70.0 acid

See footnotes at end of table.

TABLE 4.—*Comparison of stream conditions of major rivers affected by acid mine-water drainage in the anthracite region*—Continued

Date of collection	Discharge		pH	Free acidity or free alkalinity as $CaCO_3$, p. p. m. (methyl-red indicator)	Total acidity or total alkalinity as $CaCO_3$, p. p. m. (phenolphthalein indicator)
	Sec.-ft.	G. p. m.			
Schuylkill River at Pottstown, Pa.:					
July 24, 1941	481	215,873	6.60	17 alk.	17 alk.
Oct. 21, 1941	272	122,074	7.10	44 alk.	54 alk.
Dec. 1, 1941	321	144,065	7.50	39 alk.	26 alk.
Oct. 11-20, 1944 (low)[1]	442	198,370	7.00		
Mar. 21-31, 1945 (high)[1]	2,180	978,384	6.70		
Aug. 7, 1946	720	323,136	7.10	40 alk.	35 alk.
Aug. 19, 1946	2,710	1,216,248	6.90	20 alk.	10 alk.
Average			6.85	25.7 alk.	18.5 alk.
Schuylkill River at Philadelphia, Pa.:					
Oct. 24, 1946	410	184,008	7.40	45 alk.	50 alk.
Little Schuylkill River at Port Clinton, Pa.:					
July 24, 1941	No gaging station		3.30	76 acid	145 acid
Oct. 21, 1941			4.40	68 acid	166 acid
Dec. 1, 1941			4.30	98 acid	187 acid
July 31, 1946			4.00	70 acid	105 acid
Aug. 14, 1946			4.10	80 acid	150 acid
Aug. 27, 1946			4.10	95 acid	160 acid
Average			3.85	81.0 acid	152.0 acid
Delaware River at Philadelphia, Pa.:					
Oct. 24, 1946	5,330	2,392,104	7.40	40 alk.	45 alk.

[1] Samples taken by the U. S. Department of the Interior, Geological Survey, Water Resources Branch, and the Pennsylvania Hydrographic Service, Department of Forests and Waters.

[2] Estimated.

Table 4 shows that the *p*H of samples of river water collected at the same point generally are comparable. When volumes of flow at a given sampling point are approximately the same at different sampling times, the *p*H of the river water at those times compares closely. Free and total acidity or free and total alkalinity of the river waters, as determined by chemical analyses in 1941 and 1946, are nearly the same for comparable volumes of flow.

Considering the differences in the volume of flow at different times, table 4 shows two points of importance:

1. Changes in the acidity or the alkalinity of the river water, as indicated either by its *p*H or by analytical determinations of free and total acidity or free and total alkalinity, cannot be predicted by changes in the volume of flow. In some instances decreased volumes of flow accompany decreased alkalinity or increased acidity, whereas in others decreased volumes of flow accompany increased alkalinity or decreased acidity.
2. The changes in free and total acidity or free and total alkalinity (in parts per million) are much less marked than the corresponding changes in the volume of flow. For example, when the volume of flow changed in the ratio of 6:1 or more the acidity or alkalinity changed only in a ratio of 2:1 or less (table 4). The greatest acidity or alkalinity in many instances was less than 50 parts per million and in almost all instances was less than 100 parts per million. Apparently, the relative concentration of acidity or alkalinity of river water remains essentially constant regardless of the variation in the volume of flow.

Table 4 shows the general condition of the major streams in the anthracite region with respect to the acidity or alkalinity of the water at specific times over a period of 5 years from 1941 to 1946 and emphasizes the following points:

1. The Susquehanna River was always alkaline at all points, except during low-water periods in July and October 1941, when samples at Danville indicated an acid condition at that point, and at Harrisburg in July 1941, when the river water was slightly acid. This river throughout its length receives a larger quantity of acid mine drainage than any other stream in the region, but the samples at Wilkes-Barre, Danville, and Harrisburg showed that the water was normally alkaline and had only a slight tendency, if any, to become acid.

Analysis of a sample of water taken in November 1946 from the West Branch of the Susquehanna River just above the point of confluence with the North Branch of the river showed that the water in the West Branch at that point was also alkaline. The West Branch does not flow through the anthracite region but does receive acid mine drainage from bituminous-coal mines in central Pennsylvania.

2. The Lehigh River at Lehigh Tannery was slightly alkaline at all times but on two occasions showeds ome acidity. Samples collected from the Lehigh River at Bethlehem, 30 miles below the coal measures, indicated that the river water was alkaline at that point at all times. The Lehigh River is a tributary of the Delaware River, joining it at Easton, Pa.

3. The Schuylkill River was acid at its headwaters near Tuscarora, Pa., but the Little Schuylkill River was alkaline at its headwaters near Hometown. Both streams were acid at their junction at Port Clinton, but at Hamburg, 14 miles below the anthracite region, the Schuylkill River was alkaline. Samples taken at Pottstown and Philadelphia were alkaline, and chemical analysis by hot titration indicated even greater alkalinity.

4. The Lackawanna River was alkaline at its headwaters near Uniondale, Pa., but became and remained acid as it passed through Archbald, Scranton, and Old Forge to the point of confluence with the Susquehanna River near Pittston. However, the comparatively small volume of highly acid water in the Lackawanna River was diluted after its confluence with the Susquehanna River, and samples at Wilkes-Barre indicated a river water that was nearly neutral.

5. A sample collected from the Delaware River in Philadelphia in October 1946 showed that the river was alkaline at that point.

6. The effects of acid mine drainage entering the Lehigh, Schuylkill, and Susquehanna Rivers rapidly disappear. These streams receive undeterminable quantities of sewage and industrial wastes along their entire course above, in, and below the anthracite region. Moreover, the Susquehanna River, after leaving the anthracite region, flows for 17.5 miles through limestone areas lying between the coal measures and Harrisburg; the Lehigh River flows for 21 miles through limestone areas lying between Lehigh Tannery and Easton; and the Schuylkill River flows for 48 miles through limestone areas lying along its course. The acid in the mine drainage reacts with and is neutralized by the sewage and industrial wastes discharged into the

rivers and is further neutralized by the limestone through which the rivers flow.

7. This investigation shows that the main streams and rivers that flow through the anthracite region are nearly always alkaline at all points within the anthracite region itself; moreover, short distances below the coal measures the rivers are permanently alkaline.

Under present conditions acid mine drainage appears to be beneficial rather than detrimental to the municipalities along the banks and scattered over the drainage basins of the Lehigh, Schuylkill, and Susquehanna Rivers because of its neutralizing action on the highly alkaline sewage and industrial wastes in the receiving streams.

Sludge and other residues that settle on the river beds as a result of the chemical reaction between the acid and alkaline contaminants in the streams are undesirable. The germicidal, inhibiting, and neutralizing effects of acid mine drainage are not controlled and are not consistent. In addition to the fact that there is no practicable means of treatment known, there is also no incentive or justification for treatment or diversion of acid mine drainage if the receiving streams remain unsuitable for any use other than disposal of sewage and industrial wastes (*23*).

Streams are polluted not only by the anthracite-mining industry but also by other industries and communities that utilize the streams for their own purposes. The control of stream pollution is the responsibility of all communities and industries that could be considered as offenders.

DETERMINATION OF AVERAGE *p*H

The importance of acid mine drainage in the anthracite region will increase rather than diminish with continued activity in the anthracite-mining industry. Because *p*H is used to show the relation of mine drainage to the chemical characteristics of the receiving streams, it is necessary to explain the method by which the average *p*H of the receiving streams is determined.

When samples of water are taken at a given gaging station at frequent and regular intervals over an extended period of time, the most probable *p*H of river water at the gaging station can be considered the *p*H that is found the greatest number of times.

The water samples shown in table 4 were taken during 1941, 1945, and 1946 at gaging stations along the rivers that pass through the anthracite region. Comparatively few samples were taken at each gaging station, and these were not taken at regular intervals. For example, eight water samples of the North Branch of the Susquehanna River were taken at Danville, Pa., in June, July, October, and November, 1941, and in July, August, and November, 1946; therefore it is not justifiable to select 7.1, the *p*H that appears the greatest number of times in the eight samples, as the most probable *p*H of the river water at Danville.

The average *p*H of a number of river-water samples collected at different times at a gaging station cannot be computed simply by dividing the sum of the numerical values of *p*H by the number of samples collected at that station. Because *p*H is a logarithm, this method of computation gives the *n*th root of the product of *n* numbers represented by the respective *p*H of each, where *n* is any number of samples for which it is desired to obtain the average *p*H. Obviously, such a method of determining an average cannot be justified mathematically.

The average *p*H of river water at the gaging stations shown in table 4 is determined in four steps in the following manner:

1. Determine the hydrogen-ion concentration of each water sample from its *p*H.
2. Weight the hydrogen-ion concentration of each sample according to the volume of stream flow by multiplying the hydrogen-ion concentration of each sample by the volume of stream flow at the time the sample was taken.
3. Compute the average hydrogen-ion concentration of all the samples by adding the weighted hydrogen-ion concentrations of the individual samples and dividing the sum by the total volume of flow for all the samples.
4. Determine the *p*H that corresponds to the average hydrogen-ion concentration. This value is the average *p*H of the stream at that gaging station.

Steps 1 and 4 can be computed from the basic equation corresponding to the definition of *p*H, but simple formulas to determine either *p*H or hydrogen-ion concentration have been derived from the basic equation.

Sørensen (*19*) has defined *p*H as the negative logarithm of the hydrogen-ion concentration $[H^+]$, or

$$pH = -\log_{10} [H^+]. \qquad (1)$$

Equation 1 is perhaps the most-simple mathematical expression of the relationship between *p*H and hydrogen-ion concentration, but the solution of this equation involves several steps and the use of negative logarithms.

The real value of *p*H is always positive and may be considered to consist of two parts—a whole number and a decimal fraction.

Let

$$x = \text{the whole number}$$

and

$$a = \text{the decimal fraction},$$

so that

$$pH = x.a,$$

or

$$pH = x + a, \qquad (2)$$

where x and a are always positive numbers.

Substituting in equation 1 the value of *p*H as expressed in equation 2,

$$pH = -\log_{10} [H^+],$$

$$x + a = -\log_{10} [H^+],$$

or

$$\log_{10} [H^+] = -x - a. \qquad (3)$$

Then

$$[H^+] = 10^{-x-a},$$

or

$$[H^+] = 10^{-x} \times 10^{-a}, \qquad (4)$$

where $[H^+]$ is expressed as a power of 10.

Tables of the common system of logarithms, that is, logarithms to the base 10, give only positive mantissas, so that it is inconvenient to evaluate a negative mantissa as required in equation 4. To obtain a positive mantissa as the antilog of $-a$, 10^{-a} can be written as

$$10^{-a}=10^{-1+(1-a)},$$

and equation 4 becomes

$$[\mathrm{H}^+]=10^{-x}\times 10^{-1+(1-a)},$$

or

$$[\mathrm{H}^+]=\frac{10^{1-a}}{10}\times 10^{-x}, \tag{5}$$

where $p\mathrm{H}=x.a$ or $x+a$.

The hydroxyl-ion concentration $[\mathrm{OH}^-]$ also may be computed directly from the known value of pH. By definition (*8*)

$$[\mathrm{H}^+]\times[\mathrm{OH}^-]=1\times 10^{-14},$$

or

$$[\mathrm{OH}^-]=\frac{10^{-14}}{[\mathrm{H}^+]}. \tag{6}$$

Substituting in equation 6 the value of $[\mathrm{H}^+]$, as expressed in equation 4,

$$[\mathrm{OH}^-]=\frac{10^{-14}}{[\mathrm{H}^+]}$$

$$[\mathrm{OH}^-]=\frac{10^{-14}}{10^{-x-a}},$$

or

$$[\mathrm{OH}^-]=10^{-14}\times 10^{x}\times 10^{a}, \tag{7}$$

where $p\mathrm{H}=x.a$ or $x+a$.

A simple formula for determining pH from a known hydrogen-ion concentration also may be developed from equation 1. The hydrogen-ion concentration first is expressed as a number between 1 and 10 times the proper power of 10. The common logarithm of $[\mathrm{H}^+]$, then, is written as

$$\log_{10}[\mathrm{H}^+]=-y+b,$$

or

$$y-b=-\log_{10}[\mathrm{H}^+], \tag{8}$$

where $-y$ is the characteristic that ranges from 0 to -14 and b is the mantissa that ranges from 0 to 0.999+.

Because

$$p\mathrm{H}=-\log_{10}[\mathrm{H}^+]$$

and

$$y-b=-\log_{10}[\mathrm{H}^+],$$

then

$$p\mathrm{H}=y-b, \tag{9}$$

where the hydrogen-ion concentration is expressed as a number between 1 and 10 times the proper power of 10, $-y$ is the real value of the characteristic of the hydrogen-ion concentration thus expressed and is also the real value of the exponent in the power of 10, and b is the common logarithm of that portion of the hydrogen-ion concentration expressed as a number between 1 and 10.

In equation 9 the minus sign is not an expression of a negative mantissa but indicates the subtraction of a positive mantissa from a positive characteristic.

The application of formulas 5, 7, and 9 is demonstrated in the following examples:

Example 1: The analysis of a sample of river water shows that the pH of the water is 7.85. What are the hydrogen-ion and hydroxyl-ion concentrations?

Solution: When $p\text{H}=7.85$, then $x=7$ and $a=0.85$. Applying formula 5, or

$$[\text{H}^+]=\frac{10^{1-a}}{10}\times 10^{-x}$$

$$[\text{H}^+]=\frac{10^{1-0.85}}{10}\times 10^{-7}$$

$$[\text{H}^+]=\frac{10^{0.15}}{10}\times 10^{-7}$$

$$[\text{H}^+]=\frac{1.412}{10}\times 10^{-7}$$

$$[\text{H}^+]=0.14123\times 10^{-7}.$$

Applying formula 7, or

$$[\text{OH}^-]=10^{-14}\times 10^{x}\times 10^{a}$$

$$[\text{OH}^-]=10^{-14}\times 10^{7}\times 10^{0.85}$$

$$[\text{OH}^-]=10^{-7}\times 10^{0.85}$$

$$[\text{OH}^-]=7.075\times 10^{-7}.$$

Example 2: The hydrogen-ion concentration of a sample of river water is 0.14123×10^{-7}. What is the pH of the water?

Solution: Rewriting the hydrogen-ion concentration as a number between 1 and 10 times the applicable power of 10,

$$[\text{H}^+]=1.4123\times 10^{-8}.$$

Then,

$$b=\log_{10}1.4123,$$

or

$$b=0.15$$

and

$$-y=\log 10^{-8},$$

or

$$-y=-8.$$

Applying formula 9, or

$$p\text{H}=y-b,$$

$$p\text{H}=8-0.15$$

$$p\text{H}=7.85.$$

The hydroxyl-ion concentration seldom is reported in the routine analyses of mine waters or of river waters receiving acid mine drainage and need not be known when the hydrogen-ion concentration is known. The formula to determine the hydroxyl-ion concentration has been developed above merely as a matter of interest in the consideration of pH and hydrogen-ion-concentration relationships.

Table 5 shows in general form the numerical value of hydrogen-ion and hydroxyl-ion concentration for all values of pH between 0 and

14 in steps of 0.05 *p*H. The value of x is the whole-number part of *p*H where *p*H is expressed as $x.a$ or $x+a$.

TABLE 5.—*Relationship of* [H⁺] *and* [OH⁻] *to* pH *(on the assumption that* $pH = log\ \frac{1}{[H^+]}$)

*p*H	$[H^+]$	$[OH^-]$	*p*H	$[H^+]$	$[OH^-]$
$x.00$	1.00×10^{-x}	$0.10\times10^{-13+x}$	$x.55$	0.28×10^{-x}	$0.36\times10^{-13+x}$
$x.05$	$.89\times10^{-x}$	$.11\times10^{-13+x}$	$x.60$	$.25\times10^{-x}$	$.40\times10^{-13+x}$
$x.10$	$.79\times10^{-x}$	$.13\times10^{-13+x}$	$x.65$	$.22\times10^{-x}$	$.45\times10^{-13+x}$
$x.15$	$.71\times10^{-x}$	$.14\times10^{-13+x}$	$x.70$	$.20\times10^{-x}$	$.50\times10^{-13+x}$
$x.20$	$.63\times10^{-x}$	$.16\times10^{-13+x}$	$x.75$	$.18\times10^{-x}$	$.56\times10^{-13+x}$
$x.25$	$.56\times10^{-x}$	$.18\times10^{-13+x}$	$x.80$	$.16\times10^{-x}$	$.63\times10^{-13+x}$
$x.30$	$.50\times10^{-x}$	$.20\times10^{-13+x}$	$x.85$	$.14\times10^{-x}$	$.71\times10^{-13+x}$
$x.35$	$.45\times10^{-x}$	$.22\times10^{-13+x}$	$x.90$	$.13\times10^{-x}$	$.79\times10^{-13+x}$
$x.40$	$.40\times10^{-x}$	$.25\times10^{-13+x}$	$x.95$	$.11\times10^{-x}$	$.89\times10^{-13+x}$
$x.45$	$.36\times10^{-x}$	$.28\times10^{-13+x}$	$x+1.00$	$.10\times10^{-x}$	$1.00\times10^{-13+x}$
$x.50$	$.32\times10^{-x}$	$.32\times10^{-13+x}$			

Table 5 was prepared by computing the hydrogen-ion and hydroxyl-ion concentrations for each general value of *p*H shown. The use of this table where known *p*H, hydrogen-ion concentrations, or hydroxyl-ion concentrations are listed eliminates the necessity of performing the computations for each sample. Again, the hydroxyl-ion concentration serves no direct purpose in the determination of *p*H or of hydrogen-ion concentration but is included as a matter of interest.

Table 5 may be used in the solution of examples 1 and 2, page 18.

In example 1, where the *p*H of the sample is known to be 7.85, the value of x in the table is 7 and in the *p*H column $x.85$ is read as 7.85. The corresponding hydrogen-ion concentration is read immediately in the $[H^+]$ column as $0.14\times10^{-x}=0.14\times10^{-7}$. The hydroxyl-ion concentration is read in the $[OH^-]$ column as $0.71\times10^{-13+x}=0.71\times10^{-13+7}=0.71\times10^{-6}$.

In example 2, where the hydrogen-ion concentration of the sample is known to be 0.14123×10^{-7}, $-x=-7$ and 0.14×10^{-x} in the $[H^+]$ column is read as 0.14×10^{-7}. In the *p*H column the corresponding *p*H of $x.85$ is read immediately as 7.85.

GRAPHIC METHOD OF DETERMINING AVERAGE *p*H

The determination of hydrogen-ion concentration from *p*H or *p*H from hydrogen-ion concentration is developed further in graphic form in figure 4. Where the average *p*H of a number of samples is desired several steps of mathematical computation are saved by using figure 4.

The exponential curve defined by equation 1,

$$pH = -log_{10}\,[H^+],$$

is reduced to a straight line (fig. 4) by plotting on semilogarithmic graph paper the relationships expressed in the equation. The values of *p*H are plotted on the abscissa axis (OX), and the hydrogen-ion concentration in grams per liter times 10^7 are plotted on the ordinate axis (OY). Figure 4 shows only that part of the straight line between

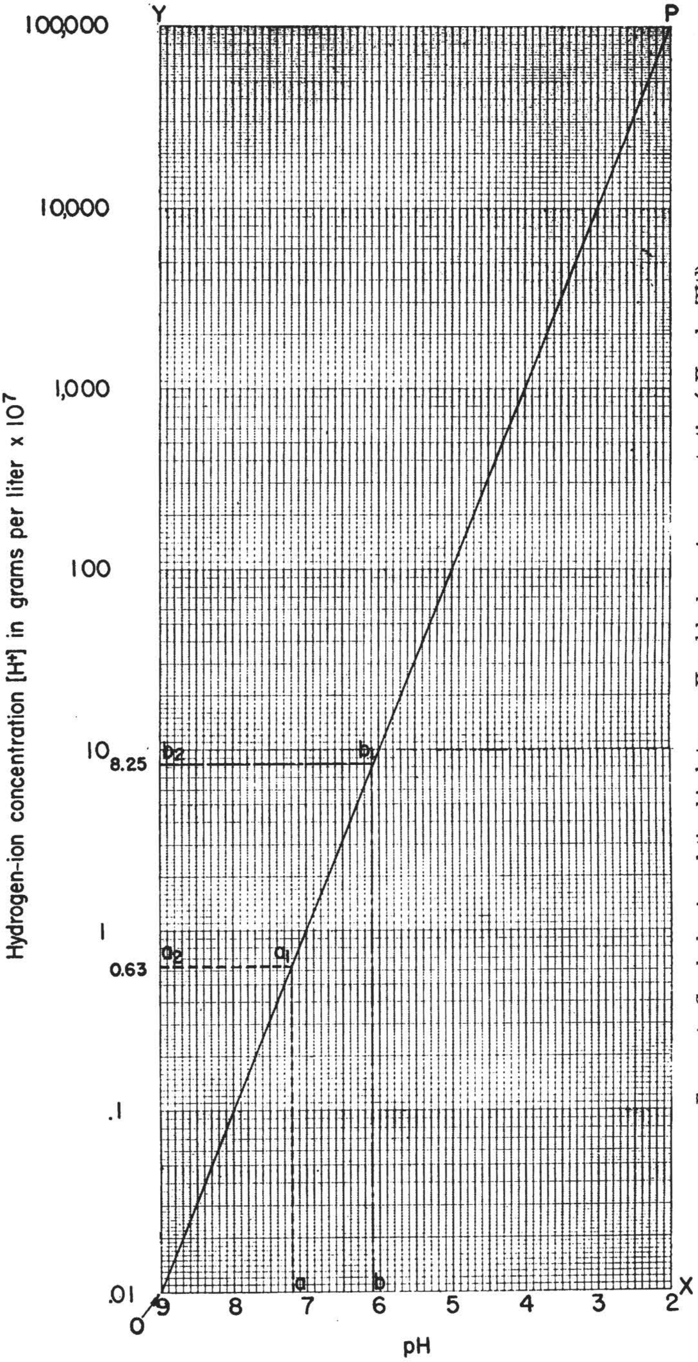

FIGURE 4.—Graph showing relationship between pH and hydrogen-ion concentration ($pH = -\log [H^+]$).

the points *p*H=2.0 and *p*H=9.0, the maximum range of *p*H observed in this investigation.

The average *p*H of the eight river-water samples taken at Danville can be determined by the use of a graph as follows:

Figure 4 is used to determine graphically the hydrogen-ion concentration from the *p*H of a given water sample. For example, the first sample of river water taken at Danville and shown in table 6 has a *p*H of 7.2. The hydrogen-ion concentration is obtained by constructing line aa_1 parallel to OY from the point 7.2 on the abscissa axis to the intersection with line OP. From point a_1 a line is constructed parallel to OX to intersect OY at point a_2. Point a_2 is the hydrogen-ion concentration, or 0.63×10^{-7}. In a similar manner the hydrogen-ion concentration can be determined from the *p*H value for all the samples taken at Danville.

The weighted hydrogen-ion concentration of each sample shown in table 6 is obtained by multiplying its hydrogen-ion concentration by the volume of stream flow at the time the sample was taken. The average hydrogen-ion concentration of all the samples is obtained by adding the weighted hydrogen-ion concentration of the individual samples and dividing this sum by the total volume of the stream flow of all the samples.

The average *p*H is determined graphically from the corresponding average hydrogen-ion concentration by using figure 4. The average hydrogen-ion concentration for the eight samples taken at Danville is 8.25×10^{-7}.

From a point 8.25 on the ordinate axis line b_2b_1 is constructed parallel to OX, intersecting line OP at b_1. Line b_1b is then constructed parallel to OY, intersecting OX at point b. Point b equals a *p*H of 6.1, which is the average *p*H of the eight samples taken at Danville.

TABLE 6.—*Calculations for determining average* pH, *average free acidity or alkalinity, and average total acidity or alkalinity of river-water samples taken from the Susquehanna River at Danville, Pa.*

Volume of stream flow, g. p. m.	*p*H	Hydrogen-ion concentration $[H^+]\times10^7$	G. p. m.× $[H^+]$	Free acidity or free alkalinity as $CaCO_3$, p. p. m.	Free acidity or free alkalinity, p. p. m.× g. p. m.	Total acidity or total alkalinity as $CaCO_3$ p. p. m.	Total acidity or total alkalinity, p. p. m.× g. p. m.
2,625,480	7.2	0.63	1,654,052	9 alk.	23,629,320	11 alk.	28,880,280
942,480	6.3	50.00	47,124,000	0		5 acid	−4,712,400
453,288	4.7	200.00	90,657,600	13 acid	−5,892,744	45 acid	−20,397,960
1,068,144	7.5	.32	341,806	17 alk.	18,464,448	24 alk.	26,067,456
3,204,432	7.1	.79	2,531,501	15 alk.	48,066,480	5 alk.	16,022,160
3,922,512	7.1	.79	3,098,784	10 alk.	39,225,120	10 alk.	39,225,120
3,545,520	7.1	.79	2,800,960	15 alk.	53,182,800	15 alk.	53,182,800
2,275,416	7.5	.32	728,133	35 alk.	79,639,560	40 alk.	91,016,640
Total 18,037,272			148,936,836		256,314,984		229,284,096
Average	6.1	8.25		14.2 alk.		12.7 alk.	

Figures 5, 6, 7, and 8 are graphs indicating the trend of average *p*H, average free acidity or alkalinity, and average total acidity or alkalinity of the Susquehanna, Lackawanna, Lehigh, and Schuylkill Rivers.

The average *p*H, average free acidity or alkalinity, and average total acidity or alkalinity shown in figures 5, 6, 7, and 8 must be considered approximations owing to the influence of such factors as wet and dry seasons of the year, active or abandoned mines, volumes of flow, and changes in unwatering of mines.

Because of these different factors and because of other contaminants in addition to acid mine drainage emptying into the streams, the acid load in the streams attributable to mine drainage cannot be determined accurately from the analyses of samples taken from the rivers. The acid load that enters the rivers from mine-water dis-

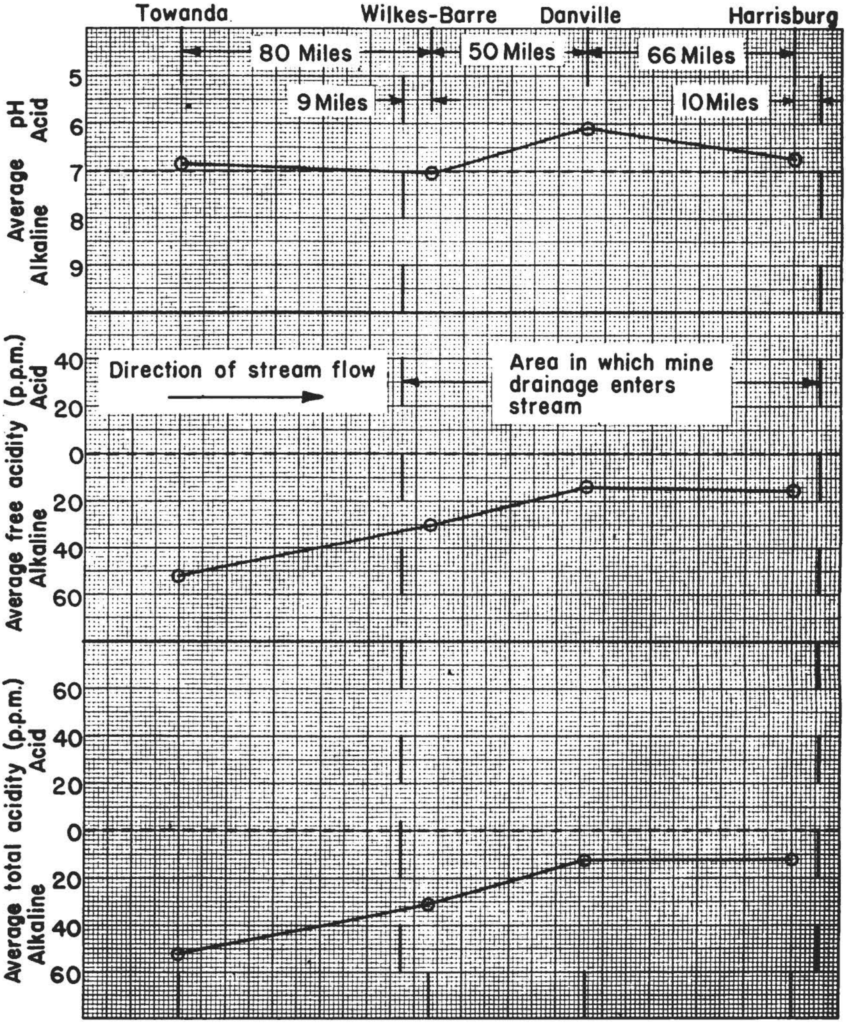

FIGURE 5.—Comparison of average *p*H, average free acidity or alkalinity, and average total acidity or alkalinity of the Susquehanna River at four gaging stations.

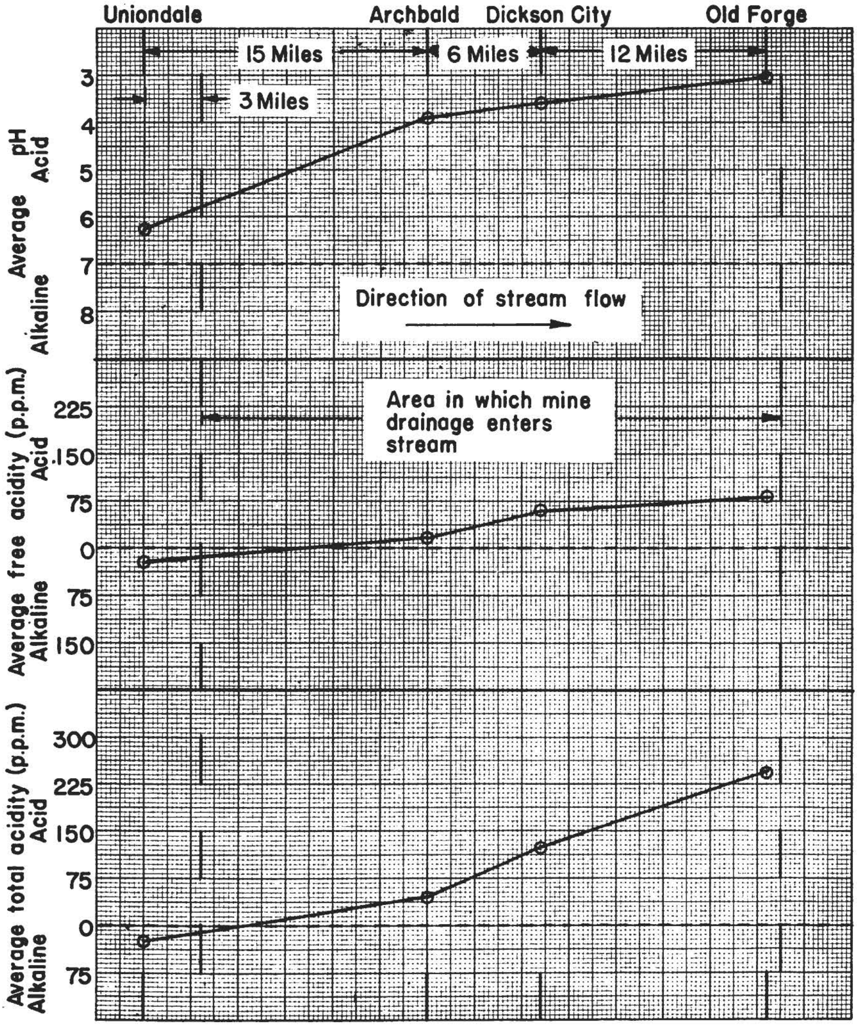

FIGURE 6.—Comparison of average *p*H, average free acidity or alkalinity, and average total acidity or alkalinity of the Lackawanna River at four gaging stations.

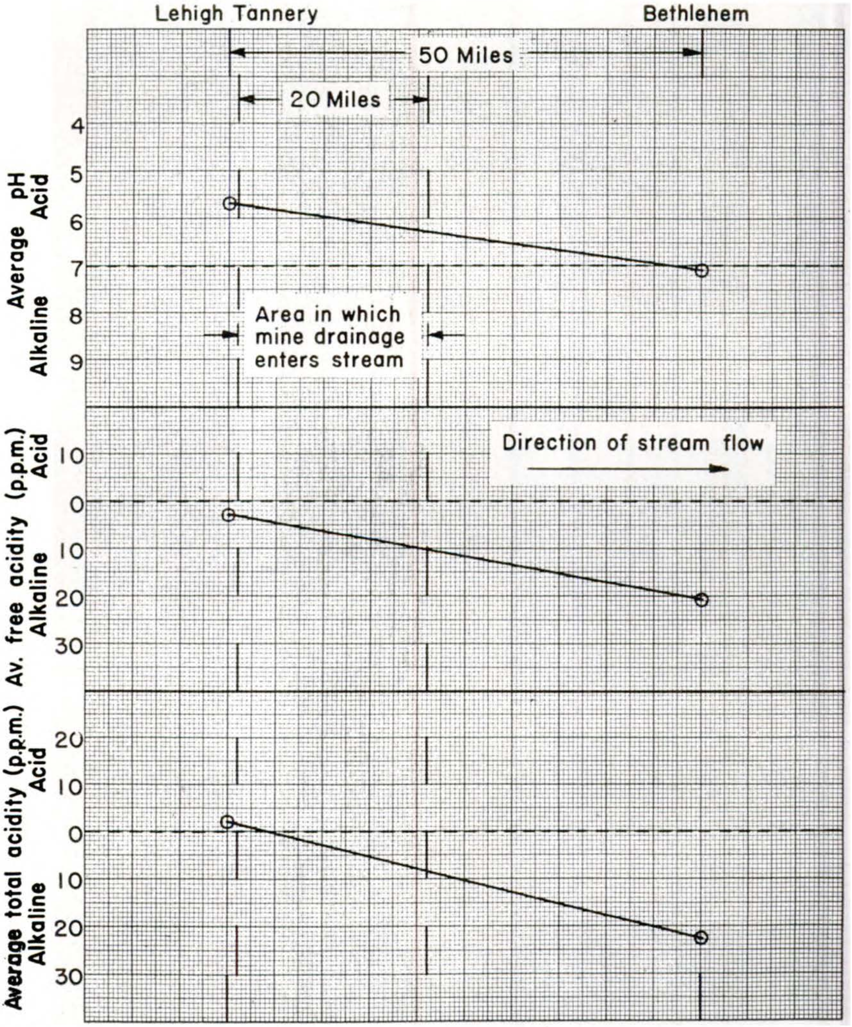

FIGURE 7.—Comparison of average *p*H, average free acidity or alkalinity, and average total acidity or alkalinity of the Lehigh River at two gaging stations.

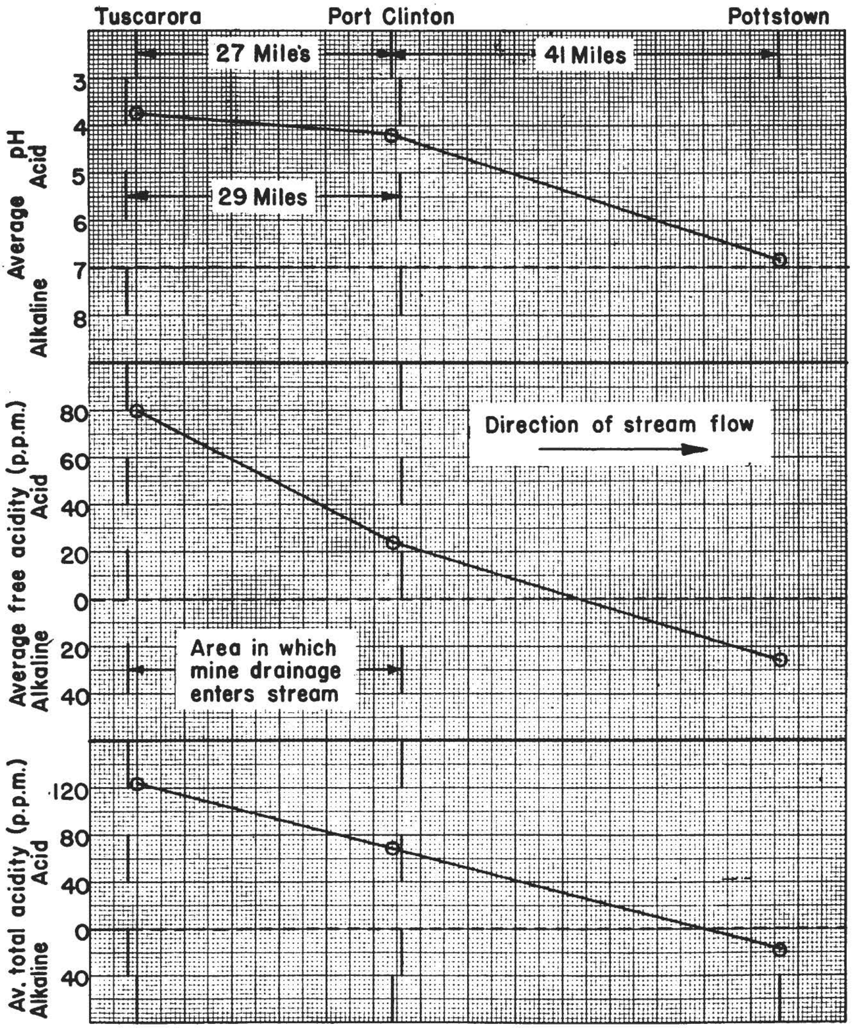

FIGURE 8.—Comparison of average *p*H, average free acidity or alkalinity, and average total acidity or alkalinity of the Schuylkill River at three gaging stations.

charges can be determined only from the analyses of samples of all mine-water discharges.

STREAM-FLOW DATA

A study of stream-flow records indicates that the Bureau of Mines samples were collected in 1941 and 1946 during low-water periods. Table 7 shows the average flow during the sampling periods, as compared with the general average for the period during which the Commonwealth of Pennsylvania made gage recordings.

TABLE 7.—*Stream-flow data for various sampling locations*

Location	Discharge, cubic feet per second		
	Average of 1941 sampling	Average of 1946 sampling	General average
Susquehanna:			
Towanda	1, 508	4, 165	26 years—10,050
Wilkes-Barre	2, 653	6, 305	45 years—13,350
Danville	2, 835	7, 940	41 years—15,070
Harrisburg	5, 137	12, 250	54 years—34,300
Lehigh:			
Lehigh Tannery	221	284	25 years—657
Bethlehem	810	1, 945	15 years—2,205
Schuylkill: Pottstown	358	1, 715	17 years—1,814

CHEMICAL ANALYSES OF MINE-WATER DISCHARGES

During 1941 analyses were made of samples of mine water from every known discharge point in the Northern, Eastern Middle, Western Middle, and Southern fields. The discharge points included drainage tunnels and pump discharges. The samples collected and analyzed in 1946 were representative of all the fields but included only the larger discharges.

Figures 9 to 13, inclusive, show drainage discharges at some of the large mines in the anthracite region.

The data obtained in 1941 and 1946 are compiled in tables 8, 9, and 10. They show the number of samples collected and tested in each anthracite field, together with their *p*H, free and total acidity, and free and total acid loads. Free acidity or free alkalinity is expressed as equivalent parts per million of calcium carbonate, using methyl-red indicator. Total acidity or total alkalinity is expressed as equivalent parts per million of calcium carbonate, using phenolphthalein indicator. The total weight of water and the free- and total-acid loads are expressed in short tons (2,000 pounds) per day.

Table 11 is a summary of the water and the acid loads expressed in tons (2,000 pounds) per day discharged from each of the four anthracite fields and from the entire anthracite region during 1941. The acid load is expressed both as $CaCO_3$ and as H_2SO_4. The drainage-tunnel discharges and mine discharges are shown separately. The sum of drainage-tunnel discharges and the mine discharges are shown for each of the four fields and for the entire region.

FIGURE 9.—Mine pump discharging 260,000,000 gallons a month into a breaker storage pond.

FIGURE 10.—Two discharges, totaling 24,000 g. p. m., from one colliery in the Northern field.

FIGURE 11.—Tunnel receiving 11,400 g. p. m. from several collieries in the Eastern Middle field.

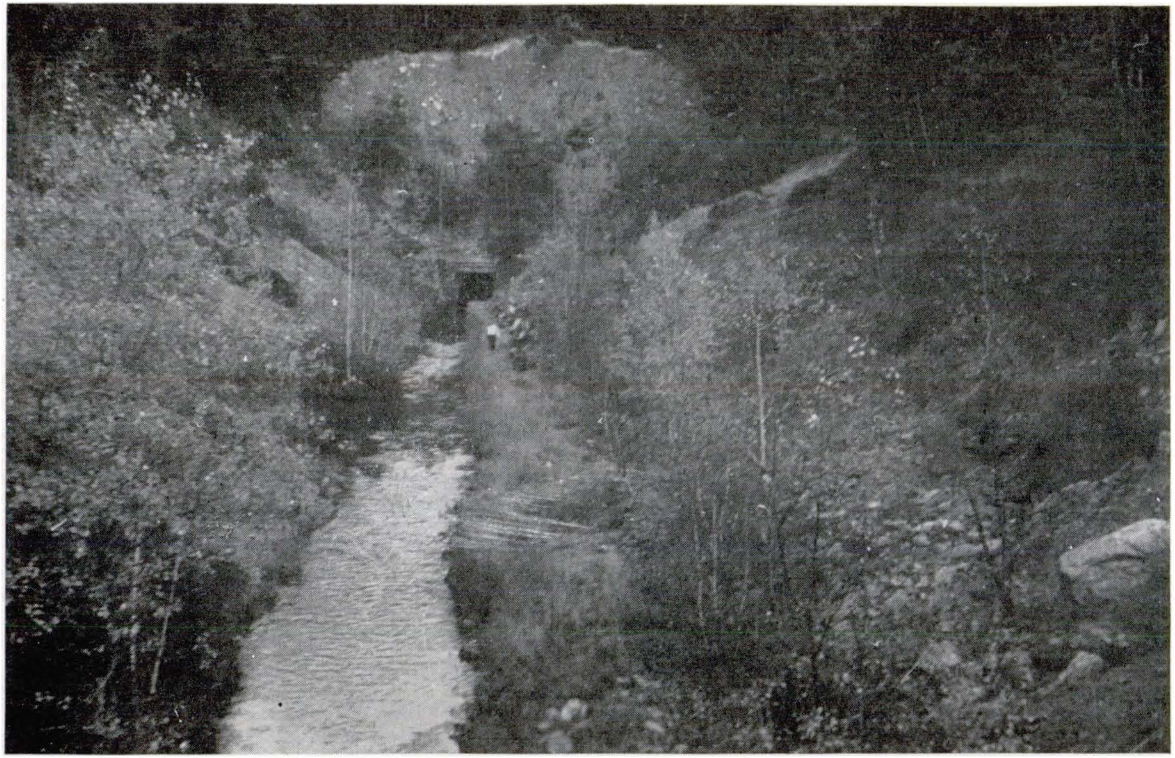

FIGURE 12.—Tunnel receiving 134,000,000 gallons of mine water a month.

FIGURE 13.—Weir installation for measuring mine-water drainage.

TABLE 8.—*Compilation of information on volume, pH, free-acid loads, and total-acid loads of mine-water discharges*

NORTHERN ANTHRACITE FIELD

Company	Colliery	Sample	Date	Discharge		pH	Free acidity or free alkalinity as $CaCO_3$, p. p. m. (methyl-red indicator)	Total acidity or total alkalinity as $CaCO_3$, p. p. m. (phenolphthalein indicator)	Total weight of water per day, short tons	Load per day, short tons			
				Volume	Rate of flow					1941		1946	
										Free acidity as $CaCO_3$	Total acidity as $CaCO_3$	Free acidity as $CaCO_3$	Total acidity as $CaCO_3$
A	1	Mine-pump discharge	May 19, 1941	4,680,000	Gallons per month	7.0	148 alk.	43 alk.	627				
	2 (*a*)	Mine drainage	May 20, 1941	64,000,000	do.	2.8	169 acid	411 acid	8,576	1.45	3.52		
	(*a*)	do.	Oct. 17, 1946	122,914,250	do.	4.7	65 acid	120 acid	16,471			1.07	1.98
	(*b*)	Slope-pump discharge	May 20, 1941	33,450,000	do.	6.1	51 alk.	54 alk.	4,482				
	(*c*)	do.	do.	38,030,000	do.	4.3	134 acid	416 acid	5,096	.68	2.12		
	3 (*a*)	Mine-pump discharge	May 21, 1941	88,800,000	do.	3.4	63 acid	132 acid	11,899	.75	1.57		
	(*a*)	do.	Oct. 21, 1946	197,920,375	do.	3.3	105 acid	170 acid	26,521			2.78	4.51
	4 (*a*)	do.	May 20, 1941	92,760,000	do.	6.5	88 alk.	96 alk.	12,430				
	(*a*)	do.	Oct. 17, 1946	247,920,000	do.	7.0	35 acid	75 acid	33,221			1.16	2.49
	(*b*)	Slope-pump discharge	May 20, 1941	6,000,000	do.	7.4	133 alk.	103 alk.	804				
	(*c*)	Mine-pump discharge	do.	1,150,000	do.	7.7	86 alk.	94 alk.	154				
	5 (*a*)	do.	May 21, 1941	106,380,000	do.	3.2	150 acid	329 acid	14,255	2.14	4.69		
	(*a*)	do.	Oct. 21, 1946	121,958,750	do.	3.3	95 acid	140 acid	16,342			1.55	2.29
	6	do.	May 20, 1941	13,780,000	do.	3.2	129 acid	345 acid	1,847	.24	.64		
	7 (*a*)	do.	May 21, 1941	118,700,000	do.	2.9	363 acid	537 acid	15,906	5.77	8.54		
	(*a*)	do.	Oct. 21, 1946	260,098,375	do.	3.1	220 acid	350 acid	34,853			7.67	12.20
	8 (*a*)	do.	May 20, 1941	26,200,000	do.	4.4	119 acid	421 acid	3,511	.42	1.48		
	(*b*)	Mine discharge	do.	68,900,000	do.	3.1	224 acid	419 acid	9,233	2.07	3.87		
	(*c*)	Drift drainage	Jan. 30, 1942	(1)			92 acid	445 acid					
	9 (*a*)	Slope-pump discharge	May 20, 1941	21,400,000	do.	2.9	251 acid	535 acid	2,868	.72	1.53		
	(*b*)	Mine-pump discharge	do.	28,730,000	do.	3.6	26 acid	206 acid	3,850	.10	.79		
	(*c*)	Drift drainage	Jan. 30, 1942	(1)			97 acid	550 acid					
	10 (*a*)	Mine-pump discharge	May 19, 1941	83,900,000	do.	3.3	324 acid	616 acid	11,243	3.64	6.93		
	(*a*)	do.	Oct. 17, 1946	72,768,750	do.	3.9	415 acid	665 acid	9,751			4.05	6.48
	11 (*a*)	do.	May 19, 1941	11,900,000	do.	4.3	4 alk.	100 acid	1,595		.16		
	(*b*)	Slope-pump discharge	do.	24,680,000	do.	7.3	270 alk.	116 alk.	3,307				
	12 (*a*)	Mine-pump discharge	May 20, 1941	213,000,000	do.	2.8	166 acid	361 acid	28,542	4.74	10.30		
	(*a*)	do.	Oct. 17, 1946	202,109,250	do.	4.5	70 acid	140 acid	27,083			1.90	3.79
	13 (*a*)	do.	May 21, 1941	382,900,000	do.	3.0	261 acid	529 acid	51,309	13.39	27.14		
	(*a*)	do.	Oct. 21, 1946	465,164,250	do.	3.0	240 acid	405 acid	62,332			14.96	25.24
	14	do.	May 20, 1941	33,550,000	do.	2.8	419 acid	824 acid	4,496	1.88	3.70		
	15 (*a*)	do.	May 21, 1941	75,000,000	do.	2.9	316 acid	474 acid	10,050	3.18	4.76		
	(*a*)	do.	Oct. 21, 1946	94,350,000	do.	2.9	240 acid	415 acid	12,643			3.03	5.25
	16 (*a*)	do.	May 19, 1941	16,750,000	do.	5.1	41 alk.	45 alk.	2,245				
	17	do.	do.	22,000,000	do.	3.0	572 acid	1,104 acid	2,948	1.69	3.25		

	18(*a*)	Mine discharge	do	14, 900, 000	do	3. 0	634 acid	1, 215 acid	1, 997	1. 27	2. 43		
	(*b*)	Main-conduit water	do	93, 300, 000	do	3. 0	748 acid	1, 302 acid	12, 502	9. 35	16. 28		
	(*b*)	do	Oct. 17, 1946	154, 025, 000	do	3. 0	640 acid	835 acid	20, 639			13. 21	17. 23
	(*c*)	Tunnel discharge	May 19, 1941	670, 000	do	3. 1	116 acid	171 acid	90	. 01	. 02		
	(*d*)	Slope-pump discharge	do	8, 590, 000	do	3. 2	332 acid	564 acid	1, 151	. 38	. 65		
	19 (*a*)	do	do	8, 400, 000	do	3. 0	735 acid	1, 602 acid	1, 126	. 83	1. 80		
	(*b*)	do	do	19, 800, 000	do	2. 8	854 acid	1, 283 acid	2, 653	2. 27	3. 40		
	(*c*)	do	do	34, 300, 000	do	2. 8	982 acid	1, 467 acid	4, 596	4. 51	6. 74		
	(*d*)	Mine discharge	do	7, 350, 000	do	2. 9	1, 159 acid	1, 713 acid	985	1. 14	1. 69		
	20 (*a*)	Slope-pump discharge	do	21, 126, 000	do	3. 6	71 acid	105 acid	2, 831	. 20	. 30		
	(*b*)	Mine-pump discharge	do	41, 300, 000	do	3. 4	274 acid	682 acid	5, 534	1. 52	3. 77		
	(*b*)	do	Oct. 17, 1946	30, 476, 571	do	3. 0	555 acid	1, 030 acid	4, 084			2. 27	4. 21
	21	Mine discharge	May 21, 1941	4, 100, 000	do	4. 2	37 acid	66 acid	549	. 02	. 04		
	22	Mine-pump discharge	Oct. 21, 1946	59, 200, 000	do	3. 3	85 acid	130 acid	7, 933			. 67	1. 03
B	1	Drift drainage	May 2, 1941	50	Gallons per minute	3. 7	32 acid	79 acid	300	. 01	. 02		
	2	do	do	[3] 900	do	6. 2	4 alk.	13 acid	5, 400		. 07		
	3 (*a*)	Mine-pump discharge	Oct. 10, 1946	9, 000	do	3. 3	145 acid	260 acid	54, 000			7. 83	14. 04
	(*a*)	do [2]	May 2, 1941	3, 500	do	3. 3	79 acid	308 acid	21, 000	1. 66	6. 47		
	(*a*)	do	Dec. 8, 1941	3, 500	Gallons per minute (22 hours a day).	3. 0	155 acid	348 acid	19, 250	2. 99	6. 70		
	4 (*a*)	do [2]	May 2, 1941	6, 110	Gallons per minute	3. 4	139 acid	334 acid	36, 660	5. 10	12. 24		
	(*a*)	do	Dec. 8, 1941	6, 110	do	3. 1	182 acid	421 acid	36, 660	6. 67	15. 43		
	(*a*)	do	Oct. 12, 1946	4, 500	do	2. 9	120 acid	250 acid	27, 000			3. 24	6. 75
	5 (*a*)	do	May 2, 1941	7, 438	do	3. 9	50 acid	129 acid	44, 628	2. 23	5. 76		
	(*a*)	do	Oct. 12, 1946	7, 000	do	3. 8	30 acid	40 acid	42, 000			1. 26	1. 68
	6 (*a*)	do	May 2, 1941	8, 246	do	3. 3	279 acid	650 acid	49, 476	13. 80	32. 16		
	(*b*)	Underground drainage	Dec. 8, 1941	(1)		3. 0	184 acid	340 acid					
	7 (*a*)	Mine-pump discharge	May 2, 1941	9, 629	Gallons per minute	3. 3	298 acid	1, 024 acid	57, 774	17. 22	59. 16		
	(*a*)	do [2]	Dec. 9, 1941	9, 629	do	3. 1	171 acid	408 acid	57, 774	9. 88	23. 57		
	(*a*)	do	Oct. 10, 1946	24, 000	do	3. 1	160 acid	300 acid	144, 000			23. 04	43. 20
	(*b*)	Drift drainage	Dec. 9, 1941	(1)		6. 0	45 alk.						
	(*c*)	Mine-pump discharge	do	(1)		3. 0	590 acid	3, 398 acid					
	8 (*abc*)	do	June 6, 1941	142, 790, 300	Gallons per month	2. 7	1, 062 acid	2, 770 acid	19, 848	21. 08	54. 98		
	(*b*)	do	do			2. 7	1, 056 acid	2, 750 acid					
	(*c*)	do	do			2. 8	1, 033 acid	3, 740 acid					
	(*d*)	Underground drainage	Dec. 10, 1946	(1)		3. 7	400 acid	2, 240 acid					
	(*d*)	Mine-pump discharge	Oct. 10, 1946	3, 000	Gallons per minute	2. 8	405 acid	805 acid	18, 000			7. 29	14. 49
C	1 (*a*)	do	May 26, 1941	29, 759, 632	Gallons per month	5. 8	6 alk.	119 acid	3, 988		. 47		
	(*a*)	do	Oct. 29, 1946	75, 000, 000	do	3. 1	160 acid	720 acid	10, 050			1. 61	7. 24
	2 (*a*)	do	May 26, 1941	55, 050, 000	do	5. 6	Neutral	24 acid	7, 377		. 18		
	(*a*)	do	Oct. 29, 1946	53, 000, 000	do	3. 3	85 acid	155 acid	7, 102			. 60	1. 10
	(*b*)	do	May 26, 1941	161, 622, 000	do	6. 0	2 alk.	8 alk.	21, 657				
	(*b*)	do	Nov. 4, 1946	50, 000, 000	do	3. 3	95 acid	145 acid	6, 950			. 66	1. 01
	(*c*)	do	Oct. 29, 1946	77, 000, 000	do	7. 2	35 alk.	35 alk.	10, 318				
	(*d*)	do	do	150, 000, 000	do	6. 6	45 alk.	45 alk.	20, 100				
	3 (*a*)	do	May 26, 1941	94, 100, 160	do	4. 4	37 acid	155 acid	12, 609	. 47	1. 95		
	(*a*)	do	Oct. 29, 1946	105, 000, 000	do	3. 9	115 acid	225 acid	14, 070			1. 62	3. 17
	4 (*a*)	Slope-pump discharge	May 26, 1941	53, 436, 000	do	5. 7	Neutral	13 acid	7, 160		. 09		
	(*a*)	Mine-pump discharge	Oct. 29, 1946	33, 000, 000	do	3. 5	70 acid	125 acid	4, 422			. 31	. 55
	(*b*)	do	May 26, 1941	134, 976, 000	do	5. 9	6 alk.	24 acid	18, 087		. 43		
	(*b*)	do	Oct. 29, 1946	36, 000, 000	do	6. 3	75 alk.	55 alk.	4, 824				
	(*c*)	do	do	105, 000, 000	do	6. 1	55 alk.	45 alk.	14, 070				

See footnotes at end of table.

TABLE 8.—*Compilation of information on volume, pH, free-acid loads, and total-acid loads of mine-water discharges*—Continued

NORTHERN ANTHRACITE FIELD—Continued

Company	Colliery	Sample	Date	Discharge		pH	Free acidity or free alkalinity as $CaCO_3$, p. p. m. (methyl-red indicator)	Total acidity or total alkalinity as $CaCO_3$, p. p. m. (phenolphthalein indicator)	Total weight of water per day, short tons	Load per day, short tons			
										1941		1946	
				Volume	Rate of flow					Free acidity as $CaCO_3$	Total acidity as $CaCO_3$	Free acidity as $CaCO_3$	Total acidity as $CaCO_3$
D	1 (*a*)	Mine-pump discharge	May 27, 1941	77,000,000	Gallons per month	3.6	327 acid	661 acid	10,318	3.37	6.82		
	(*b*)	Underground sump	do			3.3	427 acid	1,128 acid					
	(*c*)	Pump discharge before liming	June 12, 1941			3.1	445 acid	962 acid					
	(*d*)	Pump discharge after liming	do	(4)		3.4	422 acid	864 acid					
	(*e*)	Underground sump	May 27, 1941			2.8	602 acid	988 acid					
	2	do	do	(1)		2.8	411 acid	1,160 acid					
	3	do	do	256,000,000	Gallons per month	5.7	26 alk.	30 alk.	34,304				
	4 (*a*)	Mine-pump discharge	do	129,989,000	do	6.5	2 alk.	21 alk.	17,419				
	(*b*)	do	do	52,110,000	do	3.0	382 acid	869 acid	6,983	2.67	6.07		
	5	do	do	16,000,000	do	3.7	108 acid	358 acid	2,144	.23	.77		
	6	do	do	1,000,000	do	6.5	69 alk.	52 alk.	134				
E	1	do	May 13, 1941	27,000,000	do	4.1	37 acid	179 acid	3,618	.13	.65		
	2	Breaker discharge	do	2,500	Gallons per minute	4.2	11 acid	108 acid	15,000	.17	1.62		
F	1 (*a*)	Mine-pump discharge	May 23, 1941	35,316,000	do	3.0	217 acid	421 acid	4,732	1.03	1.99		
	(*b*)	do	do	55,950,000	do	5.0	4 alk.	16 acid	7,497		.12		
	2	do	do	35,820,000	do	4.9	5 acid	63 acid	4,800	.02	.30		
	3	do	do	37,380,000	do	6.7	36 alk.	41 alk.	5,009				
G	1 (*a*)	Mine-pump discharge	June 10, 1941	57,264,000	Gallons per month	2.9	975 acid	1,760 acid	7,960	7.76	14.01		
	(*b*)	do	do	29,340,000	do	2.8	616 acid	1,010 acid	4,078	2.51	4.12		
	(*c*)	do	do	36,708,000	do	2.9	348 acid	698 acid	5,102	1.78	3.56		
	(*ab*)	do	Oct. 31, 1946	142,314,000	do	2.8	545 acid	1,010 acid	19,070			10.39	19.26
	(*c*)	do	Nov. 4, 1946	45,294,000	do	3.0	200 acid	380 acid	6,296			1.26	2.39
	2 (*a*)	Underground-water sump	June 10, 1941	86,000,000	do	3.2	401 acid	870 acid	11,954	4.79	10.40		
	(*b*)	Fresh-water sump	do	131,000,000	do	6.7	87 alk.	34 alk.	18,209				
	(*c*)	Mine-water sump	do	139,000,000	do	5.9	4 alk.	240 acid	19,321		4.64		
	(*d*)	Slope-pump discharge	do	5,000,000	do	6.5	79 alk.	84 alk.					
	(*e*)	Mine-pump water (mixed)	Nov. 4, 1946	(1)		4.3	40 acid	55 acid					
	(*c*)	Mine-pump water (mine)	do	(1)		3.9	115 acid	215 acid					
	(*a*)	Mine-pump discharge	do	(1)		2.9	645 acid	925 acid					

H	1 (*a*)	Drift drainage	Oct. 13, 1941	(1)	--------	2.3	3,610 acid	7,695 acid	--------	--------	--------	--------	--------
	(*a*)	do	Oct. 17, 1941	(1)	--------	2.9	277 acid	503 acid	--------	--------	--------	--------	--------
	(*b*)	Slope-pump discharge	do	(1)	--------	3.4	121 acid	303 acid	--------	--------	--------	--------	--------
	(*c*)	Mine-pump discharge	do	(1)	--------	6.3	41 alk.	30 alk.	--------	--------	--------	--------	--------
	(*d*)	do	do	(1)	--------	6.3	111 alk.	23 alk.	--------	--------	--------	--------	--------
	(*e*)	Underground-water sump	do	(1)	--------	3.2	179 acid	485 acid	--------	--------	--------	--------	--------
	(*f*)	Water at slope weir	May 14, 1941	1,000	Gallons per minute	3.5	13 acid	34 acid	6,000	.08	.20	--------	--------
	(*g*)	Water at standpipe	do	1,000	do	5.2	Neutral	26 acid	6,000	--------	.16	--------	--------
I	1 (*a*)	Mine-pump discharge [5]	Mar. 26, 1947	319,920,000	Gallons per month	3.1	70 acid	125 acid	42,869	--------	--------	5.36	3.00
	(*b*)	do.[5]	do	[6]133,920,000	do	3.9	85 acid	130 acid	14,456	--------	--------	1.88	1.23
	(*c*)	do.[5]	do	279,000,000	do	3.4	40 acid	90 acid	37,386	--------	--------	3.36	1.50
	(*d*)	Breaker discharge [5]	do	19,530,000	do	5.5	40 alk.	35 alk.	2,617	--------	--------	--------	--------
J	1	do.[5]	do	26,040,000	do	3.6	30 acid	85 acid	3,489	--------	--------	.30	.10

EASTERN MIDDLE ANTHRACITE FIELD

A	1	Breaker water	Nov. 12, 1941	60,000	Gallons per day (3 days a week).	3.1	329 acid	545 acid	107	0.04	0.06	--------	--------
B	1 (*a*)	Outside-pump discharge	Nov. 6, 1941	49,000,000	Gallons per month	2.8	942 acid	1,220 acid	6,811	6.42	8.31	--------	--------
	(*b*)	Inside-pump discharge	do	43,000,000	do	2.9	814 acid	1,272 acid	5,977	4.87	7.60	--------	--------
C	1	Outside-pump discharge	Nov. 5, 1941	500	Gallons per minute (8 hours a day).	3.6	47 acid	50 acid	1,000	.05	.05	--------	--------
D	1	do	May 21, 1941	4,100,000	Gallons per month	4.2	37 acid	66 acid	549	.02	.04	--------	--------
E	1	Breaker discharge	Nov. 18, 1941	[3] 950	Gallons per minute (7½ hours a day).	3.5	445 acid	708 acid	1,781	.79	1.26	--------	--------
F	1 (*a*)	do	Nov. 5, 1941	4,500,000	Gallons per day (16 days a month).	3.2	514 acid	816 acid	10,001	5.14	8.16	--------	--------
	(*b*)	Slope discharge	Nov. 12, 1941	1,350	Gallons per minute (7 hours a day).	2.8	387 acid	529 acid	2,363	.91	1.25	--------	--------
	(*c*)	Shaft discharge	do	1,600	Gallons per minute (6 hours a day).	3.2	248 acid	377 acid	2,400	.60	.91	--------	--------
	(*d*)	Drift drainage	do	[3] 100	Gallons per minute	3.2	111 acid	163 acid	600	.07	.10	--------	--------
G	1 (*a*)	Slope discharge	Nov. 6, 1941	1,700	Gallons per minute (16 hours a day).	3.0	461 acid	676 acid	6,800	3.13	4.60	--------	--------
	(*b*)	do	do	1,500	do	3.4	97 acid	150 acid	6,000	.58	.90	--------	--------
H	1 (*a*)	Breaker water [7]	June 12, 1941	16,672,000	Gallons per month	3.6	282 acid	539 acid	2,317	.65	1.25	--------	--------
	(*b*)	do	do	16,672,000	do	3.0	555 acid	685 acid	2,317	1.29	1.61	--------	--------
	2 (*a*)	do.[7]	do	28,215,000	do	3.9	208 acid	618 acid	3,922	.82	2.42	--------	--------
	(*b*)	do.[7]	do	28,215,000	do	2.9	692 acid	1,076 acid	3,922	2.71	4.22	--------	--------
I	1	Mine-water discharge	Oct. 28, 1941	[3] 200	Gallons per minute	3.6	18 acid	34 acid	1,200	.02	.04	--------	--------
J	1	do	do	1,000	Gallons per day	3.1	342 acid	624 acid	6,000	2.05	3.74	--------	--------
K	1	do	do	2,000	Gallons per minute (7 hours a day).	3.2	174 acid	311 acid	3,500	.61	1.09	--------	--------

See footnotes at end of table.

TABLE 8.—*Compilation of information on volume, pH, free-acid loads, and total-acid loads of mine-water discharges*—Continued

WESTERN MIDDLE ANTHRACITE FIELD

Company	Colliery	Sample	Date	Discharge		pH	Free acidity or free alkalinity as $CaCO_3$, p. p. m. (methyl-red indicator)	Total acidity or total alkalinity as $CaCO_3$, p. p. m. (phenolphthalein indicator)	Total weight of water per day, short tons	Load per day, short tons			
				Volume	Rate of flow					1941		1946	
										Free acidity as $CaCO_3$	Total acidity as $CaCO_3$	Free acidity as $CaCO_3$	Total acidity as $CaCO_3$
A	1 (*a*)	Mine-water discharge [8]	Sept. 16, 1941			3.7	189 acid	300 acid					
	(*b*)	Breaker discharge [8]	do			3.3	487 acid	1,098 acid					
B	1	Mine-water discharge	Aug. 21, 1941	[3] 1,000	Gallons per minute	3.5	140 acid	471 acid	6,000	0.84	2.83		
C	1	Breaker discharge	Sept. 25, 1941	[3] 3,000	do	4.1	108 acid	364 acid	18,000	1.94	6.55		
D	1 (*a*)	Shaft-pump discharge	Sept. 18, 1941	55,950,000	Gallons per month	2.4	461 acid	735 acid	7,777	3.59	5.72		
	(*a*)	do	Sept. 23, 1946	67,500,000	do	2.8	270 acid	650 acid	9,383			2.53	6.10
	(*b*)	Slope-pump discharge	Sept. 18, 1941	36,000,000	do	2.5	392 acid	1,517 acid	5,004	1.96	7.59		
	(*b*)	do	Sept. 23, 1946	46,290,000	do	3.2	100 acid	200 acid	6,434			.64	1.29
	(*c*)	do	Sept. 18, 1941	23,700,000	do	2.2	982 acid	1,554 acid	3,294	3.23	5.12		
	2	Drift drainage	Sept. 17, 1941	[3] 150	Gallons per minute	6.0	3 alk.	56 alk.	900				
	3 (*a*)	Mine discharge	do	[3] 100	do	2.1	1,059 acid	1,843 acid	600	.64	1.11		
	(*b*)	do	do	[3] 3,000	do	5.5	94 alk.	321 acid	18,000		5.78		
	(*b*)	Mine-pump discharge	Sept. 23, 1946	2,250	do	6.1	125 alk.	20 alk.	13,500				
	4	Drift drainage	Sept. 19, 1941	[3] 20	do	2.5	277 acid	387 acid	120	.03	.05		
	5	Mine discharge	do	[3] 150	do	4.3	24 acid	1,088 acid	900	.02	.98		
	6 (*a*)	Breaker discharge	Aug. 21, 1941	2,000	do	2.9	413 acid	598 acid	12,000	4.96	7.18		
	(*b*)	Mine-water discharge	do	2,500	do	2.5	292 acid	377 acid	15,000	4.38	5.66		
	7	do	Sept. 19, 1941	13,728,000	Gallons per month	2.7	371 acid	1,359 acid	1,908	.71	2.59		
	8	do	do	[3] 500	Gallons per minute	3.3	255 acid	882 acid	3,000	.77	2.65		
	9 (*a*)	Mine-pump discharge	Sept. 16, 1941	84,800,000	Gallons per month	5.1	8 acid	398 acid	11,787	.09	4.69		
	(*a*)	do	Sept. 25, 1946	2,115	Gallons per minute	6.0	30 alk.	50 alk.	12,690				
	10	do	Sept. 19, 1941	15,500,000	Gallons per month	3.5	121 acid	519 acid	2,155	.26	1.12		
	11	Drift drainage	do	[3] 1,000	Gallons per minute	2.9	111 acid	198 acid	6,000	.67	1.19		
	12	Mine-pump discharge	Aug. 21, 1941	11,921,000	Gallons per month	2.9	366 acid	972 acid	1,597	.58	1.55		
	13	Slope-pump discharge	Sept. 18, 1941	3,414,000	do	2.4	429 acid	688 acid	475	.20	.33		
	14	Drift drainage	Sept. 16, 1941	2,100	Gallons per minute	4.2	132 acid	991 acid	12,600	1.66	12.49		
	15 (*a*)	Mine-pump discharge	Aug. 21, 1941	132,489,000	Gallons per month	2.6	448 acid	1,390 acid	17,754	7.95	24.68		
	(*a*)	do	Sept. 25, 1946	1,842	Gallons per minute	3.1	405 acid	695 acid	11,052			4.48	7.68
	(*b*)	Drift drainage	Aug. 21, 1941	(1)		2.6	427 acid	1,383 acid					
	16 (*a*)	Mine-pump discharge	do	2,000	Gallons per minute (16 hours a day).	3.1	371 acid	858 acid	8,000	2.97	6.87		
	(*a*)	do	Sept. 25, 1946	5,237	Gallons per minute	3.4	505 acid	825 acid	31,422			15.87	25.92
	17	Slope-pump discharge	Sept. 19, 1941	45,400,000	Gallons per month	4.1	13 acid	250 acid	6,311	.08	1.58		
	18	Mine-water discharge	Sept. 16, 1941	44,053,728	do	4.9	21 alk.	319 acid	6,123		1.95		
	19 (*a*)	Mine-pump discharge	Sept. 17, 1941	54,913,000	do	6.4	161 alk.	66 alk.	7,633				
	(*b*)	do	do	8,734,000	do	6.4	26 alk.	36 alk.	1,214				

D	20	do	do	[3] 500	Gallons per minute	5.2	39 alk.	121 acid	3,000	--------	.36	--------	--------
	21 (*a*)	do	Sept. 18, 1941	70,700,000	Gallons per month	2.7	134 acid	324 acid	9,827	1.32	3.18	--------	--------
	(*a*)	do	Sept. 23, 1946	99,721,000	do	4.0	40 acid	125 acid	13,861	--------	--------	.55	1.73
	22	Breaker discharge	Aug. 21, 1941	111,330,000	do	3.6	74 acid	479 acid	14,918	1.10	7.15	--------	--------
	23 (*a*)	Mine-pump discharge	Sept. 19, 1941	128,328,000	do	5.7	114 alk.	101 alk.	17,838	--------	--------	--------	--------
	(*a*)	do	Sept. 23, 1946	51,840,000	do	5.3	30 acid	270 acid	7,206	--------	--------	.22	1.95
	24	do	Sept. 17, 1941	[3] 500	Gallons per minute	3.3	92 acid	253 acid	3,000	.28	.76	--------	--------
	25	Breaker discharge	Aug. 21, 1941	84,328,000	Gallons per month	3.6	113 acid	669 acid	11,300	1.28	7.56	--------	--------
E	1 (*a*)	Mine-pump discharge	June 10, 1941	131,000,000	do	3.1	248 acid	735 acid	18,209	4.52	13.38	--------	--------
	(*a*)	do	Oct. 31, 1946	185,614,500	do	3.1	335 acid	610 acid	24,872	--------	--------	8.33	15.17
	(*b*)	Slope-pump discharge	do	6,000,000	do	6.9	70 alk.	55 alk.	804	--------	--------	--------	--------
	(*c*)	do	do	13,032,000	do	4.1	30 acid	45 acid	1,746	--------	--------	.05	.08

SOUTHERN ANTHRACITE FIELD

A	1	Breaker discharge	Aug. 8, 1941	[3] 500	Gallons per minute	2.7	406 acid	688 acid	3,000	1.22	2.06	--------	--------
	2	Tunnel drainage	Aug. 5, 1941	(1)	--------	3.6	21 acid	50 acid	--------	--------	--------	--------	--------
	3 (*a*)	Mine-pump discharge	do	3,000	Gallons per minute (7 hours a day).	4.5	16 acid	308 acid	5,250	.08	1.62	--------	--------
	(*b*)	do	do	2,500	Gallons per minute	2.3	345 acid	616 acid	15,000	5.18	9.24	--------	--------
	(*c*)	Breaker discharge	do	(1)	--------	2.9	61 acid	271 acid	--------	--------	--------	--------	--------
	4	Tunnel discharge	Aug. 7, 1941	1,500	Gallons per minute	3.2	129 acid	342 acid	9,000	1.16	3.08	--------	--------
	5 (*a*)	Slope-pump discharge	July 29, 1941	[3] 2,000	do	5.3	11 alk.	203 acid	12,000	--------	2.44	--------	--------
	(*b*)	Mine discharge	do	[3] 1,500	do	6.2	Neutral	5 acid	9,000	--------	.05	--------	--------
	(*c*)	Slope-pump discharge	do	(1)	--------	5.7	13 alk.	15 alk.	--------	--------	--------	--------	--------
	6	Mine-pump discharge	July 28, 1941	[3] 150	Gallons per minute	4.5	Neutral	16 acid	900	--------	.01	--------	--------
	7 (*a*)	do	July 31, 1941	1,000	do	6.1	71 alk.	56 alk.	6,000	--------	--------	--------	--------
	(*b*)	Breaker-water discharge	do	1,500	do	5.9	5 acid	8 acid	9,000	.05	.07	--------	--------
	8	Mine discharge	July 29, 1941	[3] 500	do	2.9	32 acid	53 acid	3,000	.10	.16	--------	--------
	9	Breaker discharge	July 28, 1941	[3] 150	do	4.4	5 acid	16 acid	900	--------	.01	--------	--------
	10	do	Aug. 5, 1941	77,500,000	Gallons per month	6.9	159 alk.	99 alk.	10,385	--------	--------	--------	--------
	11 (*a*)	Mine-pump discharge	July 29, 1941	[3] 2,000	Gallons per minute	5.2	4 alk.	5 acid	12,000	--------	.06	--------	--------
	(*b*)	Mine discharge	do	[3] 250	do	2.9	53 acid	84 acid	1,500	.08	.13	--------	--------
	(*c*)	Drift drainage	do	[3] 150	do	2.5	256 acid	321 acid	900	.23	.29	--------	--------
	(*d*)	Mine drainage	do	[3] 4,500	do	2.8	187 acid	358 acid	27,000	5.05	9.67	--------	--------
	12	Mine-pump discharge	July 31, 1941	60,000,000	Gallons per month	6.3	49 alk.	39 alk.	8,040	--------	--------	--------	--------
	13	do	July 29, 1941	[3] 150	Gallons per minute	3.5	26 acid	40 acid	900	.02	.04	--------	--------
	14	Breaker discharge	Aug. 6, 1941	1,500	Gallons per minute (16 hours a day).	6.8	9 alk.	6 alk.	6,000	--------	--------	--------	--------
	15	Mine discharge	do	1,200	Gallons per minute	4.0	66 acid	577 acid	7,200	.48	4.15	--------	--------
	16	do	Aug. 5, 1941	[3] 500	do	5.9	171 alk.	94 alk.	3,000	--------	--------	--------	--------
	17 (*a*)	Drift drainage	Aug. 8, 1941	300	do	2.9	166 acid	208 acid	1,800	.30	.37	--------	--------
	(*b*)	do	do	300	do	2.8	226 acid	327 acid	1,800	.41	.59	--------	--------
	18	Slope-pump discharge	Sept. 25, 1946	3,900	do	3.4	245 acid	370 acid	23,400	--------	--------	5.73	8.66

See footnotes at end of table.

TABLE 8.—*Compilation of information on volume, pH, free-acid loads, and total-acid loads of mine-water discharges*—Continued

SOUTHERN ANTHRACITE FIELD—Continued

Company	Colliery	Sample	Date	Discharge		pH	Free acidity or free alkalinity as $CaCO_3$, p. p. m. (methyl-red indicator)	Total acidity or total alkalinity as $CaCO_3$, p. p. m. (phenolphthalein indicator)	Total weight of water per day, short tons	Load per day, short tons			
				Volume	Rate of flow					1941		1946	
										Free acidity as $CaCO_3$	Total acidity as $CaCO_3$	Free acidity as $CaCO_3$	Total acidity as $CaCO_3$
B	1 (*a*)	Mine-pump discharge	July 3, 1941	22,550,000	Gallons per month	3.9	155 acid	592 acid	3,022	0.47	1.79		
	(*a*)	do	Oct. 15, 1946	32,780,000	do	3.9	215 acid	570 acid	4,393			0.94	2.50
	2 (*a*)	do	July 3, 1941	41,770,000	do	2.9	1,030 acid	2,120 acid	5,597	5.76	11.87		
	(*a*)	do	Oct. 15, 1946	40,510,000	do	2.8	730 acid	1,425 acid	5,428			3.96	7.73
	(*b*)	Fresh water	July 10, 1941	(1)		5.4	Neutral	Neutral					
	3 (*a*)	Mine-pump discharge	July 2, 1941	53,040,000	Gallons per month	3.6	269 acid	1,066 acid	7,107	1.91	7.58		
	(*a*)	do	Oct. 15, 1946	56,460,000	do	3.1	415 acid	680 acid	7,566			3.14	5.14
	4 (*a*)	do	July 2, 1941	6,604,000	do	5.4	17 alk.	250 acid	885		.22		
	(*b*)	do	July 3, 1941	6,604,000	do	4.4	24 alk.	356 acid	885		.32		
	(*c*)	do	do	6,604,000	do	5.7	24 alk.	261 acid	885		.23		
	(*d*)	do	do	6,604,000	do	5.9	24 alk.	303 acid	885		.27		
	(*e*)	do	July 2, 1941	6,604,000	do	3.1	1,043 acid	2,040 acid	885	.92	1.81		
	(*f*)	Underground drainage	May 7, 1941	(1)		5.1	Neutral	34 acid					
	(*g*)	Mine drainage	do	(1)		2.7	340 acid	487 acid					
	(*h*)	Flume discharge	do	(1)		2.7	885 acid	1,735 acid					
	(*i*)	Mine-pump discharge [9]	Oct. 15, 1946	38,090,000	Gallons per month	3.0	1,225 acid	2,095 acid	5,104			6.25	10.69
	5 (*a*)	do	July 2, 1941	31,308,000	do	3.0	556 acid	972 acid	4,195	2.33	4.08		
	(*a*)	do	Oct. 15, 1946	19,780,000	do	2.5	315 acid	585 acid	2,651			.84	1.55
	(*b*)	do	July 2, 1941	10,830,000	do	3.2	529 acid	1,209 acid	1,451	.77	1.75		
	(*b*)	do	Oct. 15, 1946	9,020,000	do	3.0	450 acid	755 acid	1,209			.54	.91
	6	Flume discharge	July 10, 1941	(1)		3.4	68 acid	158 acid					
	7 (*a*)	Mixed mine and fresh water	do	69,854,000	Gallons per month	4.4	Neutral	5 acid	9,360		.05		
	(*a*)	Mine-pump discharge	Oct. 15, 1946	34,570,000	do	4.1	110 acid	240 acid				.51	1.11
	(*b*)	Breaker discharge	July 10, 1941	(1)		4.5	Neutral	45 acid					
	(*c*)	Dorr thickener overflow	May 7, 1941	(1)		4.8	3 acid	61 acid					
	8 (*a*)	Mine-pump discharge	July 2, 1941	86,604,000	Gallons per month	2.9	574 acid	1,043 acid	11,605	6.66	12.10		
	(*a*)	Mine drainage	Oct. 14, 1946	99,372,000	do	3.2	275 acid	420 acid	13,316			3.66	5.59
	(*b*)	Fresh water	July 10, 1941	(1)		5.3	Neutral	Neutral					
	(*c*)	Breaker discharge	do	(1)		6.1	21 alk.	19 alk.					
	(*d*)	Including breaker discharge	do	(1)		5.1	3 acid	13 acid					

C	1	Mine discharge	Sept. 25, 1946	500	Gallons per minute	6.3	120 alk.	190 alk.	3,000				
D	1 (*a*)	Slope-pump discharge	Aug. 7, 1941	111,600,000	Gallons per month	2.6	610 acid	1,130 acid	14,954	9.12	16.90		
	(*b*)	Breaker discharge	do	(1)		2.8	424 acid	888 acid					
	(*c*)	Slope-pump discharge	do	44,640,000	Gallons per month	3.4	200 acid	508 acid	5,982	1.20	3.04		
	(*d*)	do	Aug. 20, 1941	13,392,000	do	2.7	2,348 acid	3,529 acid	1,795	4.21	6.33		
E	1	Breaker discharge	Aug. 6, 1941	1,800	Gallons per minute (16 hours a day).	3.4	473 acid	1,080 acid	7,200	3.41	7.78		
F	1	do	Aug. 8, 1941	1,000	Gallons per minute	6.5	137 alk.	99 alk.	6,000				
G	1	Shaft overflow	Aug. 7, 1941	500	do	3.2	166 acid	306 acid	3,000	.50	.92		
H	1	Drift drainage	July 28, 1941	[3] 150	do	2.9	198 acid	279 acid	900	.18	.25		
I	1 (*a*)	Mine discharge	July 29, 1941	[3] 4,000	do	2.3	440 acid	740 acid	24,000	10.56	17.76		
	(*b*)	do	do	[3] 1,000	do	2.3	535 acid	890 acid	6,000	3.21	5.34		
	(*c*)	do	do	[3] 700	do	2.5	761 acid	1,135 acid	4,200	3.20	4.77		
J	1 (*a*)	Drift drainage	July 31, 1941	[3] 200	do	5.5	16 acid	198 acid	1,200	.02	.24		
	(*b*)	Tunnel drainage	do	2,500	do	3.8	4 alk.	3 acid	15,000		.05		
K	1	Drift drainage	do	400	do	5.1	61 acid	187 acid	2,400	.15	.45		
L	1 (*a*)	do	July 28, 1941	[3] 150	do	3.9	3 acid	29 acid	900		.03		
	(*b*)	do	do	[3] 150	do	2.6	311 acid	474 acid	900	.28	.43		
	(*c*)	do	do	[3] 400	do	2.6	316 acid	479 acid	2,400	.76	1.15		
	(*d*)	Mine drainage	do	[3] 150	do	2.8	124 acid	263 acid	900	.11	.24		
M	1	Shaft overflow	Aug. 6, 1941	100	do	5.0	8 acid	45 acid	600	.00	.03		
N	1 (*a*)	Mine-pump discharge [2]	July 31, 1941	9,765,000	Gallons per month	5.1	9 alk.	Neutral	1,309				
	(*a*)	do	Aug. 6, 1941	9,765,000	do	4.7	11 alk.	922 acid	1,309		1.21		
O	1 (*a*)	do	July 31, 1941	1,800	Gallons per minute	6.9	62 alk.	51 alk.	10,800				
	(*b*)	Breaker discharge	do	133,920,000	Gallons per month	6.8	Neutral	4 alk.	17,945				

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[1] Not available.

[2] Repeated sample 1941 not included in total-acid loads.

[3] Estimated.

[5] Included in (*a*).

[4] Sample taken in 1947.

[6] 107,880,000 to river, 26,040,000 to J.

[7] Mine water used in breaker and discharged into drainage tunnel.

[8] Mine water used in breaker and discharged into abandoned mine.

[9] Sample from colliery 4 (*a*, *b*, *c*, *d*, and *e*).

TABLE 9.—*Compilation of information on volume, pH, free-acid loads, and total-acid loads of mine water from drainage tunnels in the anthracite region*

NORTHERN FIELD

Colliery	Date	Discharge		pH	Free acidity or free alkalinity as $CaCO_3$, p. p. m. (methyl-red indicator)	Total acidity or total alkalinity as $CaCO_3$, p. p. m. (phenolphthalein indicator)	Total weight of water per day, short tons	Load per day, short tons			
		Volume	Rate of flow					1941		1946	
								Free acidity as $CaCO_3$	Total acidity as $CaCO_3$	Free acidity as $CaCO_3$	Total acidity as $CaCO_3$
1	May 2, 1941	6,500	Gallons per minute	3.1	69 acid	263 acid	45,000	3.11	11.84		
	Sept. 4, 1946	300	do	3.7	70 acid	130 acid	1,800			0.13	0.23
2	July 11, 1941	[1] 5,000	do	2.3	311 acid	635 acid	30,000	9.33	19.05		
	Sept. 4, 1946	[1] 5,000	do	3.2	175 acid	300 acid	30,000			5.25	9.00
3	May 2, 1941	3,000	do	4.1	34 acid	121 acid	18,000	.61	2.18		
	Sept. 10, 1946	5,000	do	4.4	25 acid	35 acid	30,000			.75	1.05
Total								13.05	33.07		
						EASTERN MIDDLE FIELD					
1 [2]	May 21, 1941	134,000,000	Gallons per month	3.0	511 acid	788 acid	17,956	9.18	14.15		
	Nov. 17, 1941	130,000,000	do	2.9	664 acid	974 acid	18,070	12.00	17.60		
	Oct. 21, 1946	134,000,000	do	2.9	480 acid	735 acid	17,956			8.62	13.20
2	Nov. 17, 1941	86,400,000	do	3.1	285 acid	416 acid	11,578	3.30	4.82		
	Oct. 21, 1946	86,400,000	do	3.3	150 acid	180 acid	11,578			1.74	2.08
3	Nov. 5, 1941	7,300	Gallons per minute	3.0	474 acid	695 acid	43,800	20.76	30.44		
4	June 12, 1941	11,900	do	3.1	610 acid	939 acid	71,400	43.55	67.04		
	Oct. 31, 1946	11,400	do	2.9	515 acid	850 acid	68,400			35.23	58.14
5	Nov. 17, 1941	[1] 3,000	do	3.2	221 acid	308 acid	18,000	3.98	5.54		
6	do	[1] 2,500	do	2.9	524 acid	734 acid	15,000	7.86	11.01		
7	Nov. 18, 1941	[1] 5,000	do	3.1	245 acid	398 acid	30,000	7.35	11.94		
8	June 12, 1941	[1] 1,500	do	3.1	306 acid	429 acid	9,000	2.75	3.86		
9	do	[1] 500	do	2.8	1,128 acid	1,344 acid	3,000	3.38	4.03		
Total								104.93	156.28		

WESTERN MIDDLE FIELD

1	Sept. 17, 1941	[1]3,000	Gallons per minute	5.5	116 acid	321 acid	18,000	2.09	5.78		
2	do	[1]5,000	do	2.6	561 acid	1,099 acid	30,000	16.83	32.97		
3	do	50,448,000	Gallons per month	2.2	648 acid	1,056 acid	7,012	4.54	7.40		
	Sept. 23, 1946	77,760,000	do	2.8	195 acid	840 acid	10,809			2.11	9.08
4	Sept. 18, 1941	[1]3,000	Gallons per minute	2.4	890 acid	2,308 acid	18,000	16.02	41.54		
	Sept. 23, 1946	156,783,000	Gallons per month	2.9	685 acid	1,305 acid	21,792			14.93	28.44
Total								39.48	87.69		

SOUTHERN FIELD

1	Sept. 29, 1941	[1]50	Gallons per minute	2.8	540 acid	750 acid	300	0.16	0.23		
2	July 29, 1941	200	do	5.6	4 alk.	8 acid	1,200		.01		
3	Aug. 6, 1941	50	do	6.3	17 alk.	24 alk.	300				
4	Sept. 29, 1941	[1]500	do	3.1	387 acid	682 acid	3,000	1.16	2.05		
5	Aug. 8, 1941	100	do	6.2	28 alk.	34 alk.	600				
6	do	700	do	4.3	29 acid	229 acid	4,200	.12	.96		
7[2]	July 29, 1941	[1]7,000	do	3.8	18 acid	134 acid	42,000	.76	5.63		
	Aug. 6, 1941	[1]7,000	do	4.4	26 acid	137 acid	42,000	1.09	5.75		
	Sept. 25, 1946	[1]7,000	do	4.2	55 acid	75 acid	42,000			2.31	3.15
Total								2.53	9.00		
Grand total, all fields								159.99	286.04		

[1] Estimated.
[2] Repeated sample 1941 not included in total-acid loads.

TABLE 10.—*Compilation of information on volume, pH, free-acid loads, and total-acid loads of miscellaneous rivers and streams in the anthracite region*

Name and location	Date	Discharge	*p*H	Free acidity or free alkalinity as $CaCO_3$, p. p. m. (methyl-red indicator)	Total acidity or total alkalinity as $CaCO_3$, p. p. m. (phenolphthalein indicator)	Total weight of water per day, short tons	Load per day, short tons (1946)	
							Free acidity as $CaCO_3$	Total acidity as $CaCO_3$
Lackawanna River:								
Above Clinton colliery	May 2, 1941	(1)	7.3	9 alk.	11 alk.			
Below Clinton colliery	do	(1)	7.1	6 alk.	4 alk.			
Above Wilson Creek at Simpson	do	(1)	5.9	Neutral	24 acid			
Below mouth of Wilson Creek	do	(1)	4.4	do	26 acid			
At Jermyn	do	(1)	4.0	24 acid	82 acid			
Above Gravity slope at Archbald	do	(1)	4.0	29 acid	76 acid			
Above Dana drift below Gravity	do	(1)	4.0	29 acid	76 acid			
At Winton 500 feet below Dana drift	do	(1)	3.9	26 acid	84 acid			
Above Grassy Island at Olyphant	do	(1)	4.9	13 acid	55 acid			
Above Olyphant shaft	do	(1)	3.9	32 acid	124 acid			
Below Olyphant shaft	do	(1)	3.5	103 acid	287 acid			
Above Marvine pump	do	(1)	3.4	82 acid	245 acid			
600 feet below Marvine pump discharge	do	(1)	3.0	300 acid	313 acid			
150 feet above Von Storch discharge	May 13, 1941	(1)	3.2	26 acid	90 acid			
500 feet below Von Storch discharge	do	(1)	3.8	32 acid	103 acid			
Below Pennsylvania Coal Co. tunnel	May 2, 1941	(1)	3.7	53 acid	322 acid			
150 feet above No. 30 (Volpe)	May 14, 1941	(1)	5.7	Neutral	16 acid			
300 feet below No. 28 (Volpe)	do	(1)	4.8	3 acid	13 acid			
Above Baker	May 21, 1941	(1)	3.7	50 acid	158 acid			
Below Baker	do	(1)	3.7	50 acid	158 acid			
Junction of Schuylkill and Little Schuylkill Rivers near Port Clinton	Oct. 21, 1941	(1)	4.5	16 acid	90 acid			
Do	Dec. 1, 1941	(1)	4.7	13 acid	55 acid			
Pond Creek	Oct. 28, 1941	(1)	3.6	13 acid	58 acid			
Panther Creek:								
At Edwardsville	May 7, 1941	(1)	3.5	32 acid	66 acid			
About 100 yards below No. 6	do	(1)	4.6	3 acid	63 acid			
Above Lansford	do	(1)	5.8	2 alk.	2 alk.			
Preston Creek: Discharge from Huber at Hanover Township	May 19, 1941	(1)	3.6	26 acid	206 acid			
Creek at Askam shaft	do	(1)	3.0	390 acid	624 acid			
Rausch's Creek: East Branch, 1,000 feet north of Valley View	July 28, 1941	(1)	2.9	124 acid	234 acid			
Shamokin Creek at bridge, Route 14	July 23, 1941	(1)	2.4	269 acid	462 acid			

Solomon's Creek:									
25 feet above No. 4 slope	May 19, 1941	(1)	7.6	Neutral	2 alk.				
150 feet below No. 4 slope	do	(1)	2.8	266 acid	521 acid				
200 feet below junction of Solomon's and Preston Creeks	do	(1)	3.4	95 acid	271 acid				
Wilson Creek above Wilson Creek tunnel	May 2, 1941	(1)	7.1	79 alk.	43 alk.				
Shamokin Creek at Weigh Scale, Pa	Nov. 19, 1946	38 sec.-ft.	3.3	95 acid	215 acid		102, 600	9.75	22.06
Mahanoy Creek on Highway No. 14	do	(2)	3.5	160 acid	295 acid				
Mahantango Creek on Highway No. 14	do	36 sec.-ft.	6.0	Neutral	5 alk.		97, 200		
Wisconisco Creek (canal) at Millersburg, Pa	do	(2)	7.1	20 alk.	10 alk.				
Wisconisco Creek (main) at Millersburg, Pa	do	(2)	7.2	20 alk.	10 alk.				
Stony Creek near Dauphin, Pa	do	(2)	7.1	5 alk.	10 alk.				
Swatara Creek on Highway No. 125	do	(2)	4.6	Neutral	15 acid				
Swatara Creek at Middletown, Pa	do	102 sec.-ft.	7.8	85 alk.	85 alk.		275, 400		

[1] No gaging station.
[2] Not available.

TABLE 11.—*Summary of water and acid loads discharged daily from each of the four anthracite fields and from the anthracite region during 1941, short tons*

Field	Drainage-tunnel discharges					Mine discharges					Drainage-tunnel and mine discharges				
	Water	Free-acid load as—		Total-acid load as—		Water	Free-acid load as—		Total-acid load as—		Water	Free-acid load as—		Total-acid load as—	
		$CaCO_3$	H_2SO_4	$CaCO_3$	H_2SO_4		$CaCO_3$	H_2SO_4	$CaCO_3$	H_2SO_4		$CaCO_3$	H_2SO_4	$CaCO_3$	H_2SO_4
Northern	93, 000	13.05	12.79	33.07	32.41	782, 083	153.37	150.30	354.94	347.84	875, 083	166.42	163.09	388.01	380.25
Eastern Middle	219, 848	104.93	102.83	156.28	153.15	45, 088	25.30	24.79	38.11	37.35	264, 936	130.23	127.63	194.39	190.50
Western Middle	73, 012	39.48	38.69	87.69	85.94	252, 244	46.03	45.11	142.65	139.80	325.256	85.51	83.80	230.34	225.73
Southern	51, 600	2.53	2.48	9.00	8.82	304, 422	70.09	68.69	143.03	140.17	356, 022	72.62	71.17	152.03	148.99
Total, all fields	437, 460	159.99	156.79	286.04	280.32	1, 383, 837	294.79	288.89	678.73	665.16	1, 821, 297	454.78	445.69	964.77	945.47

In table 11 each mine and tunnel discharge is represented by a single sample of the discharge from the given mine or tunnel. The samples were collected at different times over a period of 8 months. The data given in tables 8, 9, 10, and 11 indicate the magnitude of the acid-mine-drainage problem. Thus, the 1,821,297 tons of mine water discharged daily from all the mines in the anthracite region, the daily free-acid load of 445.69 tons (as H_2SO_4), and the daily total-acid load of 945.47 tons (as H_2SO_4) afford an estimate of the volume and acid content of the mine drainage discharged daily into the receiving streams flowing through the anthracite region.

COST OF NEUTRALIZATION

Methods of neutralizing acid mine drainage have been known for many years (*11*) but have not been applied to any great extent until recently (*12*). Acid mine water is neutralized by adding alkaline salts to the acid water and then discharging the resultant mixture into streams, with or without settling of the precipitated solids. Quicklime, agricultural lime, granular limestone, and hydrated lime have been utilized in the neutralization of acid mine water. Although hydrated lime costs more than quicklime, it is the form of lime most commonly used, principally because of its greater neutralizing power and smaller quantity of sludge.

The quantity of hydrated lime required to treat acid mine water depends on the end point sought, the acid content of the mine water, and the quantity of water to be treated.

The cost of complete neutralization of the acid mine drainage at four widely separated points selected at random in the anthracite region is itemized as follows:

Colliery A—Pumping 24,000 g. p. m. having a *p*H of 3.1:

Hydrated lime a day	$793. 50
Labor, 3 shifts at $8	24. 00
Power	10. 00
Chemical supervision	2. 00
Interest and depreciation on plant and equipment	16. 50
Total cost a day	846. 00

Production at colliery A—1,063 tons a day.
Cost of neutralization per ton of coal—$0.795.

Colliery B—Pumping 465,164,250 gallons per month having a *p*H of 3.0:

Hydrated lime a day	$345. 00
Labor, 3 shifts at $8	24. 00
Power	7. 50
Chemical supervision	2. 00
Interest and depreciation on plant and equipment	16. 50
Total cost a day	395. 00

No production at colliery B; cost must be charged against tonnage produced at other collieries of the company.

Colliery C—Pumping 4,500 g. p. m. having a *p*H of 3.1:

Hydrated lime a day	$149. 50
Labor, 3 shifts at $8	24. 00
Power	5. 00
Chemical supervision	2. 00
Interest and depreciation on plant and equipment	16. 50
Total cost a day	197. 00

Production at colliery C—2,312 tons a day.
Cost of neutralization per ton of coal—$0.09.

Collieries D—Draining 12,000 g. p. m. having a pH of 2.9:

Hydrated lime a day	$402.50
Labor, 3 shifts at $8	24.00
Power	10.00
Chemical supervision	2.00
Interest and depreciation on plant and equipment	16.50
Total cost a day	455.00

Production at collieries D—4,346 tons a day.
Cost of neutralization per ton of coal—$0.105.

This tabulation shows only the cost of neutralization by slaked lime. If complete removal of the acid in mine drainage is to be accomplished, the cost of artificial settling and of separation equipment or the cost of the excavation and periodic cleaning of natural settling basins must be added to the cost of neutralization by slaked lime. In addition, the cost of disposal of the sludge that results from chemically treated water must also be considered and may well become a major factor in any large-scale operation.

Complete neutralization of acid mine drainage in the anthracite region, even if it were possible, would burden the anthracite industry with an exorbitant, if not prohibitive cost (*12*).

The problem of mine drainage in anthracite mines is discussed in reports by Ash, Westfield, and others (*1, 2, 3, 4*). Mine drainage is a major problem in anthracite mines, and the difficulties, instead of diminishing, are becoming increasingly greater. No practicable method of removing the acid properties of mine drainage is known, and it seems illogical that an additional burden of cost should be placed on the industry in an attempt to remedy an acid-water condition that, because of the sewage and industrial wastes that find their way into the receiving streams, is at present distinctly beneficial rather than detrimental.

The sealing of mines or sections of mines to prevent the formation of acid in mine water has been accomplished successfully in some bituminous-coal mines (*14, 15, 22, 23*).

Whether abandoned mines in the anthracite region can or should be sealed to exclude air from water and thereby attempt to prevent the formation of acid is doubtful. To effectively seal anthracite mines appears to be impossible because of the number of man-made openings to the surface, the number of cave holes, the general subsidence over mined-out areas that has caused fissures in the strata between mine workings and the ground surface, the numerous stripping pits exposing permeable coal beds to water and atmospheric air, and the large number of workable beds that have dips ranging from flat to vertical.

SUMMARY

Acid drainage from mining operations in the anthracite region of Pennsylvania is a problem in stream sanitation confronting communities situated along the banks of the receiving streams and scattered over their drainage basins both in and outside the anthracite region. It is therefore one of the principal factors to be considered in the conduct of any anthracite mine-flood-prevention program.

The pH of samples of river water collected at the same point generally are comparable. When volumes of flow at a given sampling point are approximately the same at different sampling times, the *p*H of the river water at those times compares closely. Free and total acidity or free and total alkalinity of river waters as determined by chemical analyses in 1941 and 1946 are nearly the same for comparable volumes of flow.

Considering the differences in the volume of flow at different times, two points of importance become apparent:

1. Changes in the acidity or the alkalinity of river water, as indicated either by its *p*H or by analytical determinations of free and total acidity or free and total alkalinity, cannot be predicted by changes in the volume of flow. In some instances decreased volumes of flow accompany decreased alkalinity or increased acidity, whereas in others decreased volumes of flow accompany increased alkalinity or decreased acidity.
2. The changes in free and total acidity or free and total alkalinity (in parts per million) are much less marked than the corresponding changes in the volume of flow. For example, when the volume of flow changed in a ratio of 6:1 or more, the acidity or alkalinity changed only in a ratio of 2:1 or less. The greatest acidity or alkalinity in many instances was less than 50 parts per million and in almost all instances less than 100 parts per million. Apparently, the relative concentration of acidity or alkalinity of river water remains essentially constant regardless of the variation in the volume of flow.

This investigation shows that the main streams and rivers that flow through the anthracite region are almost always alkaline at all points within the anthracite region itself; moreover, short distances below the coal measures the rivers are permanently alkaline.

The Susquehanna River was always alkaline at all points, except during low-water periods in July and October 1941, when samples at Danville indicated an acid condition at that point, and at Harrisburg in July 1941, when the river water was slightly acid. Throughout its length this river receives a greater quantity of acid mine drainage than any other stream in the region, but the samples at Wilkes-Barre, Danville, and Harrisburg showed that the water was normally alkaline and had only a slight tendency, if any, to become acid.

Analysis of a sample of water taken in November 1946 from the West Branch of the Susquehanna River just above the point of confluence with the North Branch of the Susquehanna River showed that the water in the West Branch at that point was also alkaline. The West Branch does not flow through the anthracite region but does receive acid mine drainage from bituminous-coal mines in central Pennsylvania.

The Lehigh River at Lehigh Tannery was slightly alkaline at all times but on two occasions showed some acidity. Samples collected from the Lehigh River at Bethlehem, 30 miles below the coal measures, indicated that the river water was alkaline at that point at all times. The Lehigh River is a tributary of the Delaware River, joining it at Easton, Pa.

The Schuylkill River was acid at its headwaters near Tuscarora, Pa., but the Little Schuylkill River was alkaline at its headwaters near Hometown. Both streams were acid at their junction at Port Clinton, but at Hamburg, 14 miles below the anthracite region, the Schuylkill River was alkaline. Samples taken at Pottstown and

Philadelphia were alkaline, and chemical analysis by hot titration indicated even greater alkalinity.

The Lackawanna River was alkaline at its headwaters near Union dale, Pa., but became and remained acid as it passed through Archbald Scranton, and Old Forge to the point of confluence with the Susquehanna River near Pittston. However, the comparatively small volume of highly acid water in the Lackawanna River was diluted after its confluence with the Susquehanna River, and samples at Wilkes-Barre indicated a river water that was nearly neutral.

A sample collected from the Delaware River in Philadelphia in October 1946 showed that the water was alkaline at that point.

The effects of acid mine drainage entering the Lehigh, Schuylkill, and Susquehanna Rivers rapidly disappear. These streams receive undeterminable quantities of sewage and industrial wastes along their entire course above, in, and below the anthracite region. Moreover, the Susquehanna River, after leaving the anthracite region, flows for 17.5 miles through limestone areas lying between the coal measures and Harrisburg; the Lehigh River flows for 21 miles through limestone areas lying between Lehigh Tannery and Easton; and the Schuylkill River flows for 48 miles through limestone areas lying along its course. The acid in the mine drainage reacts with and is neutralized by the sewage and industrial wastes discharged into the rivers and is further neutralized by the limestone through which the rivers flow.

Under present conditions acid mine drainage appears to be beneficial rather than detrimental to the municipalities along the banks and scattered over the drainage basins of the Lehigh, Schuylkill, and Susquehanna Rivers because of its neutralizing action on the highly alkaline sewage and industrial wastes in the receiving streams.

Sludge and other residues that settle on the river beds as a result of the chemical reaction between the acid and alkaline contaminants in the streams are undesirable. The germicidal, inhibiting, and neutralizing effects of acid mine drainage are not controlled and are not consistent. In addition to the fact that there is no practicable means of treatment known, there is also no incentive or justification for treatment or diversion of acid mine drainage if the receiving streams remain unsuitable for any use other than disposal of sewage and industrial wastes.

Streams are polluted not only by the anthracite-mining industry but also by other industries and communities that utilize the streams for their own purposes. The control of stream pollution is the responsibility of all communities and industries that could be considered as offenders.

The 1,821,297 tons of mine water discharged daily from all the mines in the anthracite region, the daily free-acid load of 445.69 tons (as H_2SO_4), and the daily total-acid load of 945.47 tons (as H_2SO_4) afford an estimate of the volume and acid content of the mine drainage discharged daily into the receiving streams flowing through the anthracite region.

If complete removal of the acid in mine drainage is to be accomplished, the cost of artificial settling and of separation equipment or the cost of the excavation and periodic cleaning of natural settling basins must be added to the cost of neutralization by slaked lime. In addition, the cost of disposal of the sludge that results from chemically treated water must also be considered and may well become a major factor in any large-scale operation.

Complete neutralization of acid mine drainage in the anthracite region, even it it were possible, would burden the anthracite industry with an exorbitant if not prohibitive cost.

Mine drainage is a major problem in anthracite mines, and the difficulties encountered, instead of diminishing, are becoming increasingly greater. No practicable method of removing the acid properties of mine drainage is known, and it seems illogical that an additional burden of cost should be placed on the industry in an attempt to remedy an acid-water condition that, because of the sewage and industrial wastes that find their way into the receiving streams, is at present distinctly beneficial rather than detrimental.

Whether abandoned mines in the anthracite region can or should be sealed to exclude air from water and thereby attempt to prevent the formation of acid is doubtful. To effectively seal anthracite mines appears to be impossible because of the number of man-made openings to the surface, the number of cave holes, the general subsidence over mined-out areas that has caused fissures in the strata between mine workings and the ground surface, the numerous stripping pits exposing permeable coal beds to water and atmospheric air, and the large number of workable beds that have dips ranging from flat to vertical.

BIBLIOGRAPHY

1. ASH, S. H. Mine Water—A Major Problem in the Pennsylvania Anthracite Region. Proc. 32d ann. conv., Mine Inspector's Inst. America, 1941, pp. 127–146.
2. ———. Water Problem in the Pennsylvania Anthracite Mining Region. Bureau of Mines Inf. Circ. 7175, 1941, 11 pp.
3. ASH, S. H., AND WESTFIELD, JAMES. Flood-Prevention Projects at Pennsylvania Anthracite Mines. A Preliminary Study. Bureau of Mines Rept. of Investigations 3868, 1946, 25 pp.
4. ASH, S. H., CASSAP, W. E., WESTFIELD, JAMES, EATON, W. L., ROMISCHER, W. M., PODGORSKI, E. J., AND JOHNSON, L. H. Flood-Prevention Projects at Pennsylvania Anthracite Mines. Progress Report for 1945. Bureau of Mines Rept. of Investigations 4109, 1947, 107 pp.
5. CLARK, W. MANSFIELD. The Determination of Hydrogen Ions. Williams & Wilkins Co., Baltimore, Md., 1920, 317 pp.
6. CRIGHTON, ANDREW B. Mine-Drainage Stream Pollution. Trans. Am. Inst. Min. and Met. Eng., vol. 69, 1923, pp. 434–446.
7. EDWARDS, DEAN G. Public Interest and Welfare as Affected by the Anthracite Mine-Drainage Problem. Report prepared for Anthracite Mine Drainage Subcommittee of the Susquehanna Drainage Basin Committee, National Resources Planning Board, Jan. 14, 1941, 9 pp.
8. FINDLAY, ALEXANDER. Introduction to Physical Chemistry. Longmans, Green & Co., London, 1933, p. 329.
9. GEHM, HARRY W. Neutralization of Acid Waste Waters with an Upflow Expanded Limestone Bed. Fed. Sewage Works Assoc., Sewage Works Jour., vol. 16, No. 1, January 1944, pp. 104–120.
10. GRIFFITH, EDWARD. Mine-Drainage Practice in the Anthracite Region of Pennsylvania. Am. Inst. Min. and Met. Eng. Tech. Pub. 1907, 1945, 18 pp.
11. HANDY, J. O. Mine-Water Purification. Min. Cong. Jour., vol. 12, 1926, pp. 421–422.
12. JOHNSON, L. H. Treatment of Acid Mine Water for Breaker Use in the Anthracite Region of Pennsylvania. Bureau of Mines Inf. Circ. 7382, 1946, 14 pp.

13. Kolthoff, I. M., and Furman, N. Howell. Indicators. John Wiley & Sons, Inc., 1926, pp. 188–189.
14. Leitch, R. D., and Yant, W. P. A Comparison of the Acidity of Waters from Some Active and Abandoned Coal Mines. Bureau of Mines Rept. of Investigations 2895, 1928, 8 pp.
15. Leitch, R. D., Yant, W. P., and Sayers, R. R. Effect of Sealing on Acidity of Mine Drainage. Bureau of Mines Rept. of Investigations 2994, 1930, 11 pp.
16. MacInnes, Duncan A. The Principles of Electrochemistry. Reinhold Publishing Corporation, 1939, p. 269.
17. Perley, G. A. Modern Views of *p*H Measurements. American Dyestuff Reporter, Dec. 27, 1937.
18. Roos, George A. Mine Drainage in the Anthracite Region. Min. Cong. Jour., vol. 31, No. 6, June 1945, pp. 32–34, 50.
19. Sørensen, S. P. L. Études enzymatiques. II. Sur la mesure et l'importance de la concentration des ions hydrogène dans les réactions enzymatiques. Compt. rend. Lab. Carlsberg, vol. 8, No. 1, 1909, pp. 1–165.
20. Steiner, Kalman. *p*H, What It Means and How It's Measured. Heat., Pip., and Air Cond., vol. 16, No. 1, January 1944, pp. 11–15.
21. Stewart, A. H. Stream-Pollution Control in Pennsylvania. Fed. Sewage Works Assoc., Sewage Works Jour., vol. 17, No. 3, May 1945, pp. 586–593.
22. Coal Mining. Substantial Progress Reported in Mine Seal Program. Vol. 15, No. 2, February 1938, pp. 8–10.
23. U. S. Public Health Service. Acid Mine Drainage Studies, Supplement C. Federal Security Agency, Office of Stream Sanitation, Cincinnati, Ohio, 1942, 68 pp.

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