

1979

## Influence of Coal Mining on Water Quality in Marion and Mahaska Counties, Iowa

Thomas P. Nesler  
*Iowa State University*

Roger W. Bachmann  
*Iowa State University*

*Let us know how access to this document benefits you*

Copyright ©1979 Iowa Academy of Science, Inc.

Follow this and additional works at: <https://scholarworks.uni.edu/pias>

---

### Recommended Citation

Nesler, Thomas P. and Bachmann, Roger W. (1979) "Influence of Coal Mining on Water Quality in Marion and Mahaska Counties, Iowa," *Proceedings of the Iowa Academy of Science*, 86(4), 149-153.

Available at: <https://scholarworks.uni.edu/pias/vol86/iss4/9>

This Research is brought to you for free and open access by the Iowa Academy of Science at UNI ScholarWorks. It has been accepted for inclusion in Proceedings of the Iowa Academy of Science by an authorized editor of UNI ScholarWorks. For more information, please contact [scholarworks@uni.edu](mailto:scholarworks@uni.edu).

## Influence of Coal Mining on Water Quality in Marion and Mahaska Counties, Iowa<sup>1</sup>

THOMAS P. NESLER<sup>2</sup> and ROGER W. BACHMANN

Department of Animal Ecology, Iowa State University, Ames, Iowa 50011

In the spring and summer of 1976, a water-sampling program was carried out on the streams of Marion and Mahaska counties, where a significant portion of the coal mining in Iowa has occurred. Streams with underground mines or combinations of underground and surface mines in their watersheds had decreased values for alkalinity and increased values for specific conductance and sulfates, indicating the presence of acid mine drainage. Unless reclamation procedures are incorporated into standard mining operations, an expansion of Iowa coal mining could lead to an increase in the severity of this problem.

INDEX DESCRIPTORS: water quality, acid mine drainage, Iowa streams.

Recent interest in expanding coal mining in Iowa prompted this study on the effects of past and recent coal mining on water quality in the coal mining areas of Iowa. The process of mining high-sulfur coal, both through strip mining and deep mining, disturbs and accelerates the natural chemical breakdown of sulfuritic material, resulting in the production of a form of water pollution called acid mine drainage (AMD). This effluent from the mining area contains an array of pollutants along with sulfuric acid that may be toxic to the aquatic community.

Sulfides may be found within the coal seam as organic or mineralized sulfur, and the latter may exist as fine crystals dispersed throughout in many layers, streaks, or aggregates (sulfur balls) or as larger crystals and nodules (Aston, 1974; Brant and Moulton, 1960; Hanna and Brant, 1962; Hodge, 1938). Sulfuritic material also may occur in the sandstone and shale strata in the overburden (Corbett, 1969; Emrich and Merritt, 1969; Hanna and Brant, 1962). Spoil banks, consisting of the cast overburden containing sulfuritic materials, provide a large surface area of exposed, fractured sulfides, which are oxidized to various acid salts and eventually leached out of the surface layers (Hanna *et al.*, 1963). Erosive action continues to expose more sulfuritic material. Acidic materials also are produced by oxidation of sulfuritic materials in underground mines.

The oxidation process creating AMD in nature is typically described by slow chemical reactions accelerated by bacterial catalysis. The pathway in Figure 1 indicates iron sulfide in the overburden or mine shaft being oxidized by several means to form acid salts that are hydrolyzed to an insoluble precipitate. The role of oxidants in acid formation is divided between atmospheric oxygen and ferric iron. In the natural state, iron is in a reduced form, and initial oxidation is caused from oxygen in contact with the mineral. Iron pyrite may produce ferrous iron from simple dissociation or through oxidation by oxygen (Singer and Stumm, 1970). In order of occurrence, the sulfur component is oxidized initially, followed by oxidation of the ferrous iron (Barnes and Romberger, 1968). Upon formation of ferric iron, the reaction assumes a cyclical, self-accelerating character that can proceed without the presence of oxygen (Baker and Wilshire, 1970; Boyer, 1970; Walsh and Mitchell, 1972). The concentration of ferric iron and the ratio of ferrous to ferric iron subsequently become important fac-

tors, influencing the rate of iron sulfide oxidation directly and exponentially (Garrels and Thompson, 1960). Ferric iron may supplant oxygen as the major oxidant (Morth *et al.*, 1972; Singer and Stumm, 1970).

As a chemical reaction, the oxidation of ferrous iron has a half time of 1000 days, while the oxidation of sulfur by ferric iron is rapid by comparison (Singer and Stumm, 1970). The characteristically rapid rate of acid production observed at some mine areas is due to the action of the chemosynthetic, autotrophic iron and sulfur bacteria, *Thiobacillus ferrooxidans* and *T. thiooxidans* (upon ferrous iron oxidation), which can increase the reaction rate by a factor of 10<sup>8</sup> (Lundgren, 1971; Singer and Stumm, 1970). In the cyclical pathway of AMD formation, the bacterial acceleration of ferrous iron oxidation increases production of ferric iron which, in turn, increases the oxidation of iron sulfide sulfur, producing more ferrous iron to complete the cycle. The sulfate ion produced is considered a requirement for bacterial oxidation of ferrous iron by serving to bind the ferrous iron ion to the bacterial membrane (Lundgren, 1971). The potential of the acid bacteria is not fully attained because iron is removed from the cycle through the hydrolysis of ferric iron to its insoluble precipitate, which is unreactive with pyrite (Stumm-Zollinger, 1972). The hydrolysis process results in a series of intermediate products. The ratio of Fe:OH:SO<sub>4</sub> in any of these products depends upon the available water, the intensity of acidity, and available ferric sulfate (Leathen *et al.*, 1953; Parsons, 1968).

AMD is a complex pollutant containing, not only high concentrations of hydrogen ion, sulfates, and iron, but also other minerals that are leached out of the surrounding materials by the acidic waters. Normally insoluble metallic carbonates, silicates, and phosphates become soluble in the low pH drainage (Osborn and Hem, 1962) so that AMD, as a pollutant, has the potential for a wide range of toxic effects and water-quality degradation.

The purpose of this study was to survey the streams in a coal-producing area of Iowa to determine if the effects of AMD were present as a result of past and present mining activities. Four parameters were measured: alkalinity, specific conductance, sulfate, and total iron. If AMD is present, the levels of sulfates and total iron should be elevated because they are direct products of the oxidation process. Higher values of specific conductance also would be expected, reflecting increased ionic concentrations, while the alkalinity would be reduced due to the reaction of hydrogen ions with the carbonates and bicarbonates naturally found in Iowa waters.

### METHODS

Sampling was carried out in Marion and Mahaska counties, where a significant portion of the coal mining in Iowa has occurred. Seventy-

<sup>1</sup>Journal Paper No. J-9276 of the Iowa Agriculture and Home Economics Experiment Station, Ames, Iowa. Project No. 2109. Financed by the Iowa Coal Project.

<sup>2</sup>Present address: P.O. Box 1176, Buena Vista, CO 81211

Table 1. Calculated mean values and standard deviations for water-quality parameters of stream groups unaffected by coal mining activity (O), affected by underground coal mining only (U), and affected by both surface and underground coal mining (S-U). Numbers in parentheses indicate number of measurements used in calculation of mean. Values in footnotes are calculations including extreme values for the given parameters in the given time periods.

		Parameters			
Time period/ Stream Group		Alkalinity (mg CaCO <sub>3</sub> /L)	Specific Conductance (umhos/cm)	Sulfate (mg SO <sub>4</sub> /L)	Total Iron (mg Fe/L)
May 7-8					
	O	143.2 ± 23.6 (23)	451 ± 59 (23)	45.9 ± 16.9 (23)	0.32 ± 0.27 (19)
	U	137.2 ± 26.9 (13)	480 ± 79 (13)	75.2 ± 43.0 (13)	0.37 ± 0.31 (11)
	S-U	109.3 ± 55.0 (20)	859 ± 446 (20)	207.2 ± 222.0 (20)	0.75 ± 1.09 (18)
June 21-22					
	O	161.4 ± 19.0 (22)	479 ± 47 (22)	47.5 ± 13.6 (22)	0.23 ± 0.17 (22)
	U	149.3 ± 24.4 (13)	517 ± 135 (13)	95.2 ± 79.8 (13)	0.18 ± 0.06 (13)
	S-U	119.0 ± 59.9 (20)	849 ± 393 (18) <sup>a</sup>	391.9 ± 399.5 (20)	0.67 ± 1.03 (19) <sup>b</sup>
July 27-28					
	O	174.7 ± 34.0 (22)	456 ± 69 (22)	43.0 ± 18.2 (22)	0.21 ± 0.11 (22)
	U	136.6 ± 53.2 (13)	444 ± 139 (13)	74.3 ± 65.2 (13)	0.27 ± 0.09 (13)
	S-U	91.5 ± 79.8 (20)	1056 ± 504 (20)	493.7 ± 427.2 (20)	0.57 ± 0.83 (19) <sup>c</sup>

<sup>a</sup>3224 ± 7321 (20)

<sup>b</sup>2.95 ± 10.22 (20)

<sup>c</sup>2.73 ± 9.69 (20)

three collection stations were established, which included all the streams in those counties listed by Larimer (1974), excluding agricultural drainage ditches. The locations are given in Nesler (1977). Streams were classified according to the presence (affected) or absence (unaffected) of underground and (or) surface mines within the watershed of the given streams. Affected or unaffected status was determined from maps showing present or past mines. These were obtained from L.V.A. Sendlein and P.R. Johnson, of the Energy and Mineral Resources Research Institute at Ames, and N.E. Harl and J. Achterhof of the Department of Economics, Iowa State University. Stream sampling stations were designated as unaffected (O), affected by underground mines only (U), or affected by combinations of surface and underground mines (S-U), on the basis of the presence or absence of these activities on the respective watersheds.

Water samples were collected in the spring and summer of 1976. It was not possible to measure volume of flow in each stream so the flows at the U.S. Geological Survey gaging station on Cedar Creek near Bussey, Iowa were used as an index of relative flow. The first samples were taken on May 7-8 about 2 weeks after the spring rains and high runoff flows in the area. The flow in Cedar Creek was 160% of the long-term average flow for that stream. The next samples were collected on June 21-22 when flows had decreased to a lower base flow relative to May but following an extended period of rainstorms starting 11 days earlier. Cedar Creek was flowing at 26% of average on those days and at 31% of average on July 27-28 when the third set of samples was collected. Flows had been lower previously, but a series of rainstorms had increased flows on those days.

Water samples were collected in plastic bottles and stored in darkness at room temperature until the final analyses were completed.

Alkalinities were determined within 48-72 hours of collection by titration with 0.02 N H<sub>2</sub>SO<sub>4</sub> to a pH 4.5 end point by using a pH meter. Specific conductance was measured with a Markson 4403 Digital Electroanalyzer. Sulfates were measured with a turbidimetric method following standard methods (APHA, AWWA, WPCF, 1971) and Hach analytical procedures (Hach Chemical Co., 1975). Turbidity was measured with a Hach 2100 turbidimeter. Total iron was determined spectrophotometrically according to standard methods (APHA, AWWA, WPCF, 1971), and Hach analytical procedures (Hach Chemical Co., 1975). Optical densities were read on a Beckman DU-2 spectrophotometer.

## RESULTS

All the original data are presented in Nesler (1977). Figure 2 summarizes the results in the form of frequency histograms for the 4 parameters and the 3 sampling dates. To maintain independent samples, some stations were not included where upstream stations were sampled on the same stream. The data were most variable for the streams with both underground and surface mines in the watersheds. The lowest values for alkalinity were found in those streams along with the highest values for specific conductance, sulfate, and total iron. This is illustrated in Table 1 where the means and standard deviations are given for each of the measurements on each of the dates. In each instance, the S-U streams have the highest standard deviations. With the exception of total iron in June and specific conductance in July, there is a consistent trend in the means throughout. Alkalinities decrease in going from the O to the S-U streams, and specific conduc-

tance, sulfate, and total iron values increase in the same order.

Because the group variances are unequal and because of the large number of extreme values in the S-U group, normal statistics are inappropriate to test for the significance of differences between the groups. Instead, the values found in the streams studied were compared with similar measurements from the Iowa River by using a Chi-square test. The study streams had not been sampled prior to mining. The Iowa River was chosen because the geology of the drainage basin is similar to that of the control streams in the study area, and 10 years of continuous data (1944-1954) are available (Iowa Geological Survey, 1955). For each parameter, data were taken from the Iowa River record that coincided as closely as possible to the May, June and July sampling periods. Means were calculated for each parameter in each period and tested for significant differences between periods by the t-test after Snedecor and Cochran (1967). Most of the calculated t-values showed insignificance at the  $p = 0.05$  level, so grand means combining all 3 periods were determined for each parameter. The reference points for comparison were found by subtracting 2 standard deviations from the mean of alkalinity and adding 2 standard deviations to the mean for specific conductance, sulfate, and total iron. If the study streams are similar to the Iowa River, they would be expected to have alkalinity values greater than 111 mg/l as  $\text{CaCO}_3$ , specific conductances of less than 594 umhos/cm, sulfate concentrations of less than 62.4 mg/l, and total iron concentrations of less than 0.24 mg/l. The null hypothesis for each parameter is that the proportion of samples above and below these reference points will not be different for the 3 stream groups. The Chi-square tests for all 3 sample dates combined are given in Table 2. The null hypothesis is rejected for alkalinity, specific conductance, and sulfate, indicating that the proportions are not the same for the 3 stream groups for those parameters. No significant difference was found for the total iron concentrations.

Table 2. Chi-square analysis of measurements of alkalinity, specific conductance, sulfate, and total iron for unaffected (O), and affected (U, S-U) stream groups for the May, June, and July sampling periods.

	Stream Classification			
	O	U	S-U	Total
Alkalinity $\leq$ 111	2	7	26	35
Alkalinity $>$ 111	65	32	34	131
Total	67	39	60	166

Chi-square = 31.0  $n = 5$   $p < .01$

	Stream Classification			
	O	U	S-U	Total
Sp. Cond. $\leq$ 594	67	34	13	114
Sp. Cond. $>$ 594	0	5	47	52
Total	67	39	60	166

Chi-square = 97.8  $n = 5$   $p < .01$

	Stream Classification			
	O	U	S-U	Total
Sulfate $\leq$ 62.4	61	23	5	89
Sulfate $>$ 62.4	6	16	55	77
Total	67	39	60	166

Chi-square = 87.9  $n = 5$   $p < .01$

	Stream Classification			
	O	U	S-U	Total
Total iron $\leq$ 0.24	49	25	33	107
Total iron $>$ 0.24	18	14	27	59
Total	67	39	60	166

Chi-square = 4.59  $n = 5$  Not significant

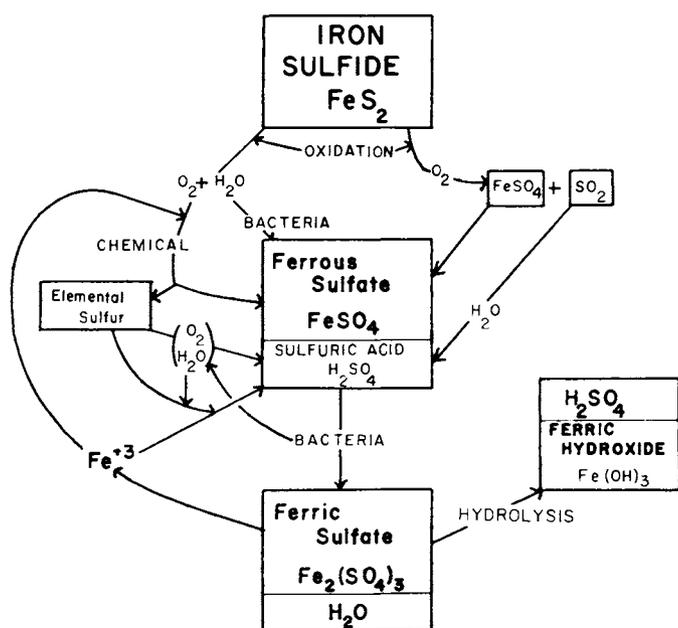


Figure 1. Oxidation-hydrolysis pathway in the formation of acid coal mine drainage.

## DISCUSSION

The data demonstrate that water quality is altered in the watersheds of Marion and Mahaska counties that have been affected by underground or combinations of surface and underground mining. This is indicated by decreased values for alkalinity and increased values for specific conductance and sulfates. Although the Chi-square test did not show significant differences for the total iron, all the extremely high values for iron were found in the watersheds with combinations of surface and underground mines. Because iron from AMD may be precipitated out in alkaline stream waters, it probably is not as good an indicator of AMD as the other parameters measured.

The tests used here are conservative inasmuch as the sampling design does not take into account the percentage of land area mined in the watersheds, the proportion of surface to underground mining, differences in the leachability of the spoils, and the distance between acid production and sampling sites. These contribute to the high variances noted in the frequency distributions. Relative to the narrow distribution of the 4 parameters for unaffected streams in each time period, the distributions in the affected groups become progressively extended in

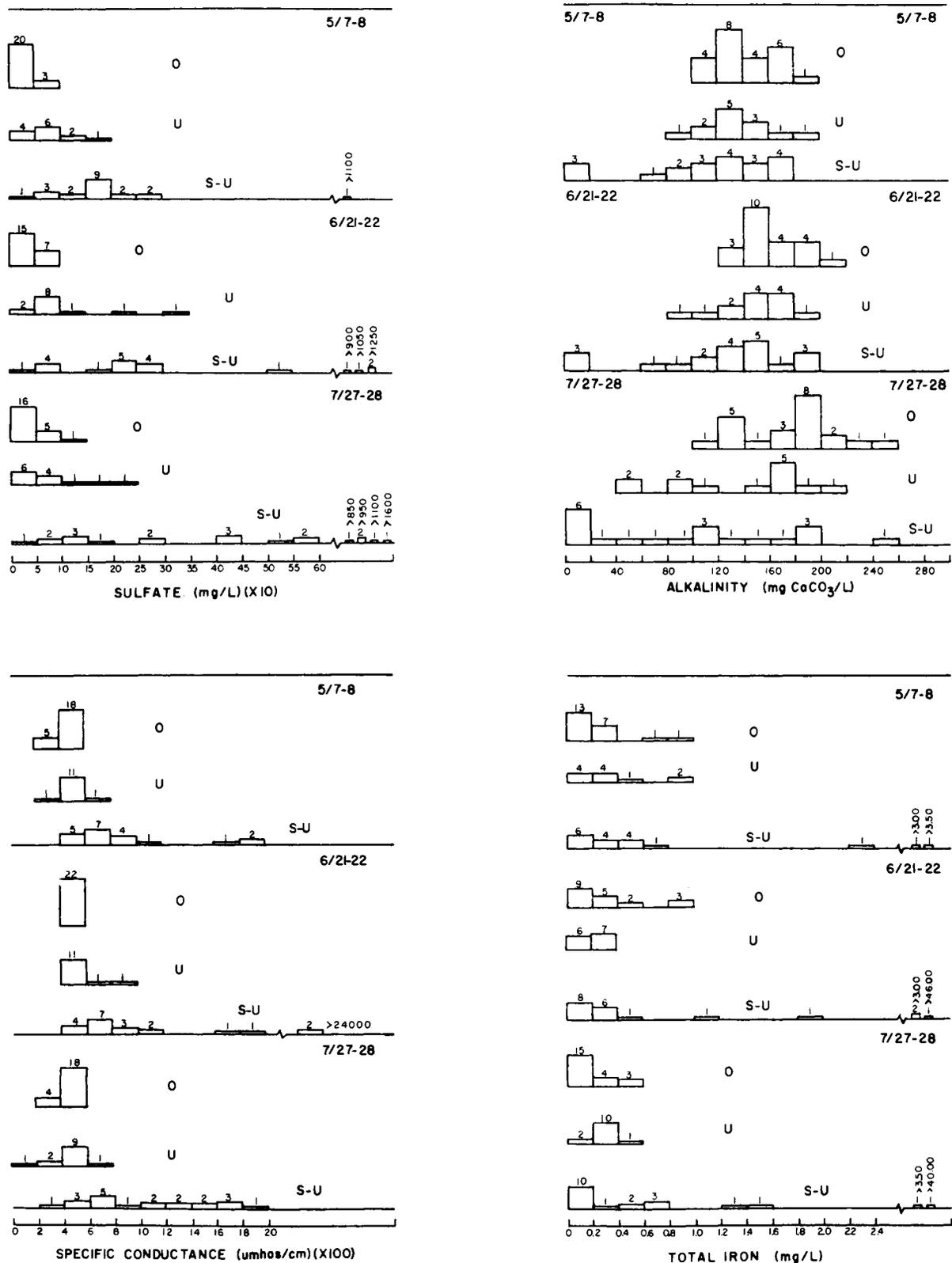


Figure 2. Frequency distributions of alkalinity, specific conductance, sulfate, and total iron measurements made on streams in watersheds unaffected by coal mining (O), affected by underground mines only (U), and affected by both surface and underground mines (S-U).

range in going from the O to the U to the S-U groups, and from May to June to July.

During stream sampling, 10 of the streams (listed in Nesler, 1977) exhibited visual evidence of AMD pollution throughout the study. Residual deposits of orange iron precipitate were observed in these streams. In some instances of severe AMD pollution, the iron precipitate completely coated the stream bottom. Flocculant iron precipitate (yellow boy) was observed suspended in the stream water in 1 instance, but affected stream waters were predominantly quite clear in contrast to the turbidity of the control streams. The substrate of the affected streams exhibited a more heterogeneous mixture of gravel, coal fragments, coal fines, coarse sand, and silt compared with the control streams. Coal fines completely obscured a stream bottom in 1 situation. Fish were never observed in these AMD-polluted streams versus normally frequent observations in other streams.

Because the production of AMD can vary with time as environmental conditions change and its impact on a receiving stream will vary with the amount of dilution water available, it is unlikely that this short-term survey detected the worst conditions that can occur in these streams. It did demonstrate that AMD pollution does exist in the streams of the coal mining areas of Iowa. Unless special steps are taken, an expansion of Iowa coal mining could lead to an increase in the severity of this problem.

#### ACKNOWLEDGMENTS

Dr. David F. Cox provided statistical consultation, and Dr. David Zimmer assisted with laboratory analysis.

#### REFERENCES

- APHA, AWWA, WPCF. 1971. Standard methods for the examination of water and wastewater. 13th ed. Amer. Public Health Assoc. New York. 874 pp.
- ASTON, W.M. 1974. Fool's gold pollutes. *Can. Min. J.* 95(3):59-61.
- BAKER, R.A., and A.G. WILSHIRE. 1970. Evaluation of potential acid mine drainage. *Water and Sewage Works* 117:10-16.
- BARNES, H.L., and S.B. ROMBERGER. 1968. Chemical aspects of acid mine drainage. *J. Water Pollut. Control Fed.* 40:371-384.
- BOYER, J.F. 1970. Coal and coal mine drainage (literature review). *J. Water Pollut. Control Fed.* 42:1179-1185.
- BRANT, R.A., and E.Q. MOULTON. 1960. Acid mine drainage manual. Ohio State Univ. Eng. Exp. Stn. Bull. 179:1-40.
- CORBETT, D.M. 1969. Acid mine-drainage problem of the Patoka River watershed, southwestern Indiana. *Indiana Water Resour. Res. Cent. Rep.* 4.
- EMRICH, G.H., and G.L. MERRITT. 1969. Effects of mine drainage on ground water. *Ground water* 7:27-32.
- GARRELS, R.M., and M.E. THOMPSON. 1960. Oxidation of pyrite by iron sulfate solutions. *Am. J. Sci.* 258-A:57-67.
- HACH CHEMICAL CO. 1975. Procedures, chemical lists and glassware for water and wastewater analysis. 3rd ed. Ames, Iowa. 196 pp.
- HANNA, G.P., and R.A. BRANT. 1962. Stratigraphic relations to acid mine water production. *Purdue Univ. Eng. Ext. Ser.* 112:476-492.
- HANNA, G.P., J.R. LUCAS, C.I. RANGLES, E.E. SMITH, and R.A. BRANT. 1963. Acid mine drainage research potentialities. *J. Water Pollut. Control Fed.* 35:275-292.
- HODGE, W.W. 1938. The effect of coal-mine drainage on West Virginia rivers and water supplies. *W. Va. Univ. Eng. Exp. Stn. Res. Bull.* 18.
- IOWA GEOLOGICAL SURVEY. 1955. Quality of surface waters of Iowa 1886-1954. *Water-Supply Bull.* 5. Iowa City.
- LARIMER, O.J. 1974. Drainage areas of Iowa streams. *Iowa Highway Res. Board Bull.* 7.
- LEATHEN, W.W., S.A. BRALEY, SR., and L.D. MCINTYRE. 1953. The role of bacteria in the formation of acid from certain sulfuritic constituents associated with bituminous coal. I. *Thiobacillus thiooxidans*. *Appl. Microbiol.* 1:61-64.
- LUNDGREN, D.G. 1971. Inorganic sulfur oxidation by iron-oxidizing bacteria. *Environ. Protection Agency Water Pollut. Control Res. Ser.* 14010 DAY 06/71.
- MORTH, A.H., E.E. SMITH, and K.S. SHUMATE. 1972. Pyritic systems: a mathematical model. *Environ. Prot. Agency Technol. Ser.* EPA-R2-72-002.
- NESLER, T.P. 1977. Water quality guidelines for acid mine drainage and strip mine areas in Iowa. M.S. Thesis, Iowa State Univ., 173 pp.
- OSBORN, E.T., and J.D. HEM. 1962. Microbiologic factors in the solution and transport of iron. *In Chemistry of iron in natural water*. U.S. Geol. Surv. Water Supply Pap. 1459-H.
- PARSONS, J.D. 1968. The effects of acid strip-mine effluents on the ecology of a stream. *Arch. Hydrobiol.* 65:25-50.
- SINGER, P.C., and W. STUMM. 1970. Acidic mine drainage: the rate determining step. *Science* 167:1121-1123.
- SNEDECOR, G.W., and W.G. COCHRAN. 1967. Statistical methods. Sixth edition. Iowa State Univ. Press, Ames. 594 pp.
- STUMM-ZOLLINGER, E. 1972. Bacterial mediation in the oxidation of pyrite. (Summary transl. from German.) *Arch. Mikrobiol.* 83:110.
- WALSH, F., and R. MITCHELL. 1972. A pH-dependent succession of iron bacteria. *Environ. Sci. Technol.* 6:809-812.