

FACTORS INFLUENCING EXCESSIVE FLOWS OF COAL STRIP-MINE EFFLUENTS

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INTRODUCTION

The production of "sulfur water" (sulfuric acid) by coal and the associated strata led to the discovery of coal in the United States about 250 years ago. Gabriel Thomas wrote in 1698, "I have reason to believe there are good coals also for I have observ'd the runs of water have the same colour as that which proceeds from the coal mines in Wales" (Eavenson, 1942).

Such acid issuing from undisturbed areas as well as from mines was observed more than 150 years ago.

"In 1803 T. M. Morris noted: 'But the spring water, issuing through fissures in the hills, which are only masses of coal, is so impregnated with bituminous and sulphurous particules as to be frequently nauseous to the taste and prejudicial to the health.' And six years later, Joshua Gilpin visited a coal mine and wrote: 'Above the coal is several feet of a mixed kind of bad coal and iron abounding in sulfur and in vitriol efflorescing in white and yellow crystals.'" (Braley, 1954a)

Therefore, the production of acid is not due to man's operations but is a normal reaction between the oxygen of the air and the sulfur and iron materials associated with the coal strata. Man's role, then, has been, and still is, one of increasing the amount of exposed material containing iron and sulfur and, consequently, the amount of acid produced.

It was first generally agreed that the oxidation of pyrites (iron sulfide) alone was responsible for the formation of acid mine-water (Winchell, 1907; Patrick, 1933; Trax, 1933). Frost and Streeter (1924) hinted at more than one form of sulfuritic iron when speaking of the acid mine-waste resulting from oxidation of the sulfides of iron. Specific reference to a second form of iron sulfide, marcasites, was made by Carpenter and Herndon (1933), Herndon and Hodge (1936), Hodge (1938), U. S. Public Health (1942), and Hoffert (1947). The excellent work of Braley (1954b) discovered a third form of iron sulfide, black amorphous pyrite. These forms differ not only in crystalline form (Hoffert, 1947; Braley, 1954b), but also in: 1) rate of reaction; 2) resultant pH; and 3) grams of sulfate produced (Braley, 1954b).

The first commercial mining of coal in the United States was begun in 1820. Within 30 years the Western Interior Coal Province of Iowa, Missouri, Arkansas, Kansas, Oklahoma, and Nebraska had been opened by stripping methods. By 1939, 119 years after the first commercial mining of coal in North America, strip-mining methods accounted for only 3.1% of all bituminous coal mined in the United States. The greatest advance in the percentage of bitumi-

nous coal mined by the strip method has occurred in the past 15 years; as a result, the production has increased to over 26% of the total of all bituminous coal mined.

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DESCRIPTION OF AREA

The study area was on the southern edge of the easternmost projection of the Western Interior Coal Province and located in central Missouri north of the Missouri River in the counties of Boone and Callaway. The extent of this coal province has been described by Campbell (1922).

Intensive research was conducted on Cedar Creek and associated strip-mine areas for a period of 27 months, June, 1952, to August, 1954, inclusive.

Cedar Creek is 44.4 miles long, running in a north-south direction with a total drop in relief of 300 feet, or a drop per mile of approximately 6.7 feet. It has a mean velocity of one-third foot per second with a traversal time of approximately eight days. The stream valley is narrow, and Cedar Creek drains approximately 200 square miles, an average of 5 square miles of watershed for each linear mile of stream.

Because of the upstream location of the source of the pollution on Cedar Creek, only Station 1 could be located above the polluted area. Stations 2 through 7 were in an area of continuous pollution, and Stations 8, 9, 10, 10a, 10b, 11, and 12 were in a downstream area which was periodically polluted (Fig. 1). Station 9 (Fig. 2) was selected as representative of the stream with a narrow valley, rock outcrop, and high bluff typical of the middle and lower watershed.

The general appearance of the strip-mine areas of this study is shown in Figure 3. The physical relationship of the strip areas to Cedar Creek and its tributaries is shown in Figure 1. Only those areas which had a role in the pollution of Cedar Creek are designated.

POLLUTION PROBLEM

There were two different aspects of acid mine pollution in Cedar Creek. The upstream area, Stations 2 through 7, was continuously polluted by acid mine-effluents originating in the strip-mine areas above Station 5 (Fig. 1). The downstream area, Stations 8 through 12, was considered unpolluted. However, during excessive flows of acid mine-effluents, part, or all, of the

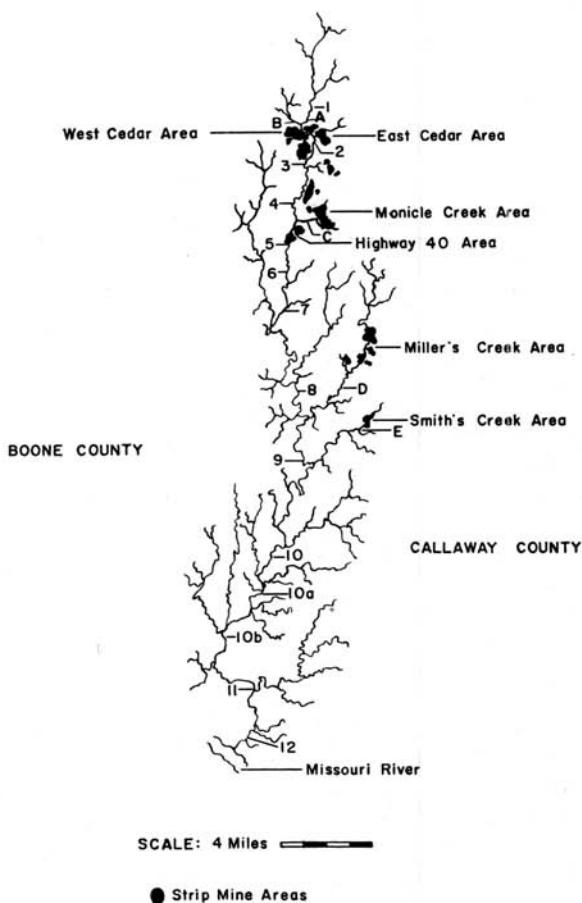


FIG. 1.—Cedar Creek sampling stations and related strip-mine areas.

latter area was polluted.

It is suggested that an excessive flow of acid mine-water into the unpolluted downstream area (Stations 8 through 12) occurs in two phases: 1) the initiation; and 2) the maintenance.

The initiation of an excessive acid flow occurs in the strip-mine area in the Cedar Creek Valley immediately above Station 5. A sizable

portion of this area drains, in terms of strip-pile runoff, directly into Cedar Creek. Here, as on the other strip-mine lands of this general area, salts produced by the breakdown of iron sulfide are concentrated by evaporation at the surface of the spill piles. Large amounts of the various sulfate salts accumulate during the warmer months of the year under the high temperatures

and prolonged dry periods. It appears that rainfall initiates excessive acid flows by dissolving the various sulfate salts from the spill piles and carrying the resultant effluent ions into the stream.

The maintenance of an excessive acid flow, to the extent that the downstream unpolluted area is affected, depends primarily upon the addition of effluent ions from the overflow of strip-mine lakes. Thus, the level of the strip-mine lakes is important, for if maintained at a high level the effluent overflow during a rain increases the distance which the acid flow will travel.

DISCUSSION

There were four, excessive acid flows during the study period of June, 1952, through August, 1954. These flows occurred in August, 1952, July, 1953, and May and June, 1954. The above acid flows were under close observation from the time they entered the downstream unpolluted area (Stations 8 through 12) until they were dissipated.

The excessive acid flows of August, 1952, and May, 1954, were alike in that they were partial flows; *i.e.*, they did not pollute the entire, downstream, usually unpolluted area of Cedar Creek. However, the dissipation of these flows was different. The dissipation of the August, 1952, flow was initiated by relatively high water which limited the toxic effects to four days. The flow of May, 1954, remained in Cedar Creek six days and was apparently dissipated by bicarbonate buffer introduced by the tributaries.

The partial acid flow of August, 1952, originated in the strip areas

located above Station 5. This flow was apparently initiated and maintained by the spill-pile runoff, which contained the effluent ions of the numerous salt deposits which had accumulated in large masses, for the strip-mine lakes did not contribute to this excessive acid flow. The partial flow of May, 1954, was initiated and maintained in the same manner. Apparently, the initiation of an acid flow originates from spill-pile runoff of accumulated salts, and, without the addition of overflow from the strip-mine lakes, the flow is of insufficient volume to carry through the entire, downstream, unpolluted area.

The excessive acid flows which were considered complete occurred in July, 1953, and June, 1954. Both flows polluted the entire, downstream, unpolluted area but were of different intensities. The excessive acid flow of July, 1953, which affected the entire length of Cedar Creek to the Missouri River, remained toxic at several downstream stations for some months, whereas the flow of June, 1954, was dissipated within 12 hours.

The complete flow of July, 1953, originated in the strip-mine areas located above Station 5 and was maintained by spill-pile runoff plus the overflow of the lakes in these areas. The complete flow of June, 1954, was initiated and maintained entirely by the spill-pile runoff. As in the case of the partial acid flows, the complete acid flows originated from the spill-pile runoff of accumulated salts. The addition of the overflow from the strip-mine lakes increased the initial flow of July, 1953, to such volume that it carried into the unpolluted area. Since



FIG. 2.—Station 9, Cedar Creek; typical of middle and lower watershed.

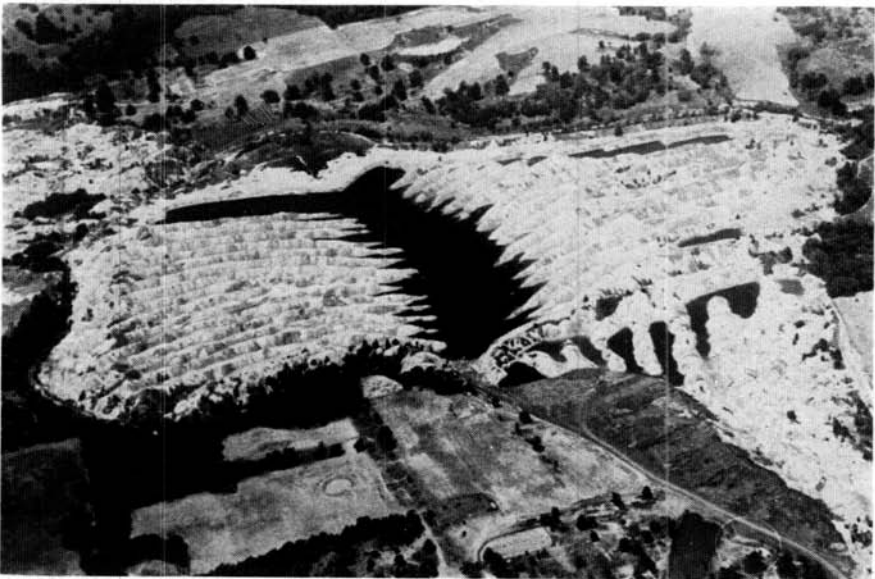


FIG. 3.—Typical strip-mine area and strip-mine lake in upper Cedar Creek area.

the volume of this complete flow was made up entirely of effluent water, the intensity of the flow was great and the effects severe and prolonged. However, without the addition of effluent ions contributed by the overflow of the strip-mine lakes but with continuing rainfall, the excessive flow of June, 1954, though being rapidly dissipated, was of sufficient volume to carry through the unpolluted downstream area.

The rate of recovery of the downstream area varied widely during the study period. The acid flow of August, 1952, moved into the unpolluted area on August 17 but was rather quickly dissipated by relatively high water on August 21. Thus, though the flow was of such intensity as to cause a fish kill at Stations 8 and 9, the recovery of these stations was quite rapid.

The flow of July, 1953, was not only intense but also of long duration. This relatively large flow entered the unpolluted area on July 5. By late afternoon of the following day the flow was below Station 11, and the effluents were affecting the smaller fishes. By the second day of the flow the silt load had precipitated in the downstream, unpolluted area, resulting in the accumulation of a light-brown floc on the bottom of the stream. Even at the end of a six-day period only a slight recovery was noted at Station 11; however, by this time the flow had slowly proceeded to within one-fourth-mile of the Missouri River. Within ten days, Stations 9, 10, and 11 showed marked recovery, yet Station 12 was still quite acid. Toxic, acid mine-water continued to flow into Station 8, whereas the initial flow remained toxic at Station 12.

This was probably due to the following facts: 1) no rain had followed the initial acid flow and thus there was no excessive non-acid water flow from either the tributaries or upper Cedar Creek; 2) by the nature of an acid flow, the intensity decreases progressively downstream and, therefore, the acid flow was less concentrated at Station 12; and 3) the comparatively low gradient from Station 12 to the Missouri River retarded the rate of flow, and the acid flow acted as a "plug" in the lower reaches of Cedar Creek. This plug remained in Cedar Creek for at least 15 days. Meanwhile, upstream from Station 11 the stream was recovering. However, farther upstream the flow of acid water into Cedar Creek was such as to contribute to the continued pollution of Station 8 which did not recover until the time of the October rains with the subsequent increase in the volume of unpolluted water from the tributaries.

On May 7, 1954, an acid flow reached Station 10a (Fig. 1), but it was apparently weak for Stations 10 and 10a showed recovery the next day, and no dead fishes were found at either station. Within six days there was a progressive decrease in the concentrations of effluent ions at Stations 9, 10, and 10a. However, at Station 8 these concentrations remained high because of a small, continuous, excessive acid flow.

The recovery of the unpolluted downstream area, following the excessive acid flow of June, 1954, was quite rapid, for this flow was dissipated by unpolluted water which followed the acid flow, diluting it upstream as the unpolluted downstream water blunted the forward movement. Thus, by the time the

acid flow had reached Station 11, it had dissipated to such an extent that it was only 300 yards in length.

In the final analysis, not only the initiation of a flow, the maintenance of such a flow, the concentrations of effluent ions, and the distances of excessive acid flow travel, but also the rate of recovery of the downstream area were dependent upon a delicate, everchanging balance in the amount, distribution, and intensity of rainfall, and, to some extent, upon the time interval between rains.

Two approaches to the control of the pollution of Cedar Creek have been offered: 1) the addition of various chemicals to render the effluent ions harmless to aquatic life; and 2) the physical movement of earth as: a) building dams; b) draining strip-mine lakes; and c) diverting runoff from surrounding areas.

The destruction of effluent ions by chemical reaction has been proven economically unfeasible in a number of studies (Carpenter and Herndon, 1933; Trax, 1933; Hodge, 1938; Penn. State Bd. Health, 1951). However, the physical movement of earth appears to have merit in partially eliminating excessive acid flows.

The construction of diversion dams to control the runoff entering the Cedar Creek strip-mine areas from the surrounding unstripped land would be impractical, for the strip areas are of such size that a flow could be initiated by the water which falls in the area itself. However, by the construction of such dams, it might be possible to control the overflow from lakes which receive a sizable runoff from the unstripped land.

The drainage of strip-mine lakes also has been offered as a possible

solution. However, the drainage of two lakes of the study area showed this method to be inadequate. Large amounts of sulfate salts were found to accumulate on the spillpiles adjacent to the drained pits, and rainfall continued to carry the resultant effluent ions directly into Cedar Creek.

On the basis of the information gathered during this study of the Cedar Creek area, the following suggestions are made. There is enough strip-mine area on which sufficient salt accumulation may occur to pollute continuously the upstream area (Stations 2 through 7). It would not be economically feasible to correct this situation by any combination of proposed methods.

Since it has been illustrated that the lakes do not contribute to the chemical breakdown of iron sulfide (Parsons, 1955), it appears that the lakes would be ideal holding areas for effluent ions. It also has been shown that the lakes must contribute to an excessive acid flow for the flow to be of such volume and intensity as to cause a severe fish kill; thus, the acid mine-water of these lakes must be contained. The key to the problem appears to lie in maintaining a relationship between watershed and lake volume such that the normal rainfall-evaporation ratio will limit the volume of water accumulated and prevent the overflow of acid water.

It is proposed that the overflow from the strip-mine lakes of the Cedar Creek area may be controlled by: 1) restriction of water to the strip pit by the construction of dams in low areas adjacent to the strip pit; and 2) restriction of excessive runoff from adjacent unstripped

lands into the pits by the construction of diversion dams.

SUMMARY

1. The production of acid mine-water is not due to man's activities but is a natural, oxidative, chemical process.

2. The potential amount of acid mine-water depends upon both the type and the amount of sulfuritic material exposed.

3. The increase in both the incidence and the intensity of coal strip-mine pollution is due to an increase of more than 26% in strip-mining activities.

4. There are two different aspects of acid mine pollution in Cedar Creek. The upstream area is continuously polluted, whereas the downstream area is periodically polluted by excessive acid flows.

5. There are two major sources within the strip-mine areas which contribute to both the continuous and the periodic pollution of the stream: 1) the accumulated sulfuritic salts on the spill piles; and 2) the strip-mine lakes.

6. Contributions from both sources are necessary to produce an excessive acid flow of such intensity as to be detrimental to the fauna of the unpolluted area of the stream.

7. The initiation, maintenance, extent, and intensity of an excessive acid flow and the rate of recovery of the stream are a function of the amount, intensity, and distribution of rainfall and, to some extent, of the time interval between rains.

8. Because of the proximity of strip piles to Cedar Creek, it is neither practical nor economically feasible to correct the continuous pollution of the upstream area.

9. Control of excessive acid flows depends upon the maintenance of a relationship between watershed and lake volume such that the normal rainfall-evaporation ratio will limit the volume of accumulated water, thus preventing acid-water overflow.

10. It is plausible that control of strip-lake overflow may be attained by the construction and maintenance of earthen dams in the strategic areas adjacent to strip-mine lakes.

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