Stream Pollution By Coal Mine Wastes

by Henry F. Hebley

This paper brings within the compass of one comparatively brief article a general description of the situation concerning the nation's water resources. It touches upon the phenomenal growth in the demand for water supply and emphasizes the problems facing the coal industry both with regard to acid mine water drainage discharged from active and abandoned mines and the suspended solids discharged to the stream system from wet coal preparation plants.

IT must always be remembered, with regard to the problem of water-borne industrial wastes, that stream pollution from any cause is just one factor in the comprehensive problem of water supply in modern times. Industries nonexistent 25 years ago are now flourishing, and supplies of water piped to homes and apartments, as well as the greater number of plumbing fixtures per dwelling and per building, have created an ever growing demand on the country's water resources. Indication of this rapid growth in demand is shown in Table I, which is quoted from Abrams.[1]

Table I. Effect of Industrial Expansion on Water Consumption In Various Sections of U.S.A.

Location	Period	Estimated Increase of Population, Pct	Increase Water Consumption, Pct
Baltimore, Md.	1938 to 48	6.0	69*
Baton Rouge, La.	1937 to 45	6.0	78†
Detroit, Mich.	1932 to 45	4.3	47*
Galveston, Texas	1931 to 43	23.0	74†
Houston, Texas	1931 to 43	34.0	61†
Texas City, Texas	1931 to 43	63.5	2500†

* Consumption of municipal supply only.
† Consumption of both the municipal and private industrial supplies.

In commenting on the growing requirements of the State of Texas, the foregoing report states that "between 1890 and 1940 the population of the State of Texas increased 287% and the water consumption 7000 per cent."

H. F. HEBLEY, Member AIME, is Research Consultant, Pittsburgh Consolidation Coal Co., Inc., Pittsburgh.

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The domestic load varies greatly, depending on the extent of the available supply and the habits of the community. According to the report of the President's Water Resources Policy Commission[2] the United States Public Health Service reported a national average of 127 gal per capita per day, varying from 60 gal in communities of 500 persons to 140 or 150 gal in cities of 10,000 or over.

Other critical areas may be cited to illustrate the inter-relation between new industrial processes and the demands for water in the area where the new enterprise is located. Powell and Wilson[3] have pointed out that during World War II, in the vicinity of Louisville, Ky., a rapid expansion of industry took place, consisting of numerous synthetic rubber plants. The demand for water increased from 37 million gal per day in 1937 to 62 million gal in 1943. These heavy requirements drew down the supply stored in the water-bearing aquifers to such an extent that urgent plans for recharging were considered. Similar situations have developed in the Los Angeles area and in the vicinity of Texas City.

Warne[4] has drawn attention to the situation in Los Angeles area, where in the West Basin the withdrawal of ground water in 1945 was 90,000 acre-ft, almost double the amount of the natural fresh water recharge. The draw down has been so severe that the level of the ground water is now below sea level, and sea water is invading the West Basin aquifers at rates up to 300 ft per year.

In the Report of the Engineers Joint Council[5] it is pointed out that in the area of Texas City the ground water table has been critically lowered. In 1930 the daily withdrawal from the water-bearing aquifer was 0.5 million gal. By 1945 the quantity withdrawn had increased to 23 million gal per day. The level of the water table, therefore, had dropped approximately 150 ft below the sea level. As a result of draining the water-bearing sands, a subsidence of the land surface of 2.4 in. per year has taken place.

One of the most spectacular episodes of water loss brought about by man's activities is described as follows by Foose:[6]

> In the vicinity of Hershey, and in the valley of Spring Creek there were at one time many springs, some of them yielding thousands of gallons per minute. One large spring in particular flowed forth to make several large ponds a few hundred feet east of the plant of the Hershey Chocolate Corporation. One of the reasons for the plant's location was this excellent source of water, known first as the Derry Spring. For more than a century the various springs were used on many of the farms in this area as their only water supply, and for nearly 50 years the Derry Spring has been used by the Hershey Chocolate Corporation. As far as it has been possible to determine, none of the large springs ever went dry, even during the longest droughts.
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> During the past fifty years many wells were drilled on farms and on properties where new homes were built. Except for very shallow wells, in which the water never stood more than several feet above the bottom of the well, none of these are known to have gone dry. A series of wells were also drilled by the expanding plant of the Hershey Chocolate Corporation. Yields ranged from 200 to 1200 gallons per minute, and a few had no yield at all, demonstrating how poor an aquifer limestone can be "in between the fractures." The Corporation wells continued to have a constant yield in wet and dry season alike, and they never affected in any way the adjacent springs or wells in the valley.
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> One and a quarter miles southwest of the Hershey Chocolate Corporation is a limestone quarrying operation about 125 feet deep. Relatively little ground water seeps into the quarry; for many years less than 1000 gallons per minute have had to be pumped to maintain operations. One and a half miles northeast of the Corporation is a larger limestone quarry and mining operation whose workings extend more than 400 feet below the surface. Until May, 1946, during normal operations about 3000 to 3500 gallons per minute of ground water were pumped out of the mine. Both of these mining operations remove limestone that is much purer than the average limestone of the valley. As a result there are many openings, large and small, that have been dissolved by water percolating through the rock fractures. Located on this same pure limestone formation is the Derry Spring. The trend of the limestone rocks in northeast-southwest is a nearly straight line connecting the spring and the large mining operation.
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> During routine mining operations in August, 1946, a blast in the hanging wall of the mine exposed a six-inch wide solution channel about 375 feet below the surface out of which poured an estimated 8,000 to 10,000 gallons of water per minute, flooding the mine in the course of a day. When this occurred nearby wells dried up, ground water seepage into an adjacent quarry ceased, the Derry Spring a mile and a half to the southwest dried up on the second day and two wells of the Hershey Chocolate Corporation were badly affected. After many months of labor the opening in the mine was sealed off with a large steel plate, the adjacent wells had water in them again, the flow of the Derry Spring was restored, and the Corporation wells were again normal.

Van Tuyl[7] has described an interesting situation regarding the influence of air conditioning and modern water uses on the water withdrawals from the aquifer underlying Pittsburgh. The strata are very permeable sands and gravels, deposited during the glacial age, and permit a rapid flow through the deposit. The storage capacity is, however, limited in extent, being approximately 800 million gal. The demand for cooling water has increased steadily since 1927, until at the present time it is double the quantity used in that year. The average withdrawal on a summer day has reached 10 million gal, which indicates a supply for only 80 days. Fortunately the recharge to the aquifer is continuous, although during the summer the draw down is from 8 to 10 ft. During winter, because of the proximity of the rivers and the ease of ground water flow, the water table is returned. The demand for water reaches a maximum in July and August, amounting to 25 pct of the total yearly volume of water pumped. During this period the demands for air condition equal the requirements of all other uses. In fact, the demands on the water resources of the aquifer have reached the maximum rate of recharge, and a further increase in water requirements cannot be satisfied from the present wells without artificial recharge. Natural recharge is limited by the prevention of rainfall soaking through the large percentage of the area of the triangle that is artificially impermeable by street paving, buildings, and parking lots.

Another notable man-made barrier is the sheet piling used to form the embankment along the Allegheny River. This wall, which is 3750 ft long and averages 33 ft deep, reduces the cross-sectional flow area into the aquifer to approximately 50 pct.

During the threatened water famine the metropolitan area of New York suffered an acute crisis, which taught the population in a most spectacular manner how dependent the individual and the community are on water in this present civilization. London, the site of which was selected by the ancient Britons because it was underlain with a porous gravel deposit providing a continuous source of water, has also in recent years been concerned with the lowering of the water table.

Table II. Typical Interstate Agreements for Control of Water Resources

COMPACT	STATES INVOLVED
The Interstate Commission on the Delaware River Basin (INCODEL)	Pennsylvania; New York; New Jersey; Delaware
The Interstate Commission on the Potomac River Basin	Pennsylvania; Maryland; West Virginia; Virginia; District of Columbia; USA U.S. Public Health Service, Office of Army Engineers
The Ohio River Valley Water Sanitation Commission	New York; Pennsylvania; Virginia; West Virginia; Ohio; Kentucky; Indiana; Illinois

With these examples before the country, it is natural that all branches of government are taking a great interest in the conservation of water resources. The comprehensive report of the President's Water Resources Policy Commission[2] is evidence of this concern at the Federal Government level.

There are many aspects of the problem, some in conflict with others: flood control, power generation, land reclamation, domestic and industrial water supply, water shed management, inland and tidal waterways, and stream pollution control. To balance these various factors will tax the combined skills of the country's outstanding engineers and economists.

Because the approach to the problem in many cases lies within the area contained in the drainage basin of the stream system, which never follows political boundary lines, interstate compacts have been adopted to facilitate the control of the water resources within the drainage area. Typical agreements are listed in Table II.

All commissions have been carrying out engineering and economic studies on which to base proposals for a well balanced project of water conservation and control in each of the drainage basins.

Recently, the proposed Incodel Interstate Water Project was made public.[8] Briefly, it calls for the construction of a series of four reservoirs in the upper reaches of the Delaware River watershed. It will provide satisfactory sources of water for the areas that require it, and it will also provide an increase in the flow of the Delaware River during the dry months of summer and autumn. The salient features of the project are given in Table III.

Table III. Apportionment of Water Supply Under Proposed Incodel Interstate Water Project

Purpose	Million Gallons
Total reservoir storage capacity	527
Recreational use (boating, fishing, etc.)	111
Water supply to New York and northern New Jersey	100
Stream flow regulation and future water supply to Philadelphia and southern New Jersey	316

Because of the widespread demands, severe competition has developed between states, between communities, and between individuals, necessitating priorities for the use of water. Highest priority is assigned to water supplies for municipal and domestic purposes. All other factors must be modified to maintain the necessary standard of priority. It is this strict insistence on water purity for the protection of public health that has impelled industry to install equipment for the treatment of its water-borne trade wastes. Roughly, such wastes can be divided into two kinds, organic and inorganic. Typical of the former are the wastes arising from packing houses, food processing plants, pulp and paper mills, cheese and butter factories, and the beet sugar industry. The inorganic trade wastes include the pickle liquor from the steel industry, brines from various wells, acid water drainage from coal mines, and liquid wastes from the metal-finishing industry. Two other great sources of pollution are domestic sewage from centers of population, and solids eroded from the soil by action of annual rainfall run-off.

As mentioned previously, there is always some interaction between wastes discharged into the stream system. An interesting example given by Beal and Braley[9] indicates the reluctance of communities to correct a situation until faced with a crisis:

> There is a city not far from Pittsburgh that uses an open creek in lieu of a trunk sewer. The drainage from three large mines, ranging in volume according to season from four to seven million gallons daily, is also pumped into this creek. It is only the acidity of this mine drainage that inhibits putrefaction of the sewage. Now, with the possibility in the offing that mine pumping will be stopped, the city government is considering buying or leasing those abandoned workings in order that it may continue to add that acid water to the city's sewage, as a prophylactic, pending the time when the city government can complete a modern sewage disposal plant.
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> This commingling of sewage and mine drainage takes care of the area immediately surrounding this city just as other industrial wastes have their inhibiting effect on other cities' sewage. But as these streams flow on they receive other streams, often naturally akaline, so that dilution and neutralization soon reduce the bactericidal and bacteriostatic effects of these industrial wastes. Because of this neutralization, new infection in the stream permits a resumption of sewage decomposition in areas that should be clean. Therefore, we may be sure that problems involved in the treatment of water-borne industrial wastes, rolling up like a snowball, are going to be among the tremendously important industrial problems of the next decade.

Biological Oxygen Demand

As pointed out by Eldridge[10] the contamination of a stream by organic wastes arises from decomposition of those wastes through the action of bacteria. In consuming this organic material, the bacteria combine it with oxygen to maintain their life processes. This is *biological decomposition*. It is generally held that *anaerobic* bacteria carry out their work in the absence of oxygen. But as Eldridge has observed, these bacteria obtain their necessary oxygen from the organic compounds which are composed of such elements as oxygen, nitrogen, carbon, sulphur, and hydrogen. The removal of oxygen leaves elements that form compounds containing no oxygen, such as ammonia and hydrogen sulphide. These compounds have characteristic foul odors. When a body of water is dominated by such anaerobic decomposition, the aquatic life of the lake or stream is destroyed because of the toxicity of the compounds. If there is an ample supply of elemental oxygen present in the body of water, *aerobic* bacteria continue the work of decomposition to yield end products such as sulphates, nitrates, water, and carbon dioxide. The foul-smelling products created by the *anaerobic* decomposition are oxidized and are harmless. Thus the oxygen contained in the stream or lake is the most important factor in disposing of organic pollution discharged to the stream system. Where oxygen is not present in sufficient quantities to complete the decomposition of organic wastes, the stream waters may be completely depleted of oxygen, whereupon the stream will become septic.

This demand for oxygen for the decomposition of organic by biochemical processes has resulted in a measure of pollution universally employed by sanitary engineers. It is known as the Biochemical Oxygen Demand, or abbreviated, B.O.D. It is defined by Phelps[11] as "the oxygen that will be demanded by the material in the course of its complete oxidation biochemically. It is not at all related to the complete oxygen requirements in chemical combustion, but is determined wholly by the availability of the material as a bacterial food and by the amount of oxygen utilized by the bacteria during its oxidation." This measure, while of great importance to such enterprises as the food processing industries, pulp and paper mills, tanneries, creameries, and domestic sewage disposal works, does not apply to such inorganic wastes as acid water drainage from coal mines and suspended solids contained in the water discharged from coal preparation plants. However, it is of interest to note that in one set of standards the measure of B.O.D. was to be applied to all wastes. That requirement has been changed.

Stream pollution created by the coal industry stems from two main sources, acid water drainage from mines and suspended solids discharged with the effluent from coal preparation plants.

Acid Mine Drainage

The acid mine water problem has been subjected to intensive research for years, and the investigations are continuing at Mellon Institute, West Virginia University, and Johns Hopkins University. It is surrounded with great difficulties, not the least of which are the stupendous volumes of water that must be handled.

According to Supplement C of the Ohio River Pollution Survey,[12] the total estimated mine acid load delivered to the Ohio River Drainage Basin was approximately 2,500,000 tons per year, a figure derived from the data collected in 1940. Since that time numerous mines have been worked out and abandoned and new operations started. The measure of confidence that can be placed in the figure, therefore, is not known, but it will serve to indicate the magnitude of the problem.

In the Mellon Institute *Survey of Mine Drainage,*[13] Dr. S. A. Braley points out:

> In general, acid mine drainage consists of a solution of iron, aluminum, calcium and magnesium sulphates. The iron and aluminum sulphates react with water to give an acid solution, whereas the calcium and magnesium sulphates contribute to the hardness. The acid coming from the iron and aluminum sulphates, neutralizes the natural alkalinity of the stream receiving the drainage.
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> The iron in the drainage may cause the receiving stream to become very turbid with iron hydroxide or, depending on the concentration of iron sulphates in the drainage, may result in a red water where the iron remains dissolved in the highly acid solution.

The mine drainage in western Pennsylvania, West Virginia, Ohio, and Kentucky, where many of the mines are shallow, is greatly affected by rainfall. Results shown in Table IV are taken from a study made by Carpenter and Herndon of mines located on the water sheds of the Monongahela and Cheat Rivers.[14] The average cover over most of these mines varied from 100 to 300 ft. Braley[15] in his work on mine acid drainage at Mellon Institute has noted a similar occurrence. In mines having shallow cover, the changes in the rate of drainage flow are closely parallel to the flow of the surface streams of the neighborhood, but the flow variation becomes more uniform as the depth of cover increases. Unfortunately, the greatest difficulty is experienced in the mines that have shallow cover, especially if their discharge is above the stream level, as the drainage ultimately reaches the water shed.

Table IV. Effect of Rainfall on Mine Drainage in Monongahela and Cheat River Area

Year	Gal Per Day Per Acre of Mined Out Area	Remarks
1928 to 1929	1000	Normal
1929 to 1930	500	Drought latter 1929, entire year 1930
1931	660	Normal

In abandoned shallow cover drift mines, the fluctuation of flow can vary as greatly as 25 to 1 in a few days and a ratio of 6 to 1 in volume of water can take place in a few hours. For example, following a heavy rainfall the flow was observed to rise from 50,000 to 700,000 gal per day in 4 hr, a ratio of 12.7 to 1. To design any kind of treatment that would automatically adjust itself to such a wide range would tax engineering ability to the utmost. Economically it would not be feasible, and in the case of abandoned mines it is out of the question. Yet the greatest volume of acid water discharge is from such mines.

A comment may be made here regarding the use of the pH measure in the study of acid mine drainage. Carpenter and Herndon[14] and Braley[15] all noted that in some cases the pH value of the stream does not rise after dilution with the alkaline waters from tributary streams. That is true for most of the acid mine discharges in western Pennsylvania and northern West Virginia. A buffering action seems to take place at an approximate pH value of 3.0 that permits appreciable quantities of alkali to be added to the acid solutions, without raising the pH. Selections from Table III in Carpenter and Herndon,[14] shown here in Table V, indicate this action. The samples were taken in northern West Virginia. Because of the existence of buffering action those investigating acid mine water problems are aware that the pH value may lead to false conclusions. That is not to say, however, that the pH value is not useful. It is generally determined and reported. It represents the hydrogen ion concentration at an equilibrium depending upon concentration and temperature, and is not a measure of the titratable acidity. The acidity of acid mine drainage is the result of the hydrolysis of the iron and aluminum salts into free acid and hydroxides and/or basic sulphates, and the total titratable acidity is the result of their complete hydrolysis.

Table V. Relation Between Dilution and pH Value

Sample No.	6	7	8	11	12
Initial Acidity in P.P.M.	1200	3600	920	950	7100
Ratio of Dilution			pH Values		
0	3.0	3.0	3.0	3.0	3.0
1 to 1	3.0	3.0	3.0	3.0	3.0
1 to 2	3.1	3.0		3.0	
1 to 5	3.2	3.0	3.2	3.3	3.0
1 to 10		3.0	3.2	3.3	3.0
1 to 20		3.0	3.8		
1 to 30					
1 to 40					
1 to 50	3.6	3.5	4.2	4.2	3.0
1 to 100	4.0	3.5	4.9	5.0	3.5
1 to 200	4.4	3.8	5.5		
1 to 400					

During their studies of the forms in which sulphur occurs in coal, Parr and Powell[16] indicated that bacterial action by some of the sulphur-producing organisms might possibly explain some of the high acidities found in mine waste waters. Investigation of this possibility was carried on by Hinkle and Koehler[17] at West Virginia University through the employment of bacteriological techniques. Two micro-organisms have been isolated that are thought to have a part in promoting the formation of acid. One of these, Thiobacillus Thiooxidans, converts elemental sulphur or sodium thiosulphate to sulphuric acid. Further study is being carried on to determine the reasons for the rapid formation of acid in abandoned mines compared to those in operation. In so far as the investigations have been carried on, these micro-organisms have not been found in alkaline mine waters.

The other organism seems to be a factor in the oxidation of ferrous sulphate to ferric sulphate with the subsequent hydrolysis to ferric hydroxide.

Temple and Colmer,[18] in continuing the work at West Virginia University, showed that the oxidation of ferrous iron in acid water to produce the characteristic red color was a bacteriological process and not one of simple atmospheric oxidation. They suggested that the bacterium be designated as Thiobacillus Ferrooxidans.

This phase of research is still subject to discussion and consideration by the various investigators as the work proceeds. Leathen and Braley[9] have investigated this aspect of the problem independently and have commented as follows:

Both sulfur and iron oxidizing bacteria have been isolated from all of the acid mine waters examined. The sulfur oxidizing bacterium has been identified as *Thiobacillus thiooxidans*, and oxidizes elemental sulfur to sulfuric acid. One statement has been found in the literature to the effect that *Thiobacillus thiooxidans* may oxidize sulfide sulfur, but that this has not been confirmed experimentally. It is believed that Mellon Institute may properly be credited with providing some experimental evidence that this organism does not oxidize sulfide sulfur, at least as it occurs in the coal measures. For, in the experiments, when graded sulfur-ball material replaced elemental sulfur in the substrates, and the substrates were inoculated with the microorganism, the normal, chemical rate of acid formation was not enhanced. Inoculation of media, containing museum grade pyrite, also, was not oxidized by these bacteria. Inoculated substrates containing museum grade marcasite, however, indicated a slight increase in acid formation which could be attributed to *Thiobacillus thiooxidans*. It is not felt that appreciable formation of acid in a mine can be attributed to this microorganism, as the sulfuritic material, "sulfur-ball", usually found in bituminous coal seams and associated rock strata are not oxidized by any of the strains of *Thiobacillus thiooxidans* used in our studies.

The iron oxidizing bacteria, which this Institute is refraining from classifying until the physiological studies are completed, have caused three to five fold increases in the amount of acid formed from sulfur-ball material and from marcasite. Museum grade pyrite was not attacked. At the present time, the amount of acid produced from sulfuritic materials by this microorganism in nature is unknown, and cannot be differentiated from that produced by strictly chemical reactions.

Recently, Dr. Jay V. Beck, Brigham Young University, has written that he has been able to demonstrate that our cultures, as well as some he obtained from Bingham Canyon, Utah, were ". . . able to convert iron pyrite to soluble iron with a decrease in pH." This observation confirms some of our work.

It is suggested that the role of the iron oxidizing bacteria in acid production may be as follows: the speed of atmospheric oxidation of the iron sulfides seems to vary directly as the available surface, the amorphous sulfur ball oxidizing with much greater rapidity than the densely crystalline pyrite. Ferrous sulfate, the product of the first atmospheric oxidation, is in chemical equilibrium with the sulfides. The iron oxidizing bacteria then oxidize ferrous sulfate to ferric sulfate, which, in contact with sulfur ball material, oxidizes the latter to ferrous sulfate while the ferric sulfate is in turn reduced to ferrous sulfate. This increased quantity of ferrous sulfate now undergoes bacterial oxidation, and the cycle repeats and repeats in the manner of an expanding spiral.

The iron oxidizing bacteria, however, should not be considered wholly detrimental in nature, but are of assistance in the deposition of ferric sulfate in streams, outside of the mine. It has been determined that concentrations of ferrous iron, oxidized only 48 percent by a strictly chemical reaction in two years, were completely oxidized by these bacteria in eight days. Such oxidations are advantageous.

The iron oxidizing bacteria, by greatly increasing the rate of oxidation, induces the deposition of basic ferric sulfate, 'yellow boy', in the shortest possible distance in the stream, confining an unsightly condition to the smallest possible area. Furthermore, it greatly assists the stream to make a very rapid recovery as far as dissolved oxygen is concerned. Dissolved oxygen is essential to all aquatic life, both plant and animal. When acid, ferrous-iron-bearing, waters enter a normal stream, the dissolved oxygen is practically depleted owing to the amount required to transfer the ferrous iron to the ferric state. If this were to take place at the slow chemical rate of oxidation, whole streams, or at least huge portions of them, would be void of all life. When the oxidation rate is increased several fold by the activity of the bacteria, this area, depleted of oxygen and void of aquatic life, is confined to the smallest possible section of the stream. The stream, then, has an opportunity to absorb atmospheric oxygen to replenish its supply. Making a rapid recovery, the stream can again support an abundance of both plant and animal life in a short distance from where the ferrugenious water entered. The organism, in this respect, is of distinct value in nature.

It is frequently stated by many who have only given cursory thought and consideration that the problem can readily be solved by neutralizing with lime. In all probability, this method of attacking such a situation stems from the installation at the Calumet Mine of the H. C. Frick Coal Co. It was installed in 1914 during World War I to produce certain specific products for gas purification that were unavailable from Germany at the time. A description of the plant is given by L. D. Tracy in the Transactions of the AIME in 1921.[19] It was abandoned immediately after the War.

To ascertain the feasibility of lime treating acid mine water, the Pennsylvania Sanitary Water Board authorized the Mellon Institute to carry out research on lime in its various forms. The following conclusions were based on the aforementioned research. They are published in a report issued by the Pennsylvania Sanitary Water Board, Department of Health, Commonwealth of Pennsylvania:[20]

1. Although acid mine drainage can be chemically treated with lime or other alkalies to neutralize the acid, such a method is not practical or feasible because of the economic and other difficulties involved.
2. The use of limestone or hydrated lime to neutralize acid mine drainage produces hard water.
3. A neutralizing treatment would be effective only if the plant were designed and staffed to treat the maximum seasonal flows and the large fluctuations caused by natural conditions.
4. After completion of mining operations on a property, continuation of the treatment indefinitely would be required.
5. The findings of the Mellon Institute Fellowship program to date show that the water that enters a mine through rock and earth strata is normal ground water, free from acid. From these results, it seems quite evident that the only hope of preventing the flow of acid drainage from a mine is by:
   a. Stopping the formation of acid from sulphuritic material on the walls and roof, or—
   b. causing the water entering the mine to

leave the mine by the shortest possible route and quickest possible time without leaching the acidic substances so formed from the walls and roof, or—

c. diverting all water from the mine. The Fellowship referred to has no confidence in any proposal to neutralize continuously the acid mine water flowing from a coal mine in Western Pennsylvania.

6. Notwithstanding the impracticability of the suggested limestone or lime treatments for continuous flow of acid drainage from mines, hydrated lime might be used successfully to neutralize casual pools of acid water found in coal workings.

In regard to the practicability of using limestone or hydrated lime, theoretically, it would require approximately 1 ton of lime to neutralize 1 ton of sulphuric acid in acid mine water. It would require a large excess of lime to complete the reaction in a reasonable time.

In regard to the availability of lime to treat these acid waters, statistics from the Minerals Year Book, 1944,[21] may be of interest, see Table VI. According to Supplement C of the Ohio River Pollution Survey[12] the acid load discharged into the Ohio River streams system from Pennsylvania approximates 889,000 tons per year. Possibly it would take all the lime that Pennsylvania produces to treat the situation. Even should there be sufficient lime to treat the acid drainage, the oxides of iron would separate as a watery gelatinous sludge which settles very slowly. If this material were to be settled before the treated drainage was discharged to the stream system, very extensive lagooning acreage would be required. In hilly terrain, similar to western Pennsylvania, West Virginia, and East Kentucky, such lagooning would present great difficulty. From time to time, such settling basins would have to be cleaned out. That poses the extremely difficult problem of disposal.

Table VI. Availability of Lime

Year	Market	Tons
1944	U.S.A. production *open market* and *captive*	6,473,563
1944	U.S.A. Total *open market-captive-chemical plants*	8,954,183
1944	Penna. Production Agric.-Bldg.-Ind.-Chem.-Refr.	1,026,292

Some study was made to ascertain if a market could be found in the paint industry for the ferric oxide, or rouge, but the results were not promising. On the other hand, if the material were deposited on the adjacent hills, the 36-in. annual rainfall would wash the sludge back into the stream system. There is another result of such a lime treatment. In the reactions that neutralize the acid, the iron in the acid mine water is replaced by calcium and all the sulphate originally present remains in solution as calcium sulphate. This material imparts permanent hardness to the water.

In the anthracite field considerable trouble is experienced with acid drainage water, and in many cases where a percentage of the volume pumped is diverted for use in the coal preparation plant or breaker the water is treated with lime for neutralization before use in the breaker equipment.

The problem of corrosion of equipment is in some cases very severe. As a result many of the companies have resorted to the use of acid-resistant metals and extra heavy dimensions in the design of the pumps, valves, and piping.

According to Ash,[22] the treatment of acid mine water for the coal cleaning plant through the use of lime has been in practice since 1932. A concentrated lime water mixture or slurry is fed either into the breaker water supply reservoir or into the pumping system. High calcium lime + 90 pct CaO, magnesium lime, MgO 5 to 25 pct, dolomitic limes, MgO 25 to 45 pct, and hydrated lime, $Ca(OH)_2$ are used. The rates of reaction of high calcium hydrated lime and of dolomitic lime are rapid. Sulphuric acid, however, forms insoluble calcium sulphate and this retards the reaction. With the dolomite magnesium sulphate is formed and is more soluble in water.

It must always be borne in mind that in the anthracite field of Pennsylvania, the amount of water that must be removed from the operations is extremely great, averaging 30 to 40 tons per ton of coal produced. As Griffith[23] has pointed out, although the average rainfall in the region has not altered, the amount of water entering the mines through breakage of the overlying strata to the surface is continually increasing. An example is given in Table VII of one of the larger operations in the northern anthracite field.

Table VII. Water Removal in Typical Anthracite Mining Operation

Years	Ratio, Tons of Water Pumped to Tons of Coal Produced
1920	8.4 to 1
1925	10.6 to 1
1930	11.4 to 1
1935	26.2 to 1
1940	32.7 to 1
1942	30.3 to 1

The difficult aspect of the problem is to make provision for controlling the drainage of abandoned or inoperative mines. Of the total volume pumped, 66 pct is discharged from the aforementioned class of properties. Under such conditions, with the economic factors involved, comprehensive planning is needed for the handling of the water of the whole anthracite region. Investigations are being carried out. One method seems the most feasible, i.e., a tunnel system arranged for draining by gravity those reservoirs that lie above the tunnel outlet and lifting mechanically the water lying below the outlet. The plans must be long range, however, as the number of inoperative and abandoned mines are on the increase. However, it should be remembered that the volume of drainage from the anthracite region, 730 sec ft, is great enough to affect the volume of flow in the surface stream system, if it is removed. It is a phase that must be taken into account.

The Suspended Solids in Washery Waters

Although at the present time "no practicable method of removing the acid properties of mine drainage is known," as Felegy, Johnson, and Westfield point out,[24] there are some methods that can be employed for the treatment of suspended solids from water discharged to the stream system from coal preparation plants. The problem of suspended solids is the second major difficulty facing the coal industry in the control of stream pollution.

The silt problem created by the anthracite industry from water discharged from the breakers has been one of long standing, and it is only in recent years, with the cooperation of the Department of Engineering of the Pennsylvania Department of

Health, that the removal of suspended solids has progressed.

The water clarification systems of various coal preparation plants have been described in detail in numerous articles, and as each one has been designed to meet the individual needs of the particular plant, no attempt will be made in this paper to cover them. Nearly all the systems employ some or all of the following equipment.

In elevated settling cones the suspended solids settle toward the apex and are drawn off as a thickened slurry or sludge, while the clarified water overflows at the surface into a launder around the periphery to a discharge funnel. There are no moving parts. Gravity and the hydrostatic head are depended on to maintain the flow of the thickened sludge.

Drag conveyor settling tanks are equipped with a slow moving scraper conveyor that drags along the bottom of the tank, then up an incline to a lip at the end of the tank. The settled material is thus removed from the tank, while the clarified water is discharged into a sump.

Dorr thickeners are generally circular in shape with a conical bottom sloping gently toward the center. A series of ploughs attached to a rotating supporting structure moves the settled sludge spiral fashion toward the center of the apparatus. The sludge is then withdrawn in its thickened state through special pumps. The clarified water overflows the launder constructed around the circumference of the unit, which is quite flexible.

Dependent on the rate of operation, this equipment may be used as a classifier removing the coarser particles, as an underflow, and overflowing the finer particles with the water into the launder.

Hydraulic cyclones developed by the Dutch coal industry in Holland have recently been applied to the clarification of washery water. This equipment, which also acts as a fine coal cleaning unit, has many applications.

For the further dewatering of the thickened sludge, centrifuges, vacuum filters, and thermal dryers are employed. The necessary pumps and piping, of course, form part of the system.

Finally, at many coal preparation plants, some or all of the water overflow from the clarification system is discharged to settling ponds or lagoons for a long period of retention prior to being discharged to the stream system. In some instances such settling basins may be cleaned out periodically, while in others the acreage and storage capacity are great enough to serve for years.

It is safe to say that with the growing demand for a reduction in the quantity of suspended solids in the washery effluent, greater care and thought must be given to the design, and more elaborate equipment will have to be installed. In passing, it may be said that the designer is not entirely responsible for the inability of the clarification system to remove sufficient solids. If the plant is designed for a stipulated capacity, and the owner increases the feed appreciably, it is virtually certain that the settling system will be overloaded. Another factor is the cost of the plant. The initial design may have provided ample equipment to yield a satisfactory effluent. However, when the estimate of cost is received, there is an immediate request for a revision of the estimate downwards. Such revisions result in the removal of some equipment from the design.

In the future, greater attention will have to be paid both by the designer of plants and the coal operator to the requirements of the regulatory bodies having control of stream pollution. At the present time there is under consideration a tentative suggestion from the Pennsylvania Department of Public Health regarding the amount of suspended solids discharged to the stream system from coal cleaning plants. It is realized that to require complete removal of all suspended matter from the water is impractical, so it was suggested that an allowance of 8 lb of −325 mesh suspended solids per ton of clean coal produced be permitted in the washery effluent discharged to the stream system. A number of competent engineers experienced in the design and operation of coal preparation plants have studied and commented on the measure. That it could present difficulties is illustrated in the criticism by Parmley,[25] who writes that the following practical difficulties should be given consideration:

Case 1.

A mine with a R.O.M. feed of 400 T.P.H. with 35% refuse containing considerable fire clay and material that will disintegrate in water. Compared with a mine with 400 T.P.H. 10% reject and a solid shale reject. The one with 35% reject will have 260 tons of clean coal and is allowed only 2080 lbs. per hour waste. In this case the operator would have a very difficult clarification problem, yet is penalized and allowed less waste material than the operator with 10% reject. In the case of 400 T.P.H. with 10% reject there will be produced 360 tons of clean coal with an allowance of 2880 lbs. per hour. In all likelihood with this case the clarification system would be very efficient and there would be less than 8 lbs. per ton wasted.

Case 2.

Take two operators with 400 T.P.H. R.O.M.—one with 40% minus ¼" material and the other with 20% minus ¼". The one with 40% minus ¼" would have a very difficult settling problem yet would be allowed only the same wastage as the one with 20% minus ¼".

Case 3.

The most glaring example is a plant with a capacity of approximately 2400 T.P.H. feed and 30% reject, giving a clean coal of 1680 T.P.H. There would be a wastage of 11840# (5.92 tons) per hour or 83 tons per 14 hour day. This is a lot of material to run to the stream. The question is how can this tonnage be wasted to the river. If wasted with water at the rate of 200 G.P.M. with 11840# per hour or 197 lbs. per minute of solids would give a water containing 10.6% solids. This wastage would be very black and no state inspector would allow such a wastage to go to the river. Yet, according to the tonnage standard, it would be legal.

Now, consider wasting in say 4000 gal. per min. (which would be very impractical), the % solids in the wastage would be ½ of 1%. With only ½ of 1% solids, the waste water would be gray and would probably be allowed to flow into the stream.

Case 4.

Take an operator with 200 T.P.H. and 15% reject or 170 T.P.H. of clean coal. The allowable wastage would be 1360 lbs. per hour or 23 lbs. per minute.

The amount of water wasted would probably depend on the operator's water source or scarcity. Wasted with 23 G.P.M. of water would give 10% solids. Due to blackness of the wasted water, it would not be allowed. If the operator had to waste the same amount of solids upon a visually approved wastage of ½ of 1%, it would be necessary to waste at the rate of 500 G.P.M. This would likely be prohibitive and uneconomical from the operator's standpoint.

It is realized that in all of the above cases the state would say that although the standards would be met, it would be up to the operator to install clarification equipment or waste the higher gallonage. It would be up to him to choose his method.

It is felt that a standard should be based on the % solids in the wasted water and limited to a maximum top size in the solids.

Just what criteria will be used it is hard to say, but that one will be adopted is certain.

The problem of a sliming clay, mentioned in Case 1, has an important bearing on the method of clarification. During recent years, the trend in the bituminous coal fields has been toward full seam mining, employing completely mechanized methods. A decade or more ago the quantity of refuse discharged from the coal preparation plant was approximately 15 to 20 pct of the raw feed. The modern plant must dispose of 25 to 35 pct of the raw feed as refuse, which in many cases contains clay material that breaks down in the wash water into fine sliming materials approaching a colloidal condition. When such situations are encountered, the washery water becomes heavily overloaded with suspended solids that are very difficult to settle in any reasonable retention time. However, that rate of settling has been increased through the use of flocculants that cause the clay to form flocs. The treatment has been varied to suit local conditions, but it is adequately covered in the literature by Samuel[26] and many others.

The acid water drainage and the discharge of washery water carrying suspended solids are the major problems encountered in the coal industry. There are other minor difficulties such as the oil slick carried off by rainfall where dust-proofing oil employed at the loading booms of the preparation plant has spilled on the ground. These are local occurrences, however, and can easily be corrected.

It is quite apparent that the coal industry is becoming aware of the demand for stream pollution control and is contributing to the research programs that are being carried on at various institutions in an effort to find some solution to acid water. To date no satisfactory treatment has been found.

Legal Controls on Stream Pollution

Industry and municipalities are becoming better informed on the obligations placed upon them through the recent legislation governing water supply and stream pollution. They are in more frequent contact with the officials of the commissions and boards that have been appointed to administer the various State, Interstate, and Federal laws and compacts. At the Federal level, Public Law 845, the 80th Congress, was adopted "to provide for water pollution control activities in the Public Health Service of the Federal Security Agency and for other purposes." Since this law was passed, the Public Health Service Agency has become increasingly active in all phases of stream pollution, and its activities will continue.

The Ohio River Valley Water Sanitation Compact, ratified by the legislatures of the eight states embraced by the Ohio River basin, outlines in the Preamble the reasons for the compact, namely:

> The rapid increase in the population of the various metropolitan areas situated within the Ohio drainage basin, and the growth in industrial activity within that area, have resulted in recent years in an increasingly serious pollution of the waters and streams within the said drainage basin, constituting a grave menace to the health, welfare and recreational facilities of the people living in such basin, and occasioning great economic loss.
>
> The control of future pollution and the abatement of existing pollution in the waters of said basin are of prime importance to the people thereof, and can best be accomplished through the cooperation of the States situated therein, by and through a joint or common agency.

The Interstate agreement between the various states in the Potomac River basin is similar in intent to the foregoing quotation.

The Commonwealth of Pennsylvania adopted a Clean Streams Act of 1937. It was amended in 1945 to include culm and silt, or suspended solids, from coal mines and coal cleaning plants. In this law, *pollution* is construed to mean the discharge to or the effects on the stream system of noxious and deleterious substances, "rendering unclean the waters of the Commonwealth to the extent of being harmful or inimical to the public health, or to animal or aquatic life, or to the use of such waters for domestic water supply, or industrial purposes, or for recreation."

Industrial wastes are construed to mean "any liquid, gaseous or solid substance, not sewage, resulting from any manufacturing or industry, or from any establishment, which causes pollution as defined, and silt, coal mine solids, rock, debris, dirt and clay from coal mines, coal collieries, breakers, or other coal processing operations."

At least 45 states have adopted some type of legislation for the conservation of water resources and the control of stream pollution. It is interesting to note that many of the states have patterned their laws on many of the clauses contained in the Pennsylvania Act No. 177, 1945, the Brunner Bill.

The enforcement of these stream pollution control laws is generally assigned to regulatory bodies or commissions appointed by the governors of the individual states. Generally the regulatory bodies are vested with almost unlimited powers. On the other hand, it is unfortunate that there is no system of checks and limitations on their acts and requirements and that they cannot be held responsible for any economic effects which may be brought about by the fullfillment of their requirements.

Wachter[27] has drawn attention to this potentially dangerous situation:

> It is characteristic of pollution abatement laws that the Commissions are not required to relate abatement requirements to actual or potential human uses of the streams. They customarily fix standards which relate theoretical stream conditions to theoretical possible uses, but are not required to relate specific requirements to actual conditions and uses. Consequently, many of them, under the laws by which they operate, have the power to require unrealistic and unnecessarily expensive degrees of treatment whether human purposes are served or not.

In such circumstances the success of the whole control program depends on the sagacity of the members of the commission.

Industry must keep fully informed of the various actions and decisions handed down by the Courts in relation to stream pollution. A case of far-reaching importance in its implications was decided by the Pennsylvania State Supreme Court. A coal mining company, using stripping methods, commenced operations on a clean stream water shed. The State Sanitary Water Board sought an injunction against the company in Dauphin County Court, since mining operations were started without a permit. The Court ruled that mining could continue, if the streams were not polluted, and ignored the contention that a permit was necessary. The Supreme Court reversed the decision on the permit question, and ruled that the Commonwealth was justified in seeking assurance that any new mining operations will not destroy the purity of a stream before issuing a permit. Thus it is practically incumbent on the Sanitary Water Board to assure itself that no new coal stripping operation is a potential source of pollution on a clean stream.

Such a responsibility, "if the Law allows it and the Court awards it," can create inequities that may cause great hurt. Two examples may be cited.

An owner of land acreage invested in rural acreage and purchased with it the mineral rights of any underlying coal seam. Subsequently, on his applying for a permit to mine the coal, the permit was denied because of a potential pollution hazard. Therefore the owner could not realize, or retrieve, his investment.

The second case is a marginal mine that is a source of employment for an isolated community of 900 persons. The property is operated at a loss, but is kept going because of the community. The mine-washing plant is polluting a nearby stream with suspended solids. Any capital expenditure to remove the solids from the water discharged cannot be justified. Economics would require that the whole operation be abandoned, and the livelihood of the community would be at an end.

Such questions as these would tax the wisdom of the members of any commission. The economic effects of all abatement programs should be carefully weighed, and the relative benefits of each scheme should be compared to assure the community the most balanced program for all its needs. Such decisions call for rare judgment. Determining the relative importance of the esthetic and recreational values as compared to local economic considerations is especially difficult but frequently necessary. Employing rational means for attacking the problem may leave a lot to be desired because the influence of the emotional and psychological bias of society plays a great part in the decision.

Little has been said regarding the equally formidable problem of providing adequate sewage treatment plants for centers of population. Many of the great cities of the USA have no treatment plants at all. The human wastes from numerous communities are discharged directly into the stream system or to tidewater. To install modern plants for centers like Pittsburgh, Louisville, or Cincinnati is a stupendous task and requires sound financial planning. Engineering techniques are, however, well known.

Erosion caused by run-off of rainfall has not been touched upon, although the stream systems of the country carry stupendous quantities of silt to the sea. Radioactive substances in the sewer systems that receive the wastes from hospitals in city centers are also a factor. Time does not permit consideration of these and many other conditions.

Conclusion

The method of attacking the whole problem of stream pollution is made extremely difficult because of the meager knowledge of the specific effects of the numerous wastes of various quantities and concentrations that enter the river basin. Little is known of their action on aquatic life, nor the interaction between themselves. A great field of investigation lies ahead, and it is to be hoped that greater knowledge will be available in the coming years for guidance of the planners and the administrators of these comprehensive programs for the conservation of the country's water resources.

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