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WATER AND RELATED PROBLEMS IN COAL-MINE AREAS OF ALABAMA

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Water-resource problems or potential problems in Alabama resulting from surface and subsurface coal mining include erosion and sedimentation, flooding, diversion of drainage, decline in water level, land subsidence, and the degradation of water quality. The degradation of water quality is the most serious and widespread coal-mine related problem in Alabama. The chemical quality of water in numerous streams draining coal-mine areas has been altered drastically. The pH of water draining from mined areas commonly ranges from 2.1 to 5.0, generally has high sulfate and dissolved solids concentrations, is hard to very hard, and may contain objectionable amounts of iron. The detrimental quality of water in some streams may persist for decades after mining has ceased. Without proper safeguards, additional mining may cause a significant deterioration in the quality of water in major streams where the more mineralized mine waters are now diluted.

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OF ALABAMA

By Alfred L. Knight and J. G. Newton

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UNITED STATES DEPARTMENT OF THE INTERIOR

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WATER AND RELATED PROBLEMS IN COAL MINE AREAS OF ALABAMA

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ABSTRACT

Since its beginning in the early 1800's, coal mining in Alabama has progressively increased and is expected to increase drastically in the future because of the increasing demand for fossil fuel to meet the energy needs of our nation. Surface and subsurface coal mining will continue to create problems that are related to water resources. Problems or potential problems resulting from one or both types of mining include erosion and sedimentation, flooding, diversion of drainage, decline in water level, land subsidence, and the degradation of water quality. The degradation of water quality is the most serious and widespread coal mine related problem in Alabama.

The chemical quality of water in numerous streams draining coal mine areas has been altered drastically. Where the water was previously suitable for most purposes, the present quality allows only limited use without expensive treatment. The pH of water draining from mined areas commonly ranges from 2.1 to 5.0, generally has high sulfate and dissolved solids concentrations, is hard to very hard, and may contain objectionable amounts of iron. The detrimental quality of water in some streams may persist for decades after mining has ceased. Without proper safeguards, additional mining may cause a significant deterioration in the quality of water in major streams where the more mineralized mine waters are now diluted.

INTRODUCTION

Increasing demands for energy and limited oil and gas reserves have placed a renewed emphasis on the development of coal resources. Coal mining in Alabama is expected to increase in future years to help meet this demand. At the same time, existing problems associated with mining will become more intensified and more complex. Unfortunately, some problems such as the deterioration of water quality, extend well beyond mining boundaries and affect adjacent areas.

PURPOSE AND SCOPE

Three questions are frequently asked by those engaged in the mining industry, by governmental officials at all levels, and by the public. First, what problems are associated with coal mining? Second, how serious are the problems? Third, what can be done to remedy the problems? Concrete answers to these pertinent questions are difficult to determine.

This project is oriented primarily toward mining's influence on the water resources of the State. Because of the magnitude of the problem and the data base available, it will consist of multiple phases. The purpose of the first phase and of this report is to (1) assimilate or determine what information is available to evaluate the problem, (2) determine the magnitude of mining activity that contributes to the overall problem, and (3) isolate and define the individual problems that have or will result from mining. The information provided will allow a factual basis for the planning and execution of more comprehensive forthcoming phases of work.

The U.S. Geological Survey has adopted a policy of including metric or International System (SI) units in all reports. For the convenience of the reader, factors for converting English units to SI units are presented in table 1.

ACKNOWLEDGMENTS

Acknowledgment is made to several individuals and agencies for significant contributions to this investigation. Messrs. Thomas W. Daniel, Jr., Willard E. Ward II, and Francis E. Evans, Jr., Geological Survey of Alabama, furnished information pertaining to the magnitude of coal mining in the State. Mr. Tom Brown, University of Alabama, provided a thorough legal search to aid in defining the history of problems associated with mining. Mr. Allen W. Kerr, Chief, Hydrology and Hydraulics Branch, Department of the Army, U.S. Corps of Engineers, provided unpublished information for problem areas investigated along major streams. Mr. J. Torbit Henry, River Basin Study Staff Leader, U.S. Department of Agriculture, Soil Conservation Service, provided valuable information regarding erosion and sedimentation along some streams. Mr. Al Curry, Tennessee Valley Authority, provided unpublished summaries evaluating the extent of mining and potential reclamation efforts in several counties in north Alabama.

Analytical results of water samples collected from streams in the Cahaba and Warrior River basins were furnished by Mr. E. John Williford, State of Alabama Water Improvement Commission.

Messrs. Raymond A. Jensen and Ljubo Lulich, Office of Water Research and Technology, U.S. Department of the Interior, provided a bibliography concerning acid-mine drainage and abstracts of reports related to water problems and coal mining.

Information concerning locations of mines and dates of operation were provided by Mr. H. T. Williams, Alabama Department of Industrial Relations, and Mr. H. Dolan, Mining Enforcement Safety Administration.

Table 1.--Factors for converting English units to International System (SI) units

Multiply English units	By	To obtain SE units
inch (in)	25.4	millimeter (mm)
foot (ft)	.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
acre	.004047	square kilometer (km^2)
cubic yard (yd^3)	.7645	cubic meter (m^3)
ton	.9072	tonne (t)
foot per mile (ft/mi)	.1894	meter per kilometer (m/km)
ton per square mile (ton/mi^2)	.3503	tonne per square kilometer (t/km^2)
cubic foot per second (ft^3/s)	28.32	liter per second (L/s)
cubic foot per second per square mile $(ft^3/s)/mi^2$	.01093	liter per second per square kilometer $(L/s)/km^2$
gallons per minute (gal/min)	.06309	liter per second (L/s)

AREA OF STUDY

GEOLOGIC SETTING

The occurrence of significant quantities of coal or lignite in Alabama is restricted almost entirely to the Pottsville Formation of Pennsylvanian age in the northern part of the state and to the Naheola Formation of Tertiary age in the southern part. Areas underlain by these principal sources of coal and lignite are shown in figure 1. Locally, strata located immediately below the Pottsville and above the Naheola contain coal or lignite reserves. Most of these reserves are included in the distribution shown in figure 1. Large quantities of bituminous coal have been and will be mined from the Pottsville Formation. Lignite in the Naheola Formation has not been mined to date but is a potential source of energy and will probably be extracted in the future.

The Pottsville Formation consists chiefly of alternating beds of gray sandstone, siltstone and shale interbedded with conglomerate, under clay, and coal. The Pottsville Formation ranges from 1,000 to 2,500 ft (305 to 760 m) thick in a large part of the area (fig. 1). In the southernmost part of the area the Pottsville Formation reaches a maximum thickness of about 9,000 ft (2,740 m) (Semmes, 1929). The formation, where thickest, contains about 60 beds of bituminous coal (Ward and Evans, 1975). The coal is the carbonaceous remnant of vegetal matter deposited in swamps, whereas the sandstone, shale, and conglomerate represent infill deposited when the swamps were inundated by ancient seas or inland bodies of water. Carbonaceous remains in some shales and sandstones indicate their proximity to vegetal matter during deposition. Deposition by ancient seas is indicated in several horizons by fossils that were restricted to that environment.

The dominant rock type in the upper part of the Pottsville Formation in which coal beds occur is shale. The shale is commonly silty and carbonaceous and grades laterally or vertically into argillaceous siltstone and very fine grained sandstone or is interbedded with them. Much of the shale contains nodules or layers of iron carbonate (siderite) or iron magnesium carbonate (ankerite); most nodules are lenses less than 3 in (76 mm) long, but the siderite also occurs as lenses as much as 1 ft (0.3 m) thick and several feet long and, in places, layers of siderite less than 1 in (25 mm) thick are interbedded with shale (Culbertson, 1964, p. 18).

Coal beds in the Pottsville Formation generally range in thickness from a few inches to 10 ft (3 m). Although some beds are persistent laterally, others are lenticular and extend for only short distances. Most of the coal is high-volatile A bituminous that contains 5 to 15 percent ash and less than 2 percent sulfur (Culbertson, 1964, p. 51). In some coal beds, pyrite is a conspicuous constituent.

Figure 1.--Distribution of principal sources of coal and lignite (modified from Ward and Evans, 1975).

The Pennsylvanian strata have been subjected to intensive faulting and folding in many areas of Alabama. This structural deformation and subsequent erosion has resulted in the dissection of the area in which the Pottsville Formation occurs. The area underlain by the Pottsville, based on major stream basins and physiographic features, is divided into the Cahaba, Coosa, Plateau, and Warrior coal fields (fig. 1). The attitude of strata within these areas varies from relatively flat lying to highly inclined.

The Naheola Formation of Tertiary age is about 200 ft (60 m) thick in west-central Alabama and consists chiefly of gray, laminated to thin-bedded carbonaceous sand, clay, and silt in the lower 150 ft (45 m) and greenish-gray glauconitic sand and laminated to thin-bedded clay in the upper 50 ft (15 m) (Newton and others, 1961). The formation trends southeastward and dips southwestward at a rate of about 35 ft/mi (6.6 m/km). It thins eastward and, in the central part of the State, is overlapped by younger strata. In the outcrop, one or more prominent beds of lignite are generally present beneath the sand and clay sequence in the upper 50 ft (15 m) of the Naheola. The lignite in most exposures generally ranges in thickness from 0.5 to 7 ft (0.2 to 2.1 m). The carbonaceous remains in the formation were deposited and buried under conditions similar to those that prevailed during the deposition of the Pottsville Formation.

HYDROLOGIC SETTING

The source of water in the coal-mining areas (fig. 1) is precipitation which, in Alabama, generally exceeds 50 in (1270 mm) annually. The occurrence and availability of ground water and surface water is governed largely by the topography and the type rocks that underlie the area. Water percolating downward into the Pottsville Formation is generally stored in and transmitted through openings along joints, fractures, and bedding planes. Water in interconnected openings moves in response to gravity from higher to lower altitudes, generally toward a stream channel where it discharges and becomes a part of the streamflow. During dry weather, this discharge constitutes all or most of the streamflow in the channel.

Water in the Pottsville occurs under both water-table and artesian conditions. This study, however, is concerned primarily with that occurring under water-table conditions. The configuration of the water table, the unconfined upper surface of the zone in which all openings are filled with water, conforms somewhat to that of the overlying topography but is influenced by geologic structure, withdrawal of water, and variations in rainfall.

The Pottsville Formation is not an aquifer that yields large quantities of water to wells, but is the source of water to most domestic wells in coal mine areas. Yields from wells rarely exceed 100 gal/min (6.3 L/s); most wells and springs yield 10 gal/min (0.6 L/s) or less (Paulson and others, 1962; Harris and McMaster, 1965). Quantitative data are not available to determine specific aquifer characteristics; however, the small yields of many wells and springs in such a broad area would indicate a low permeability. Most wells obtain water at depths of less than 250 ft (76 m), supplies at greater depths become increasingly difficult to obtain. Low yields of wells and springs tapping or discharging from massive sandstones and conglomerates suggest that primary interstitial openings have been restricted by cementation since deposition.

The Naheola Formation in which the lignite occurs is not a major aquifer in the Coastal Plain. All but the uppermost part of the unit consists chiefly of relatively impermeable silt and clay that do not yield water to wells. Sand, where present in the upper part of the formation, will yield supplies adequate for domestic and stock use. These sands are generally located in horizons above the principal beds of lignite.

Streamflow characteristics are determined by climatic, physiographic, and geologic conditions and stream-regulating conditions imposed by man. In a broad area where conditions determining streamflow characteristics are similar, basins may have similar median and floodflow characteristics. Low-flow characteristics are likely to be dissimilar, however, because of slight differences in physiography and geology. Many streams in the coal mining regions of Alabama do not have well-sustained flows. This is characteristic of basins underlain by soil or rocks that inhibit the storage of ground water. Streamflow recedes rapidly from sharply concentrated flood peaks to low flows, or even no flow between storms. These properties are reflected in the streamflow hydrographs shown in figure 2. The drainage basin for Sipsey Fork is characterized by hilly terrain, steep slopes, and is underlain by relatively impervious rocks in the Pottsville Formation. The Turkey Creek basin is characterized by gently sloping hills, relatively flat slopes, and is underlain largely by relatively impervious rocks in the Naheola Formation. Because both basins are underlain largely by relatively impervious rocks, their hydrographs reveal similar streamflow characteristics. In response to the seasonal distribution of precipitation, higher flows generally occur in the winter and spring months and lower flows in late summer and early fall.

In general, basic streamflow data and data related to the stage and contents of lakes and reservoirs have been published in annual reports by the U.S. Geological Survey. Special reports on floods, low flows, or other hydrologic studies for specific areas are also available. Information relative to these reports or basic data in the files of the U.S. Geological Survey may be obtained or examined at the district office in Tuscaloosa, Ala. Data collected in Alabama prior to the initiation of this study have been used in this report to define, in general terms, some basic streamflow characteristics within the coal mining regions. Since the development of a stream basin and the use and availability of streamflow are influenced to a large extent by extremes of flow, general discussions are directed toward these extremes and their magnitude, duration, and frequency of occurrence.

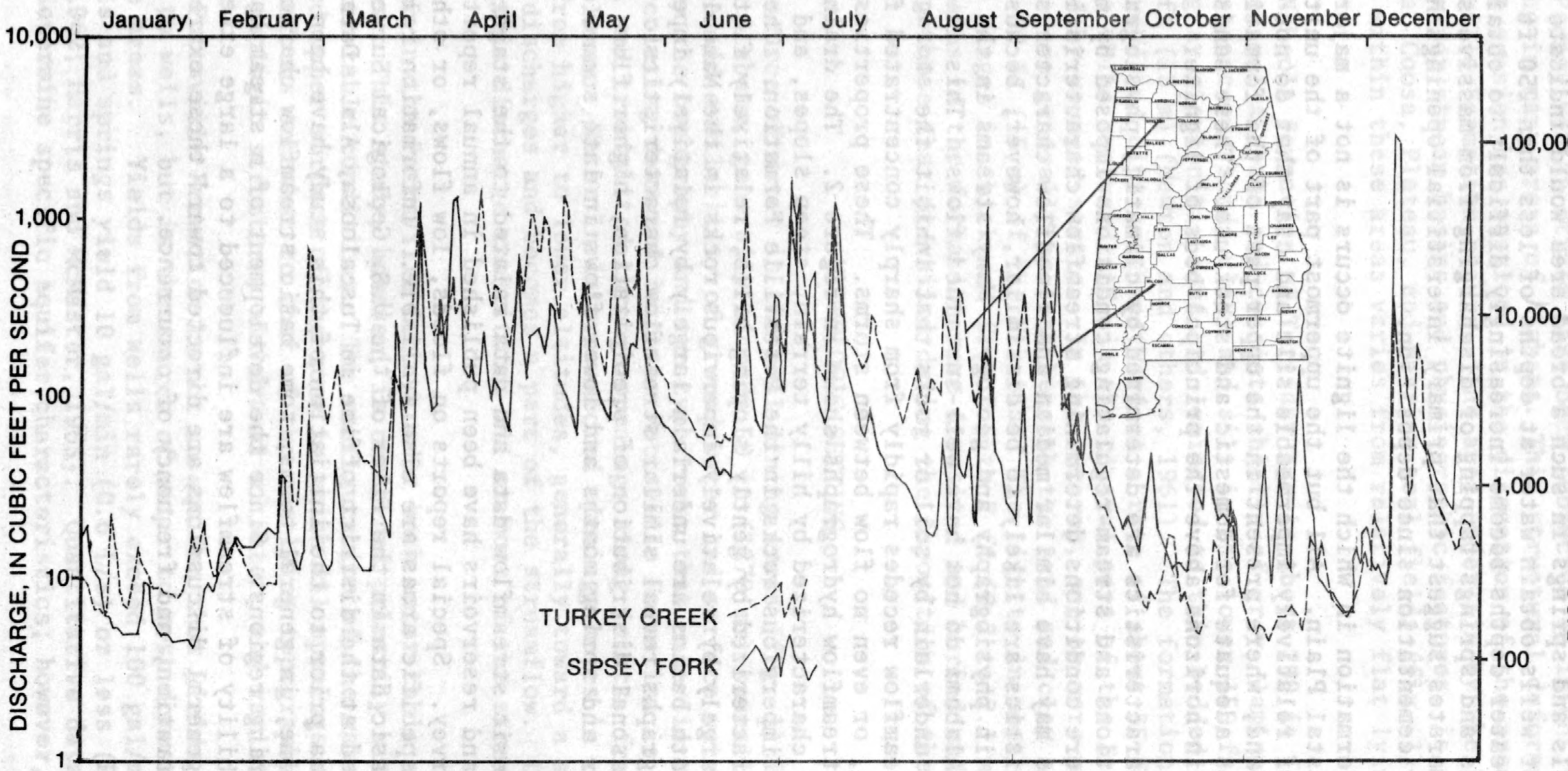


Figure 2.—Hydrographs for Sipsey Fork at Grayson and Turkey Creek at Kimbrough, October 1973-September 1974.

The variability of streamflow is best demonstrated with a flow-duration curve. This curve is a cumulative-frequency curve that shows the percent of time that a specific discharge may be equaled or exceeded during a given period. It combines into one curve the flow characteristics of a stream throughout the range of discharge, without regard to the sequence of occurrence. Hydrologic and geologic characteristics of the drainage basin are generally the major factors that determine the shape of the flow-duration curve, especially at the low end. Flow-duration curves for Sipsey Fork and Turkey Creek are shown in figure 3. Discharges are plotted in $(ft^3/s)/mi^2$ or $(L/s)/km^2$ so that most of the effects of the drainage basin size may be eliminated. The steep slopes throughout the curves denote that streamflow is highly variable and that the flow is largely from direct runoff. Steep slopes at the lower end of the curves indicate small contributions from ground-water storage. This is also reflected by their similar average flows which average about 1.5 $(ft^3/s)/mi^2$ or 16.4 $(L/s)/km^2$. Available data indicate that other stream basins within the coal mining regions would exhibit similar streamflow characteristics.

The suitability of a stream for a particular use is generally dictated by the quantity, duration, and probability of occurrence of low flows. For example, streamflow requirements for waste disposal, municipal or industrial supplies, and maintenance of fisheries, are commonly evaluated in terms of low-flow characteristics. An index generally used to define the low-flow characteristics of a stream is the lowest mean discharge for 7 consecutive days having a recurrence interval of 2 years. For simplicity, the index is referred to as the 7-day Q_2. The areal variance in the 7-day Q_2 is shown in figure 4. Within the outlined coal regions, the 7-day Q_2 generally ranges from very poor (less than 0.01 $(ft^3/s)/mi^2$ or 0.11 $(L/s)/km^2$) to poor (0.01 to 0.05 $(ft^3/s)mi^2$ or 0.11 to 0.55 $(L/s)/km^2$) (Peirce, 1967).

Use of a stream and the land adjacent to it is also governed by the magnitude and frequency of flooding. The time of occurrence of a flood cannot be predicted; however, it is possible through evaluation of past records to predict the probability of a flood of a given magnitude occurring in any year. Records on which such predictions can be based are available for some of the larger streams within the coal regions of Alabama. Where streamflow records are short and streamflow data are not available at a particular site, regional analyses of flood data provide a basis for estimating floodflows. Such an analysis for Alabama is contained in a report by Hains (1973). Except for streams draining urban areas, methods are provided for estimating flood discharges (up to the 100-year recurrence interval) at ungaged sites having drainage areas as small as 1 mi^2 (2.6 km^2). To illustrate the variation in floodflow characteristics, the magnitude of a flood having a 100-year recurrence interval for streams draining an area of 5 mi^2 (13 km^2) has been determined by using the methods outlined by Hains (1973). As shown in fig. 5, the average 100-year flood runoff ranges from 350 to 800 $(ft^3/s)/mi^2$ or 3,830 to 8,740 $(L/s)/km^2$. The higher flows are primarily the result of the occurrence of impermeable bedrock and soil; however, other factors affecting the floodflows are geographic location, channel slope, and shape of the drainage basin.

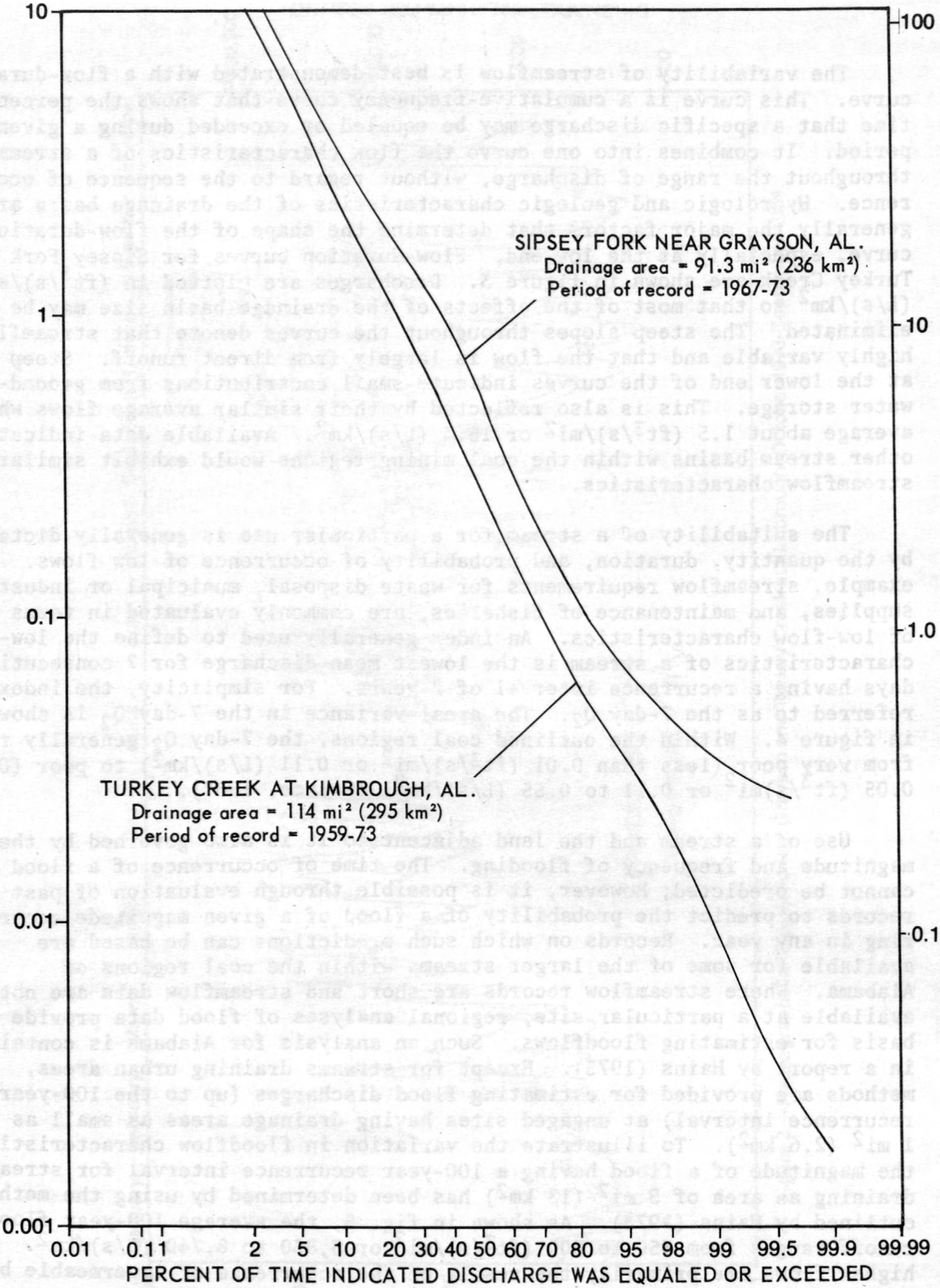


Figure 3.–Flow duration curves for Sipsey Fork at Grayson and Turkey Creek at Kimbrough.

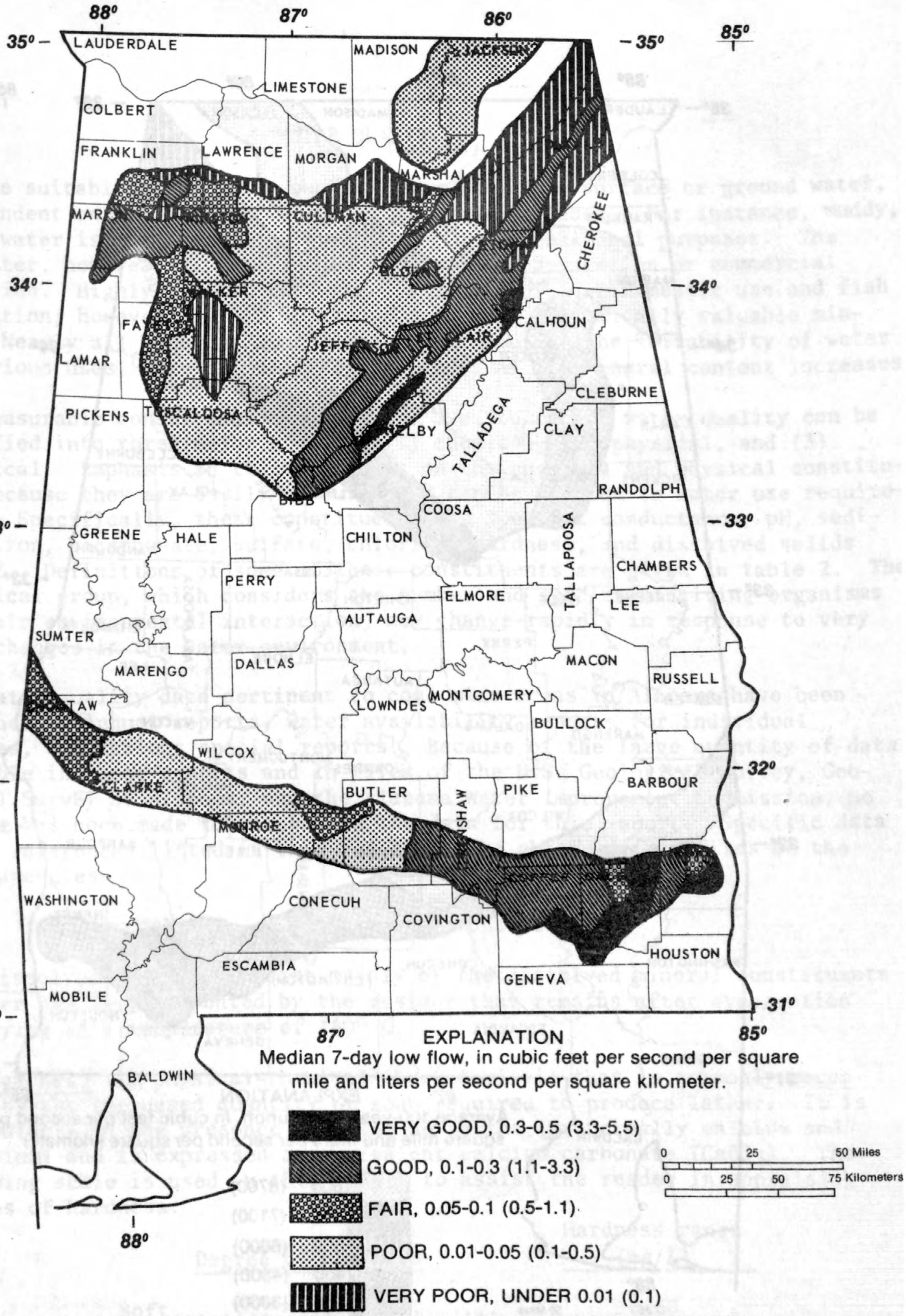


Figure 4.--Areal variation in median 7-day low-flow of streams in and near coal mining areas (modified from Peirce, 1967).

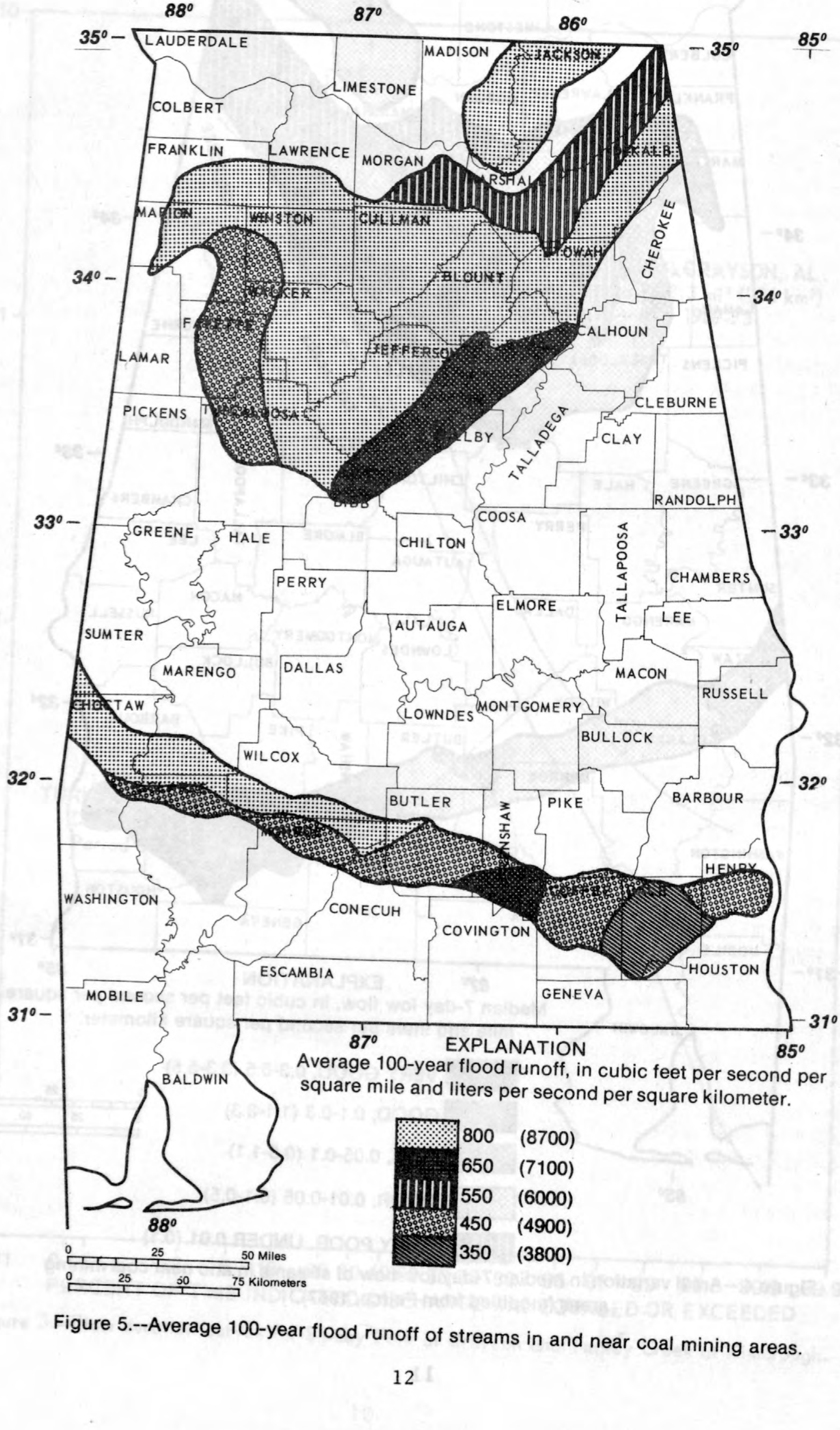


Figure 5.--Average 100-year flood runoff of streams in and near coal mining areas.

WATER QUALITY

The suitability of water quality, whether it be surface or ground water, is dependent on the use for which the water is intended. For instance, muddy, turbid water is not desirable for drinking or recreational purposes. The same water, however, may be acceptable for power generation or commercial navigation. Highly mineralized water is unsuitable for domestic use and fish propagation; however, it may be a source of some economically valuable mineral. Nearly all water is acceptable for some use. The suitability of water for various uses, however, generally declines as its mineral content increases.

Measurable constituents that may be used to define water quality can be classified into three major groups: (1) chemical, (2) physical, and (3) biological. Emphasis in this report is on the chemical and physical constituents because they are easily measured and can be related to water use requirements. Specifically, these constituents are specific conductance, pH, sediment, iron, bicarbonate, sulfate, chloride, hardness, and dissolved solids content. Definitions of some of these constituents are given in table 2. The biological group, which considers the number and species of living organisms and their environmental interaction, may change rapidly in response to very minor changes in the water environment.

Water-quality data pertinent to coal mine areas in Alabama have been published in annual reports, water availability reports for individual counties, and various special reports. Because of the large quantity of data available in those reports and in files of the U.S. Geological Survey, Geological Survey of Alabama, and the Alabama Water Improvement Commission, no attempt has been made to retabulate the data for this report. Specific data not in references listed in this report may be obtained from files of the above agencies.

Table 2.--Definitions of constituents

Dissolved solids.--Consist mainly of the dissolved mineral constituents in water and is represented by the residue that remains after evaporation and drying at a temperature of 180° C.

Hardness.--A physical-chemical characteristic that is commonly recognized by the increased quantity of soap required to produce lather. It is attributable to the presence of alkaline earths (principally calcium and magnesium) and is expressed as equivalent calcium carbonate ($CaCO_3$). The following scale is used in this report to assist the reader in appraising degrees of hardness:

Degree of hardness	Hardness range (mg/L)
Soft...........................	0-60
Moderately hard..............	61-120
Hard...........................	121-180
Very hard.....................	>180

pH.--A measure of the hydrogen-ion concentration of a solution. A pH unit is expressed as the negative $\log_{10}$ of the hydrogen-ion concentration. The pH of pure water is 7.0, acid water has a smaller pH and alkaline water a larger pH.

Sediment.--Solid material that originates mostly from disintegrated rocks and is transported by, suspended in, or deposited from water; it includes chemical and biochemical precipitates and decomposed organic material such as humus. The quantity, characteristics, and source of sediment in streams are influenced by environmental factors such as degree and length of slope, soil characteristics, land usage, and quantity and intensity of precipitation.

Specific conductance.--A measure of the ability of a water to conduct an electrical current and is expressed in micromhos per centimetre at 25° C. Because the specific conductance is related to the number and specific chemical types of ions in solution, it can be used for approximating the dissolved-solids content in the water. Commonly, the amount of dissolved solids (in milligrams per liter) is about 65 percent of the specific conductance (in micromhos per cm at 25° C). This relation is not constant from stream to stream, and it may even vary with in the same source.

The quality of water in coal mine areas unaffected by mining operations may be defined in general terms. In a reconnaissance of the region encompassing the Black Warrior River basin within the Warrior and Plateau Coal Fields (fig. 1), Cherry (1963, p. 29-30) stated: "The rocks are relatively insoluble in water; therefore, the waters draining from the area are low in mineral content." The mineral content as defined by Cherry is "a calculated value obtained by summing the individual mineral constituents dissolved in water. The mineral content ranged from 20 to 58 mg/L and the specific conductance ranged from 23 to 65 micromhos in 80 percent of the samples. The waters of this area are soft; hardness ranged from 8 to 24 mg/L in 80 percent of the samples. The pH ranged from 6.5 to 7.3. The sum of the sulfate and chloride generally was less than 10 mg/L. Most of the waters contain almost no color (less than 10 units) although a few streams have colors greater than 10 units." In the same investigation, water samples collected in the basin had iron contents less than 0.3 mg/L and, in most samples, a bicarbonate content less than 25 mg/L. Biesecker and George (1966, p. 7) reported similar findings in a study of coal-mine drainage in Appalachia.

Available data show a marked similarity in the quality of water in basins unaffected by mining but underlain by both the Pottsville and Naheola Formations. The water, with minor exceptions, is soft to moderately hard and has a bicarbonate content less than 50 mg/L, a chloride content less than 5 mg/L, a specific conductance less than 100 micromhos, and a pH of 6.2 and 8.0.

Ground water in the Pottsville Formation at depths of 200 ft (60 m) or less generally is moderately hard to hard, has a bicarbonate content in excess of 200 mg/L, sulfate and chloride contents less than 30 mg/L, iron in excess of 0.3 mg/L, a specific conductance greater than 200 micromhos, and a pH that ranges from 7.0 to 9.0. Mineralized water, with chloride being the principal constituent, is present in the formation at relatively shallow depths in structurally deformed areas in Tuscaloosa and Fayette Counties. Water similar in quality is present in the Pottsville Formation in other areas but at depth exceeding those penetrated by existing wells. In some areas water that is acidic, hard to very hard, and contains objectionable amounts of iron and sulfate is probably from wells that penetrate coal beds.

Within the lignite belt in southern Alabama, water samples from wells tapping the Naheola Formation in Marengo County (Newton and others, 1961) indicate that the water generally contains less than 0.1 mg/L iron, less than 60 mg/L sulfate, less than 15 mg/L chloride, less than 50 mg/L bicarbonate, has a specific conductance less than 250 micromhos, and a pH of 6.1 to 6.7. Depths of wells sampled were 54 ft (16.4 m) or less.

COAL MINING

The extraction of coal, since its beginning at about the turn of the 19th century, has become one of Alabama's major industries. Alabama produced 18.9 million tons (17.1 million tonnes) in 1973 which contrasts greatly with the earliest production figures of 140,000 tons (127,000 t) for the period 1870 to 1874 (Ward and Evans, 1975). Production of coal in Alabama because of anticipated energy requirements and the shortage of other fuels, is expected to increase in the future.

Estimates of recoverable coal reserves range widely from 1.03 billion tons (0.93 billion tonnes) (U.S. Department of the Interior, 1974) to 18.4 billion tons (16.7 billion tonnes) (Ward and Evans, 1975). The two estimates are based on different criteria as their variation indicates. In general, the former estimate is based largely on demonstrated reserves and existing mining technology whereas the latter estimate is based on an updated view of total resources and an advancing capability for mining deeper and narrower coal seams.

MINING METHODS

The extraction of coal is divided into surface and subsurface mining. Techniques used to accomplish both types are quite different; however, the degree and depth of mining accomplished by either are controlled largely by common factors including the thickness, inclination, depth to, and quality of the coal bed being mined. The quantity of coal being mined at the surface in recent years has exceeded that mined in the subsurface; however, this trend will probably be reversed in the future. In 1973, approximately 130 surface mines produced 60 percent of Alabama's total production (Ward and Evans, 1975).

Surface Mining

Mining at the surface is accomplished by removing (stripping) overburden to gain access to the coal bed. This is commonly referred to as "strip mining." Strip mining in Alabama began about 1912, and started contributing significantly to the total production of coal in the mid-1940's, and increased before leveling off in 1970 (Ward and Evans, 1975). One of the benefits of surface mining is that a larger percentage of coal in a seam can generally be retrieved by stripping than by subsurface mining. The depth to which strip mining is accomplished has increased significantly since the 1940's due largely to the development of specialized heavy equipment that can move large volumes of overburden in a short period of time. The average depth of stripping in Alabama prior to 1950 was probably less than 50 ft (15 m), whereas depths in 1975 commonly exceed 100 ft (30 m).

In general, surface mining is controlled by geologic structure and topography. These factors control whether the mining will be "massive" or "restricted." Massive or area mining is accomplished where the dip of strata and topography are relatively gentle (fig. 6A). Here, a linear cut is made to the underlying coal bed, the overburden is removed, and, subsequently, the coal itself. Successive parallel cuts are made with the overburden or "spoil" being used to fill in the preceding cuts. Because the volume of overburden in its shattered state is greater than the volume it occupied in the natural state, the filled area resembles a mound. Successive mounds ending next to the last cut or trench are typical of massive mining (fig. 6B).

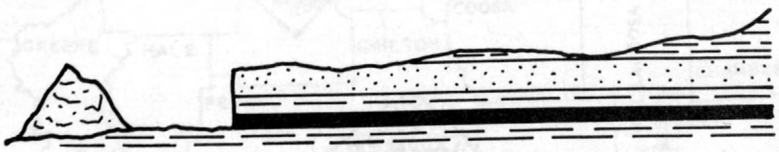
Restricted mining occurs where the topography is irregular or geologic strata dip steeply. Where the strata dip steeply, overburden along a linear strip is removed and placed in a spoil pile parallel to the cut (fig. 7A). Because the depth and amount of overburden determine whether or not mining is economically feasible, the excavation may consist of one or more parallel cuts (figs. 7A and 7B). The width of the restricted mining is narrow in comparison with area mining but in length may extend for miles. Where the dip of strata is negligible and the topographic relief is considerable, the restricted mining of coal beds in hillsides results in "contour" stripping.

Where strip mining becomes economically unfeasible due to the thickness of overburden, other methods can be utilized to remove the coal. The coal bed exposed in the cut wall of the last strip can be augered. This method utilizes multiple auger bits that are inserted into the bed and "thread" the coal back to the surface. Although not as efficient as strip mining, this method eliminates the further removal of overburden. Mining by this method is limited in Alabama but will probably increase in the future.

Magnitude

Evaluating water problems associated with the surface mining of coal necessitates mapping the area disturbed. This allows an estimation of how severely natural conditions in a given area have been altered. Available data do not allow an estimation for the entire area of study, however, high altitude photographs taken in February 1973 may be used to take an overall look at about 3,000 mi^2 (7,770 km^2) within the study area (fig. 8). Major shortcomings in the use of this photography are (1) some shallow surface mining in narrow strips done between 1912 and the mid-1940's is probably obscured by foliage, and (2) very large areas of mining activity since acquisition of the photography are not defined. Surface mining in the area of coverage probably far exceeds that in the remainder of the area of study. The percentage of the total it represents, however, is unknown.

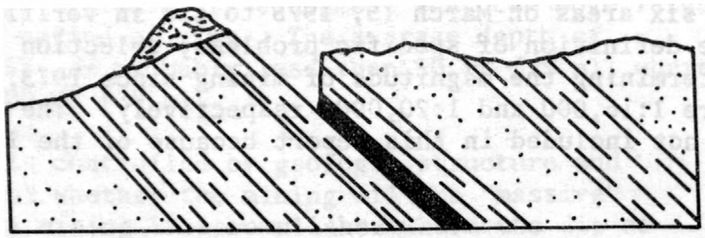
Color infrared photographs taken in February 1973 were obtained on overflights at an altitude of 60,000 ft (18,300 m), or at a scale of 1:126,720. Overflights at altitudes of 8,000 and 10,000 ft (2,440 and 3,050 m) were made in six areas on March 15, 1975 to aid in verification of previous findings, the definition of specific problems, selection of data collection sites, and determining the magnitude of mining since 1973. Scales for these flights were 1:16,000 and 1:20,000, respectively. The magnitude of mining since 1973 is not included in this report because of the limited photographic coverage.



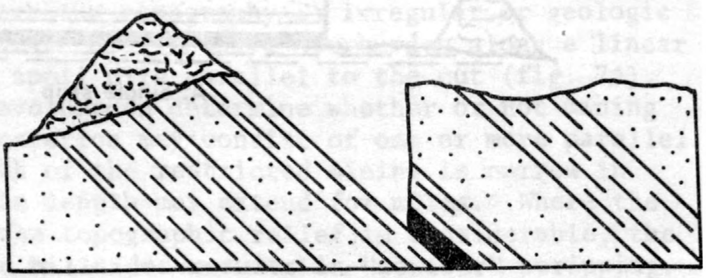
A. Single strip

B. Multiple strips

Figure 6.–Area surface mining.



A. Single strip



B. Multiple strips

Figure 7.—Restricted surface mining.

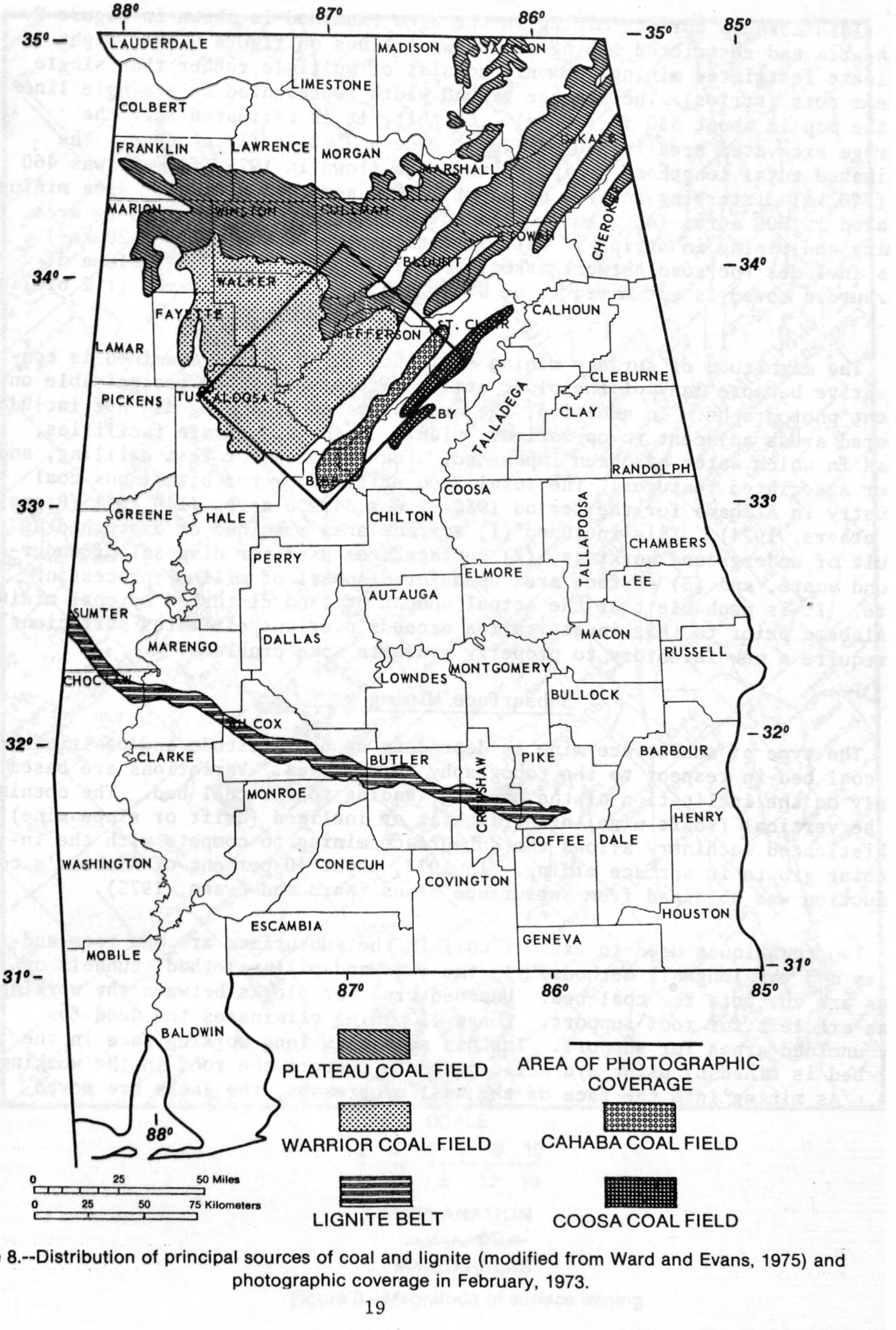


Figure 8.--Distribution of principal sources of coal and lignite (modified from Ward and Evans, 1975) and photographic coverage in February, 1973.

Identifiable surface mining in the area examined is shown in figure 9. Both area and restricted mining are shown. Lines on figure 9 that might indicate restricted mining commonly consist of multiple rather than single linear cuts (strips). The average ground width represented by a single line on the map is about 330 ft (100 m). Of this, it is estimated that the average excavated area is 250 ft (76 m) wide and 40 ft (12 m) deep. The estimated total length of strips in the area flown in 1973 (fig. 9) was 460 mi (740 km) disturbing an area of about 14,000 acres (56.7 km^2). Area mining totaled 10,500 acres (42.2 km^2). The total area directly affected by area mining and mining in strips is estimated to exceed 30,000 acres (120 km^2). This includes the road network associated with the mining. The volume of overburden moved is estimated to be about 1.6 billion cubic yards (1.2 billion m^3).

The magnitude of surface mining estimated for the area examined is conservative because many of the older strips were probably not recognizable on recent photographs. In addition, the area affected by mining did not include cleared areas adjacent to operations, plants, washers, storage facilities, areas in which water has been impounded, areas cleared for test drilling, and other associated features. The total land utilized by the bituminous coal industry in Alabama for the period 1930-71 was 34,900 acres (140 km^2) (Paone and others, 1974). This included (1) surface area subsided or disturbed as result of underground workings, (2) surface area used for disposal of underground waste, and (3) surface area used for disposal of mill or processing waste. It is probable that the actual amount of land disturbed by coal mining in Alabama prior to this investigation exceeds previous estimates sufficiently to require a new inventory to properly evaluate some problems.

Subsurface Mining

The type of subsurface mine is dependent on the attitude and position of the coal bed in respect to the topography in the area. Variations are based mainly on the inclination of the opening leading to the coal bed. The opening may be vertical (shaft mine) or horizontal or inclined (drift or slope mine). Sophisticated machinery allows the subsurface mining to compete with the increasing growth in surface mining. In 1973, about 40 percent of Alabama's coal production was obtained from subsurface mines (Ward and Evans, 1975).

Two techniques used to extract coal in the subsurface are the room-and-pillar and the longwall methods. In the room-and-pillar method, tunnels or rooms are cut into the coal bed. Unmined areas or blocks between the working areas are left for roof support. Longwall mining eliminates the need for many unmined areas for support. In this method, a long working face in the coal bed is mined by using hydraulic jacks to support the roof in the working area. As mining into the face of the wall progresses, the jacks are moved

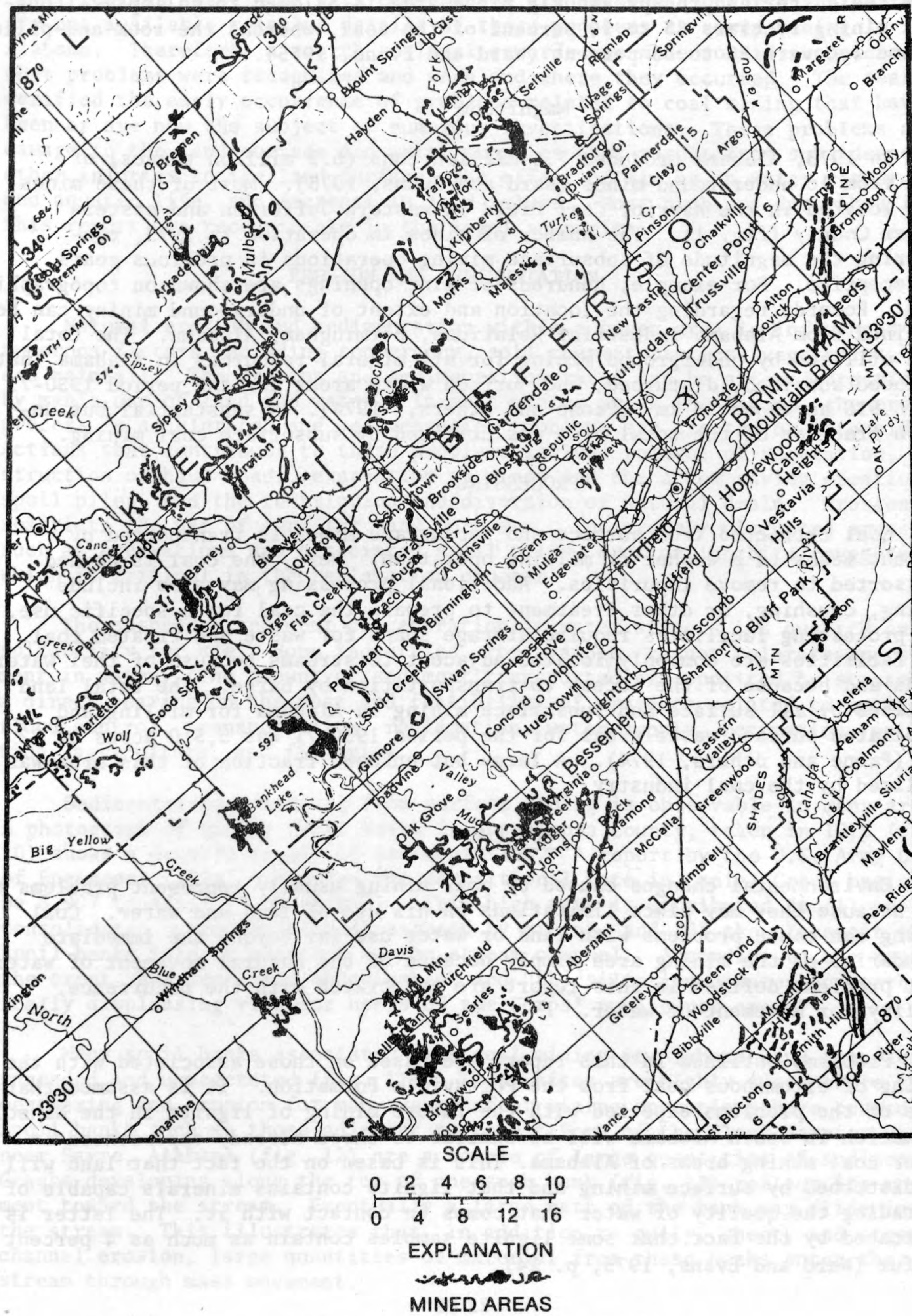


Figure 9.--Magnitude of surface mining.

with the cutter and the previously mined area is allowed to collapse. Longwall mining recovers 85 to 90 percent of the coal, whereas the room-and-pillar method recovers 50 to 60 percent (Ward and Evans, 1975).

Magnitude

In 1973, Alabama produced 7.6 million tons (6.9 million tonnes) of coal from 16 underground mines (Ward and Evans, 1975). Most of these mines were located in the Warrior Coal Field in western Jefferson and eastern Walker County (fig. 1). The number of mines in operation in 1973, considering the magnitude of subsurface mining operations in previous years, is deceptive. For example, hundreds of mine openings are shown on topographic maps. Records regarding the location and extent of underground mining can be obtained from Alabama Industrial Relations, Birmingham, Alabama. The total land utilized by underground mining for all mineral resources in Alabama that included subsided, disturbed, and surface waste areas for the period 1930-71 was 6,910 acres or 28 km^2 (Paone and others, 1974). A substantial but unknown fraction of the total area was utilized by subsurface coal mining.

PROCESSING

Coal extracted from surface and subsurface mines is transported by various means to a washer or milling operation. Here, the coal is washed and sorted to remove impurities. Additional processing may also include sizing, crushing, or other treatment to prepare the coal for a specific use. The processing facilities require storage space for waste and treated coal. The facilities are commonly located adjacent to streams because of thei water needs and because of the access to transportation by barge. The total land utilized by all surface and subsurface mining in Alabama for milling and associated surface waste areas for the period 1930-71 was 5,510 acres or 22 km^2 (Paone and others, 1974). A large but unknown fraction of this area was utilized by the coal industry.

PROBLEMS

Environmental changes caused by coal mining usually represent problems to man because they may place limitations on his use of land and water. Coal mining can cause problems with land or water use far beyond the immediate boundaries of the mining area simply because of the natural movement of water. Most problems defined in this report are associated with the occurrence, quality, or movement of water.

Problems outlined in this report are based on those associated with the mining of bituminous coal from the Pottsville Formation. It is assumed that some of the problems expected with the future mining of lignite in the Naheola Formation in south Alabama will be similar to those already experienced in other coal mining areas of Alabama. This is based on the fact that land will be disturbed by surface mining and that lignite contains minerals capable of degrading the quality of water that comes in contact with it. The latter is indicated by the fact that some lignite samples contain as much as 4 percent sulfur (Ward and Evans, 1975, p. 24).

Problems associated with coal mining are not new. Unfortunately, records are not available relating details of these problems to early mining in Alabama. Therefore, a search of legal records was made to aid in determining what problems were recognized and when and where they occurred. The search verified the early occurrence of problems related to coal mining that have been or are now the subject of numerous investigations. These problems are damage to the land surface and water supplies that result from subsidence, or other injuries to the land surface, the effect of mining on water resources and aquatic life, and decrease in land values. Most problems described in this report are recognizable in the legal summaries.

EROSION AND SEDIMENTATION

Natural erosion and sedimentation within a given area is influenced by numerous factors including topography, soil characteristics, vegetation, and rainfall. The erosion and sedimentation rates can be altered drastically by man's use of land and water. In most mining areas in Alabama, the erosional process is accelerated and sedimentation problems are created or intensified. Actions that contribute to these problems include removal of vegetation, construction of haul roads, excavation of mines and the accompanying creation of spoil piles, and the restriction and diversion of natural drain. Erosion restricts the use of land for many purposes. In severely disrupted areas such as excavations and associated spoil piles, erosion inhibits revegetation which is critical in the reclamation process.

The suspended sediment concentration in water affects its quality and its suitability for use. Some industries, for example, cannot tolerate any sediment in water. The amount of sediment transported or deposited by streams has a direct bearing on the cost and feasibility of projects related to navigation, flood control, transportation, reclamation, water supply, recreation, pollution, agriculture, and fisheries.

Sedimentation resulting from surface mining is observable in many areas. A photograph of Daniel Creek basin in Tuscaloosa County, taken in 1975 (fig. 10) shows a drastic result of sedimentation. A report by the U.S. Army Corps of Engineers (1974) estimated the depositional rate in Daniel Creek basin to be 5,907 tons/mi^2 (2,069 t/km^2). This high rate is attributed to (1) unconsolidated overburden (sand) exposed by mining, and (2) the placement of spoil banks into or adjacent to the stream channel. According to the report, the creek "has been made unnavigable" and "the siltation creates an aesthetically displeasing view for users of the Corps' public use area."

Many spoil banks associated with coal mining in Alabama have been left ungraded and unvegetated (fig. 11). These sites are highly susceptible to weathering and erosion for many years after mining operations have ceased. Spoil banks such as those adjacent to Locust Fork of the Black Warrior River near Sayre, Alabama (fig. 12) are a source of large quantities of sediment. Cracks developing along the top of one such bank (fig. 13) reflect its movement toward the stream. Eventually a large part of the bank may slide into the stream. This illustrates that, in addition to gully, sheet, and stream-channel erosion, large quantities of material from these banks enter the stream through mass movement.

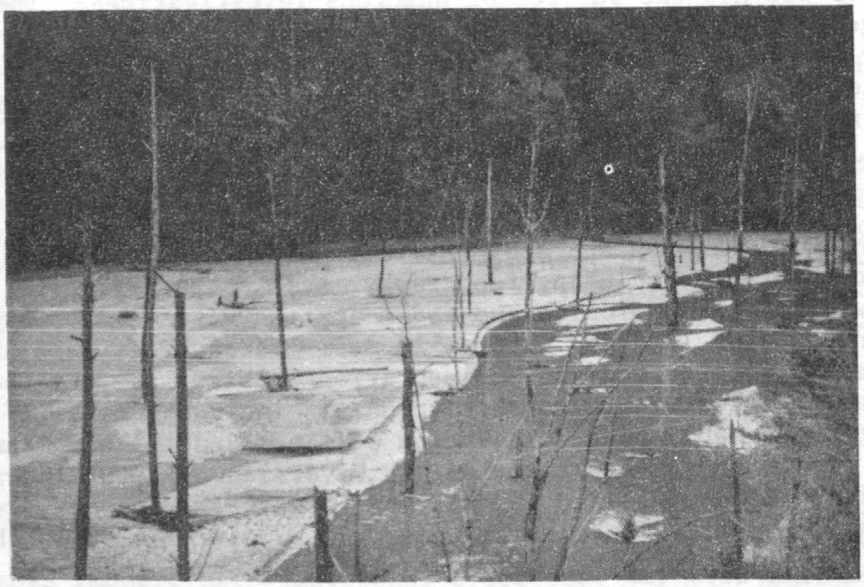


Figure 10.--Sediment deposits in upper reach of Daniel Creek, Tuscaloosa County.

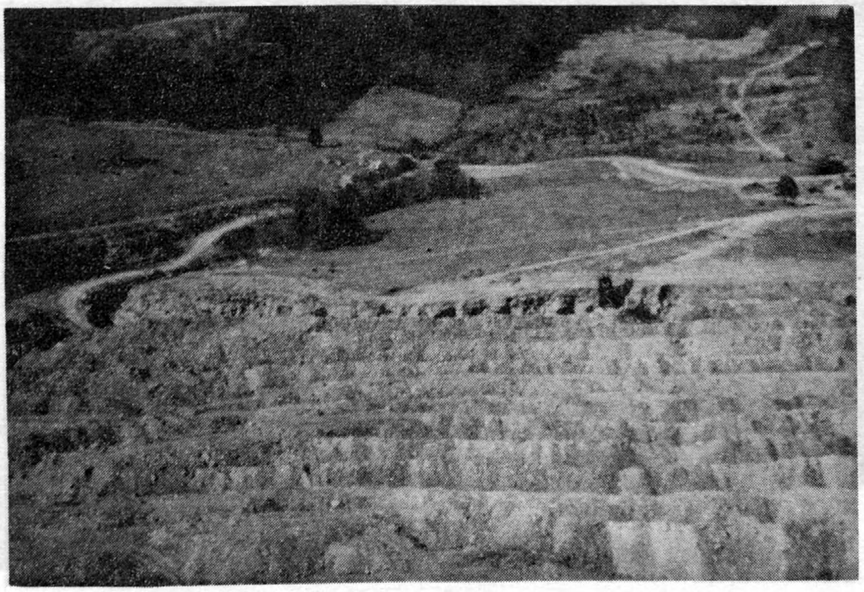


Figure 11.--Ungraded and unvegetated spoil bank.

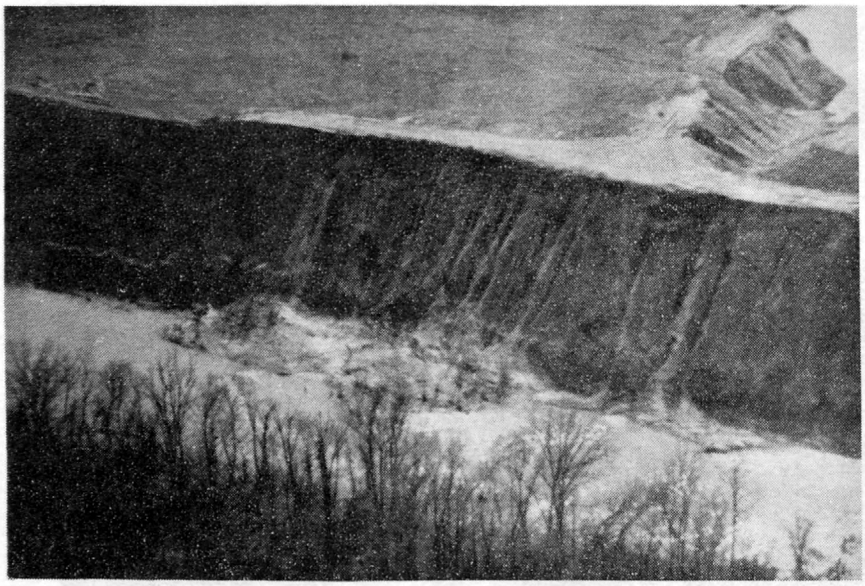


Figure 12.--Spoil banks along Locust Fork of Black Warrior River near Sayre, Ala.

Figure 13.--Cracks along top of spoil bank adjacent to stream.

When streamflow enters a lake or reservoir, its velocity and transport capacity is reduced and its sediment load is deposited. The deposition of sediment in the reservoir reduces its storage capacity and lifespan, and limits its use. One example is Harris Lake, a source of water supply for the city of Tuscaloosa. Coal mining in the immediate vicinity has been the source of sediment deposits in the lake (fig. 14). In a nearby basin in which Lake Tuscaloosa, one of the largest municipal reservoirs in Alabama, is located, sediment transport was estimated at 300 tons/mi^2 (105 t/km^2) in 1975. This may increase to 2,250 tons/mi^2 (788 t/km^2) if 5 percent of the basin is stripped for coal (E. F. Hubbard, written comm., 1975).

A study in Kentucky by Collier and others (1964) was made to evaluate the effect of strip mining on the sediment load of streams. There, a stream draining a basin in which 6.4 percent of its area had been mined discharged sediment at a rate of 1,930 tons/mi^2 (676 t/km^2) in the 1958 water year. In a nearby stream in which there was no mining in the basin, sediment was discharged at a rate of 28 tons/mi^2 (9.8 t/km^2). These and available data in Alabama indicate that the sediment yield from mined land may be 10 to 100 times greater than that from unmined land.

FLOODING

Flooding is usually not recognized as a problem until the areas affected are developed and loss of life or damage to land, buildings, or other structures occurs. Even where flooding does not produce costly damage, it can be an inconvenience. Although the occurrence of floods is a natural phenomenon, it can be aggravated by coal mining operations. The clearing of land, for example, increases the amount of runoff. When the volume of runoff is increased, channels and flood plains may not be able to accommodate the excess runoff. As the volume of runoff is increased or is concentrated in natural or artificial channels, its erosive energy is also increased and more sediment is moved from the mined areas and deposited in the stream channel and flood plain. This deposition reduces the flood plain's natural storage capacity, thereby increasing the flood potential within the basin. Daniel Creek (fig. 10), for example, has been completely filled for a distance of 4,100 ft (1,249 m) (U.S. Army Corps of Engineers, 1974).

Flooding and associated damages resulting from mining operations have been reported in Alabama for many years. Floodwaters and the sediment and debris transported and deposited by the floodwaters may destroy crops (Cane Creek Coal Mining Co. v. Brandon, 1932), deposit infertile material on the flood plains (Corona Coal Co. v. Hooker, 1920), create swampy areas, reduce the usefulness of navigational channels, and cause local damage to highways or roads (Corona Coal Co. v. King, 1920), and buildings (Brookside Pratt Mining Co. v. McAllister, 1916).

In some areas, spoil banks and erodible material have been placed adjacent to a stream channel (figs. 12 and 13). Mass movement of the material into the stream may restrict streamflow causing local flooding.

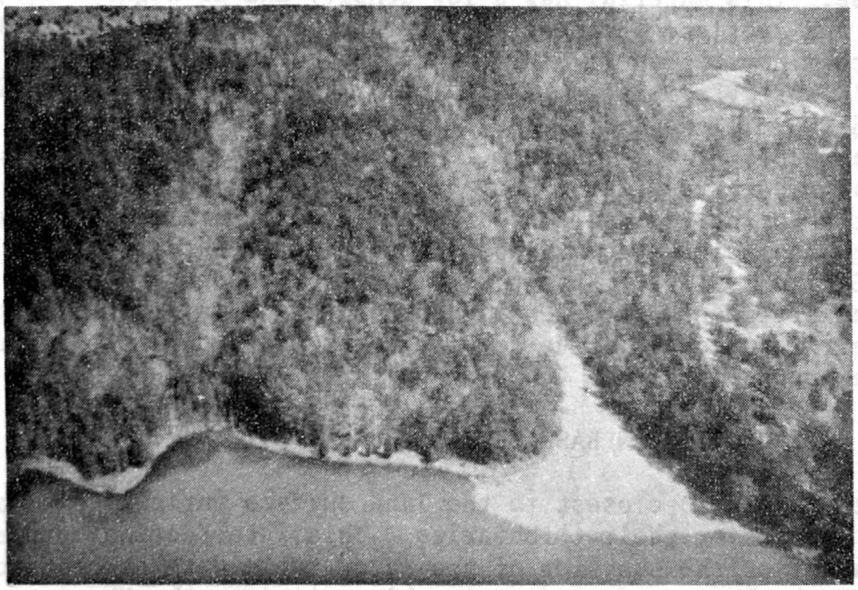


Figure 14.--Sediment deposited in Harris Lake, Tuscaloosa County.

Massive slides followed by ponding of streamflow and a sudden release could cause flood damage.

Ponds and reservoirs are constructed to aid in the mining and processing of coal. They are used as settling basins and to store water for drinking, fire fighting, and washing of coal. Dams for reservoirs used for settling basins and the storage of water for coal washing are generally constructed from coal-mine refuse. This material has a low density and is highly susceptible to weathering and erosion. Failure of these reservoirs could constitute a potential hazard to miners, property, or the public. Failure of such a structure occurred in West Virginia in 1972. Property damage associated with the failure exceeded $50 million and about 118 lives were lost (Davies and others, 1972). As a result of that failure, the Committee on Public Works of the U.S. Senate adopted a resolution whereby the U.S. Army Corps of Engineers was directed to inspect and report on potentially hazardous reservoirs associated with coal-mining activities. According to data from the U.S. Army Corps of Engineers (1975), about 15 percent of the reservoirs inspected in Alabama were judged to be "hazardous on the basis of structural deficiencies and their location relative to mine work areas, populated areas, structures, and other property."

DECLINE IN BASE LEVEL

The water table usually is closest to the land surface in lowland areas where it intersects streams or their tributaries. This intersection between ground and surface water or the position of the water table with respect to this intersection in a basin is referred to in this report as the "base level." A hypothetical diagram showing the position of the water level in respect to its point of natural discharge in a basin is illustrated in figure 15A.

Natural and man-related changes in base level produce predictable hydrologic changes that may be temporary or permanent. This is particularly true in coal mine areas where the excavation of a mine extends below the base level of the basin as illustrated in figure 15. If the excavation extends to lower altitudes, drainage from the site illustrated would cause a permanent lowering of the base level. If the excavation at the site does not extend to lower altitudes, an eventual recovery or partial recovery of the water table may result from ponding.

Wells and springs located in an area where a lowering of the base level occurs may go dry. For example, four wells that produced water for domestic supplies at Boothton in Shelby County failed during or immediately following the excavation of a strip mine (fig. 16). The wells near the excavation ranged in depth from 47 to 70 ft (14 to 21 m). The closest well failed first; the farthest last. Two of the wells went dry, the water level in the two remaining wells reportedly declined to within 5.1 ft (1.6 m) from the bottom of the wells. When the water level in the first well began to decline, the owner of the last well to be affected began to make periodic water-level measurements. The reported measurements (Edwin Booth, oral commun., 1973) and one measurement made on October 5, 1973 by the U.S. Geological Survey personnel after the well failure are shown on the

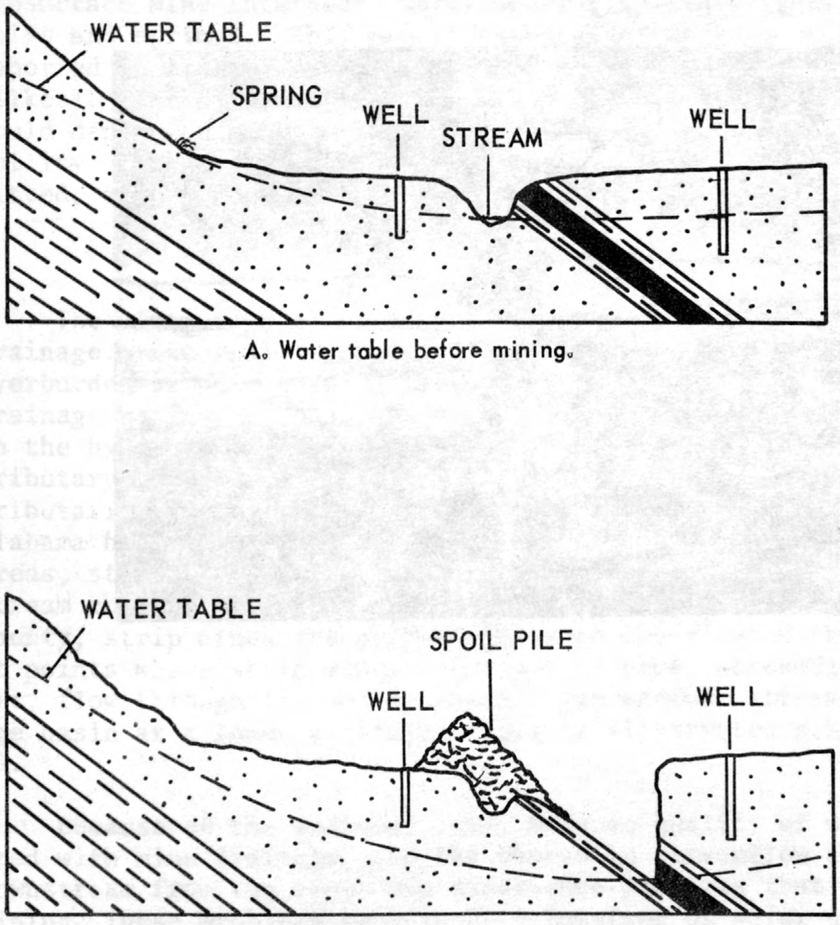
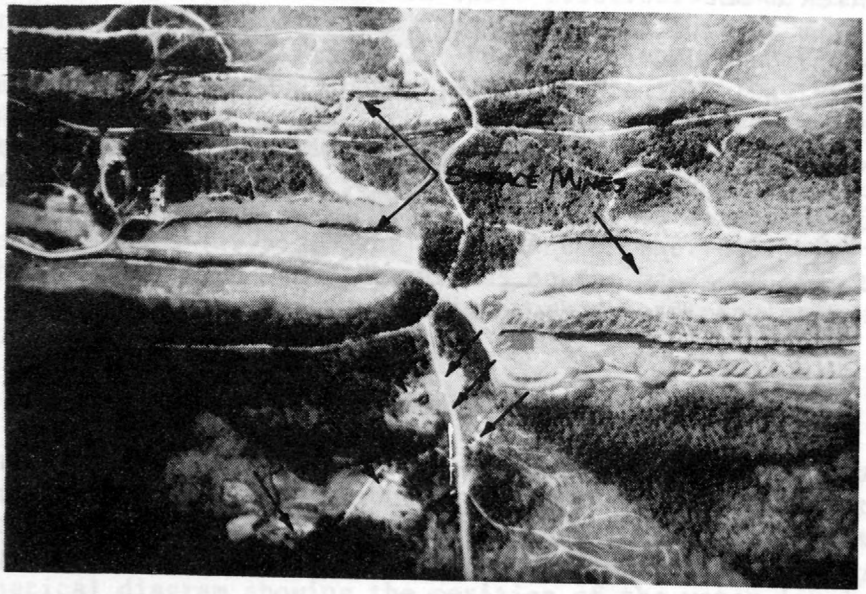


Figure 15.–Hypothetical cross-sectional diagram of basin showing water table before and after surface mining.


Surface Mines

hydrograph in figure 17. The hydrograph shows a decline in water levels in the aquifer with no apparent recovery after cessation of pumping from wells in the area. Inasmuch as the water level had previously recovered following pumping of the wells, the decline resulting from the lowering of base level probably is permanent.

The "drying up" of wells and springs also occurs where an underlying subsurface mine intersects water-bearing openings interconnected with the wells and springs. This problem associated with subsurface mining was reported in Alabama as early as 1936 (Sloss-Sheffield Steel & Iron Co. v. Wilkes). The distance from the mined site at which this phenomenon can occur would depend on many variables including the depth of the mine, the permeability of the aquifer, the type opening in which water is stored and transmitted, and the extent of the interconnected system of openings.

DIVERSION OF DRAINAGE

The alteration of natural topography by surface mining commonly diverts drainage. Excavations commonly cross natural drainages and, in some areas, overburden is placed in stream channels. Thus many small tributaries and drainage basins are obliterated or their drainage patterns changed (fig. 18). In the hypothetical diagram, streamflow was diverted from tributary A to tributary B. Such a diversion alters the streamflow characteristics of both tributaries as well as the main stream. Inspection of coal mine areas in Alabama has shown that this type of streamflow diversion is common. In some areas, streamflow is diverted by mining adjacent to the stream and moving the stream channel as mining progresses. In other areas, such as in Shelby County, strip mines are perpendicular to the flow of the stream (fig. 16). At points where strip mines intersect streams, streamflow may enter the strip pit, flow through it, and discharge into another stream in an adjacent drainage basin at a lower altitude. This is illustrated schematically in figure 19.

Because of the sediment load, adverse quality of water generally associated with mine drainage, and the change in streamflow characteristics, areas downstream from the mines may experience problems that did not exist prior to mining. These problems such as deterioration of water quality, increased cost of water treatment, increase in flooding, and insufficient water during low flow, may be noticed immediately or may go unnoticed for many years.

SUBSIDENCE

The normal occurrence and availability of ground and surface water is disrupted where subsidence occurs. Subsidence occurs where the roofs of mines are allowed to collapse, where pillars are inadequate to provide support, or where pillars are removed. The downwarping of strata due to subsidence may extend to the surface. This is well illustrated by the collapse of a shallow shaft under a bulldozer that occurred in Jefferson County in 1975 (Larry Lockett, oral commun., 1975). Although surface

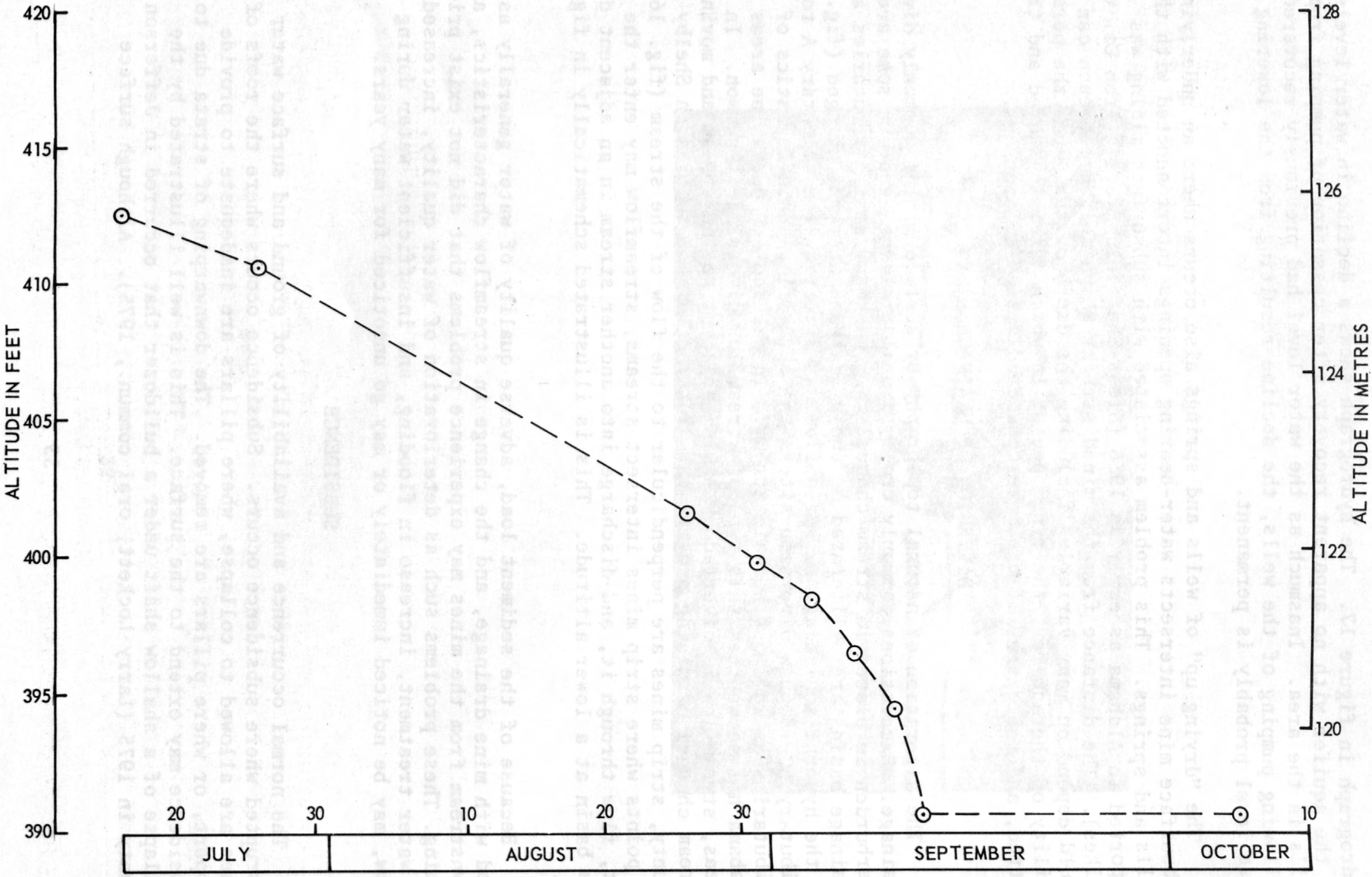


Figure 17 –Hydrograph illustrating decline of water level in well at Boothton, Shelby County (July-October 1973).

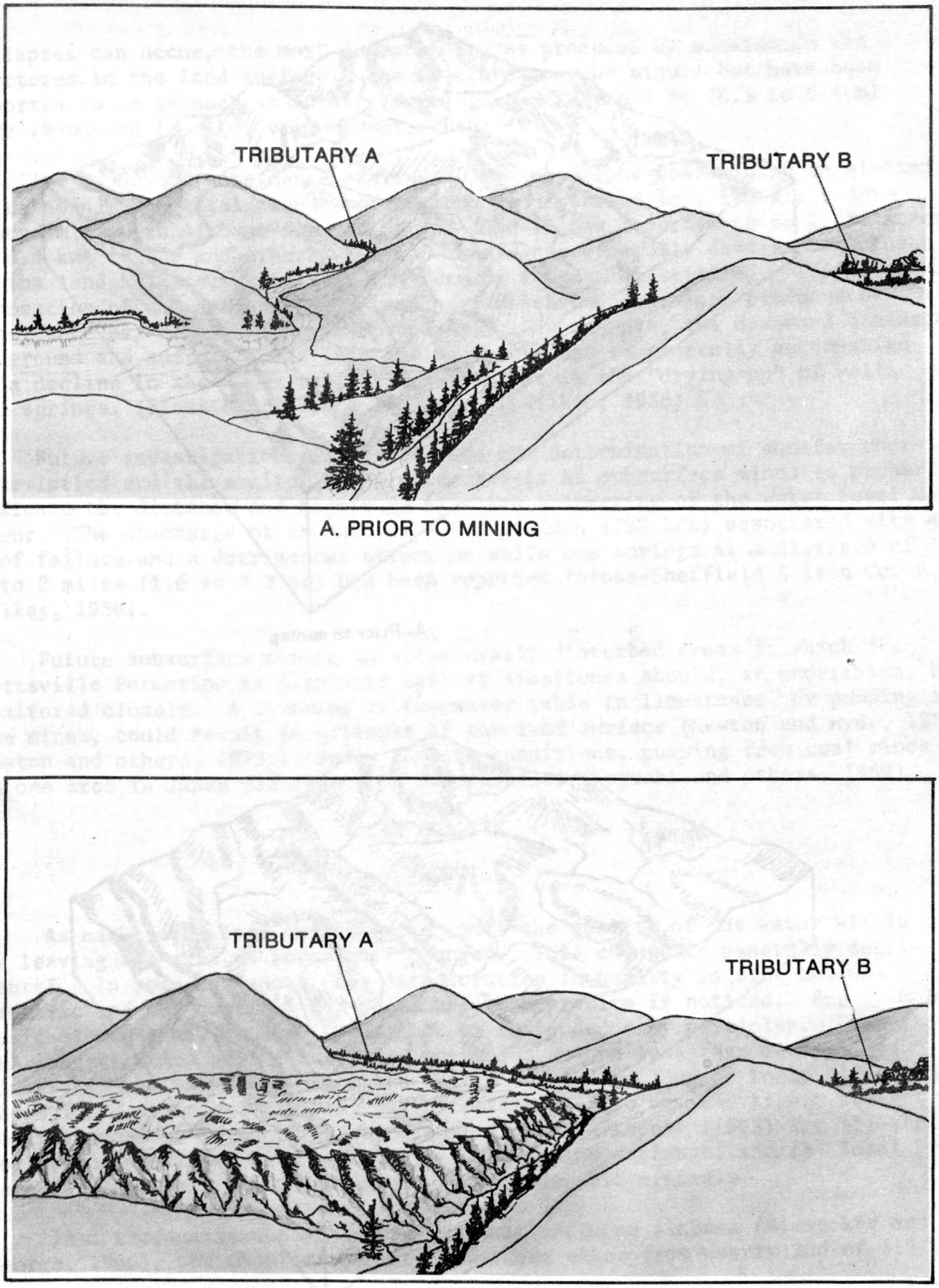
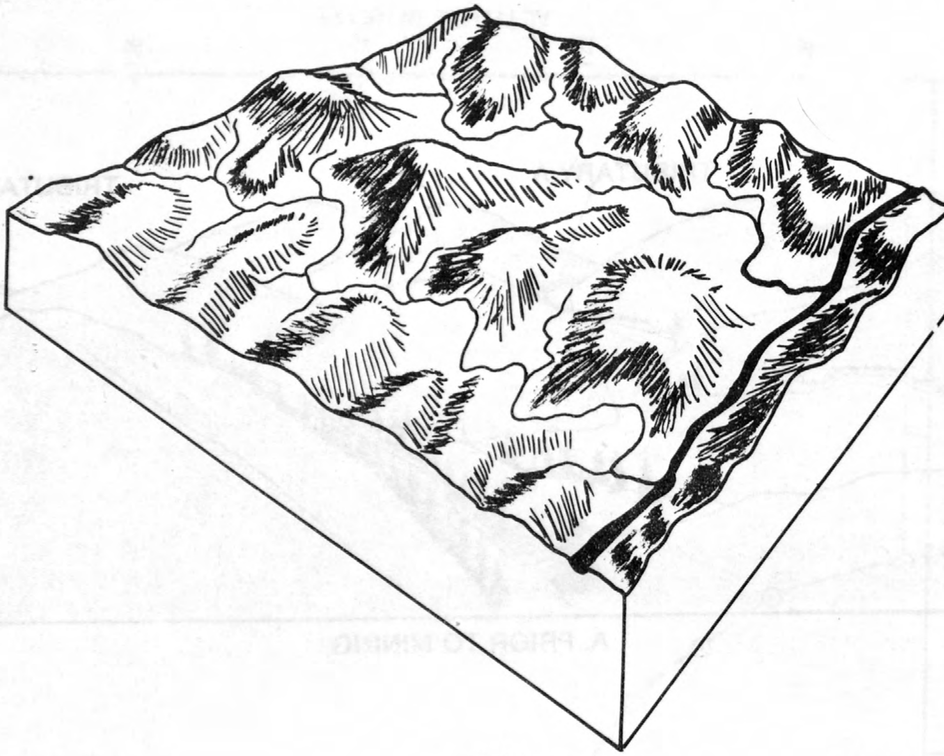
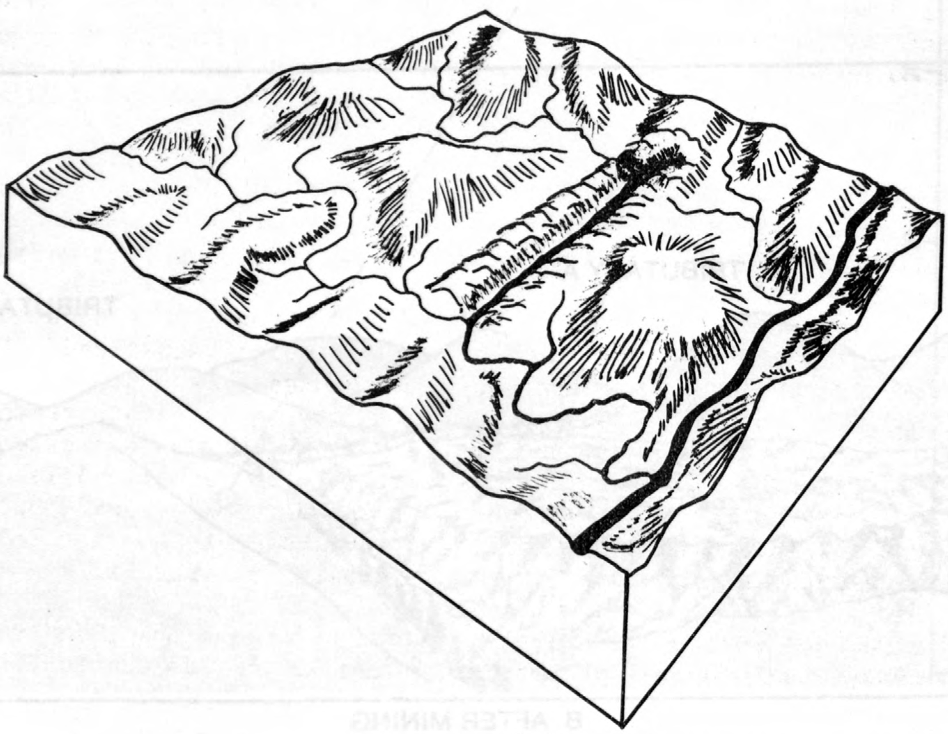


Figure 18 – Schematic diagram showing disruption of drainage patterns resulting from mining operations.



A. Prior to mining



B. After mining

Figure 19 – Schematic diagram showing diversion of streamflow through strip mine.

collapses can occur, the most common features produced by subsidence are fractures in the land surface. The fractures may be minute but have been reported to be as much as 100 ft (30 m) long and 1 to 2 ft (0.3 to 0.6 m) wide (Woodward Iron Co. v. Mumpower, 1946).

The amount of subsidence attributed to subsurface coal mining in Alabama is unknown. The total amount of subsided or disturbed area for all underground mining in Alabama for the period 1930-71 was reported to be 2,080 acres or 8.4 km^2 (Paone and others, 1974). Subsidence generally damages structures at the land surface, usually in the form of foundation settling. The interconnection of the mine with the land surface through openings produced by subsidence may also cause water problems. For example, the downward drainage of ground and surface water into the mine workings is generally accompanied by a decline in the water table and may result in the "drying up" of wells and springs. (Sloss-Sheffield & Iron Co. v. Wilkes, 1936).

Future investigations should include the determination of aquifer characteristics and the monitoring of water levels at subsurface mines to properly evaluate the distance and magnitude at which a lowering of the water level can occur. The discharge of as much as 4,000 gal/min (252 L/s) associated with a roof failure and a detrimental effect on wells and springs at a distance of 1 to 2 miles (1.6 to 3.2 km) has been reported (Sloss-Sheffield & Iron Co. v. Wilkes, 1936).

Future subsurface mining in structurally disturbed areas in which the Pottsville Formation is displaced against limestones should, if undertaken, be monitored closely. A lowering of the water table in limestones by pumping in the mines, could result in collapse of the land surface (Newton and Hyde, 1971; Newton and others, 1973). Under similar conditions, pumping from coal mines in one area in Japan did result in 90 sinkholes (Nogushi and others, 1969).

WATER QUALITY

Surface Water

As man clears land and extracts coal, the quality of the water within or leaving the area is invariably changed. This change is generally detrimental. In some instances, the deterioration in quality is slow and undramatic and may continue for years before a problem is noticed. For example, toxic elements may be easily adsorbed on suspended clay particles. Even though the concentration of the suspended particles may be less than recommended limits, as the suspended particles settle out the buildup of toxic elements in accumulated streambed material may be detrimental to aquatic life. Water quality problems as mentioned by Schneider and Barksdale (1965) are (1) stream pollution associated with industry, (2) acid mine drainage, and (3) local problems with hardness and the presence of undesirable minerals.

In a reconnaissance of Appalachia that included Alabama (Biesecker and George, 1966), the chemical quality of stream water from nearly 200 of 318 sites sampled during median flow conditions did not meet recommended drinking water standards. The deterioration in chemical quality at those sites was attributed to the presence of undesirable concentrations of solutes associated with water from coal mines. Biesecker and George noted that "southern Appalachia coal-mine drainage had less influence on stream quality than in northern Appalachia." This, however, was attributed to the fact that more coal is mined in the north than in the south, thereby exposing more sulfur-bearing material.

Water quality problems associated with coal mining in Appalachia (Biesecker and George, 1966) were (1) fish kills, (2) increase of water treatment costs for industries and municipalities, (3) increase in corrosiveness, and (4) adverse affects on the recreational use of lakes and streams.

Data and information presented by Katz (1969) indicate that water with low pH has a detrimental effect on the stream ecosystems. Although particular emphasis was put on fish and other aquatic life, Katz discusses the possible effect on certain species of birds, animals, amphibians or reptiles in areas affected by acid mine drainage. This broader effect is, in part, attributed to the fact that the food chain of a particular species has been altered. Katz also points out that low pH interferes with the stream's ability to assimilate domestic wastes. In areas where industries discharge heated water into the stream, thermal pollution in conjunction with low pH may present additional problems.

Examination of legal records shows that the detrimental effect that coal mining has on water quality was recognized in Alabama in the early 1900's. The detrimental effects recognized were related primarily to the restricted use of streams for fishing, swimming, domestic, and agricultural purposes. Although specific data concerning the chemical, physical, and biological characteristics involved are not available, the early records provide a reference as to the type of problems and some indication as to when the problems were first noticed.

Information concerning pH and culvert-pipe corrosion, prepared by Hyde and others (1969), indicated four areas within Alabama where pH of surface water ranged from 3.1 to 4.2. All of the areas were associated with active or abandoned coal mines. Although only four sites were found, it was pointed out in the report that there were possibly many other areas having low pH waters. Chemical analyses at these sites also indicated that the bicarbonate content was zero and water at three of the sites contained high concentrations of sulfates and high specific conductance values. As a part of the investigation, specific areas were selected and various types of culvert pipes were placed in the streams to study the effects of acid mine waters on the pipes. Concrete, galvanized steel, aluminum, bituminous-coated steel, bituminous-coated aluminum, and pitch-fiber pipes were tested during the study and all except the pitch-fiber pipe showed the effects of corrosion. Data and information presented by Hyde and others (1969) indicated that acid mine drainage has a detrimental effect on the service life of most drainage structures.

A more comprehensive study for the Cane Creek basin in Walker County is contained in a report by Hyde (1970). It emphasized that acid mine drainage is a problem in that it reduces the effective life of highway drainage structures, makes the water unsatisfactory for recreational use, and increases the expense of treating water for municipal or industrial uses. In streams receiving acid mine drainage, the pH is lowered, natural alkalinity is reduced, specific conductance and total hardness is increased, and the water generally contains excessive amounts of iron, manganese, aluminum, and sulfate (Hyde, 1970). One important problem mentioned by Hyde is the fact that problems associated with acid mine drainage do "not stop when active mining is completed" but "highly mineralized waters may contaminate nearby streams for many years."

The concept that problems associated with mine drainage are restricted to relatively small streams in Alabama is misleading. Although supporting data collected thus far have been for relatively small streams, it is interesting to note which streams have been sampled and which streams are affected by mine drainage. For example, a reconnaissance made in April 1975 and chemical analyses in files of the U.S. Geological Survey indicated that many tributaries of the Black Warrior River upstream from Tuscaloosa are affected by mine drainage. Within the Black Warrior River basin, water with a pH less than 4.0 is common. In addition to low pH, mine drainage is generally characterized by iron in excess of 300 ug/L, sulfate in excess of 200 mg/L, and the water is generally hard to very hard. In general, noncarbonate hardness is greater than 50 percent of total hardness. According to E. R. German (written commun., August 1975), the "median specific conductance of streams" draining the coal fields shown in figure 1, "is generally in the low to medium range, or less than 175 micromhos, except in areas affected by strip mining and waste disposal. Many streams have median specific conductance values of 50 micromhos or less. *** An area of coal mining north of Tuscaloosa includes three streams with median specific conductance values greater than 175 micromhos which are probably indicative of acid mine drainage." Because of the detrimental effects that mine drainage has on aquatic plants, fish, wildlife, and the recreational, industrial, and municipal uses of the water and adjoining land, development along the streams directly affected is very limited. As a general rule, the quality of the water improves downstream; however, at the mouth of many of the streams, the quality may not meet requirements for many uses.

The main streams, such as the Black Warrior River are, in general, more alkaline and contain lower concentrations of sulfate, iron, etc, than the tributaries. The overall effect in the main stream is to neutralize the water from the tributaries. This was illustrated in a study of Daniel Creek by the U.S. Army Corps of Engineers (1974). In that report, data indicated that, in general, the iron and sulfate concentrations and specific conductance decreased progressively in a downstream direction and that total alkalinity, turbidity and pH increased. At the mouth of Daniel Creek, where the flow from Daniel

Creek mixes with the flow from the Black Warrior River, water quality analyses indicated that the objectionable characteristics of the water mixture were reduced. In a study by Biesecker and George (1966), they state that, "The mixture of alkaline streams with mine-drainage waters eventually neutralizes all acid streams in Appalachia. Even in the badly polluted upper Ohio River basin, the added flow from the Allegheny River and other more alkaline downstream tributaries ultimately produces water of fair quality." A major question concerning neutralization by the main stream is at what point does the neutralizing capacity become overwhelmed by inflow from mine-affected streams.

Ground Water

Investigations of water quality problems associated with coal mining have been restricted almost entirely to those dealing with surface water. Little has been done in evaluating the degradation of the quality of ground water in aquifers underlying surface mines. This is remarkable in that, based on hydrologic principles, this problem has to exist and, considering the total area involved (fig. 9), should be one of the major problems associated with surface mining.

An aquifer underlying an area mined at the surface would be recharged in part by highly mineralized water that has moved through or come in contact with mining waste. The mineralized water moves down to the water table and then laterally in a direction determined by the slope of the water table. Whether this problem exists in a given area is dependent on several factors including the type and permeability of the rock underlying the mine, and the presence of fractures or other openings at the surface that are interconnected with those in the subsurface. The magnitude and extent of the problem at a given site is also dependent on numerous variables including the quantity of mineralized water, permeability of the aquifer, and the gradient of the water table.

The area in which aquifers have been or may be contaminated by mine waters in Alabama is large. It exceeds the total area disrupted by mining. Where the magnitude of mining has been determined (fig. 9), for example, the area involved would be more than that occupied by the estimated 460 linear mi (740 km) of strip-type mining and 16.3 mi^2 (42.2 km^2) of massive or area mining.

VEGETATION

A large percentage of the area underlain by the Pottsville Formation is densely forested. The quantity of timber removed by mining operations is indicated by the magnitude and distribution of surface mining (fig. 9). Reforestation of mined land has been only partly successful in many instances.

Natural reforestation of unreclaimed mining areas appears to be much slower than that in nearby open areas unaffected by mining. One such comparison in Kentucky has been described by Collier and others (1970, p. 50). It was also noted in the same study that data indicated trees irrigated by mine drainage grew more slowly than trees not irrigated by mine drainage.

Trees not removed prior to mining are commonly killed or damaged. Although the losses may not be economically significant, they do have a retarding effect on the reclamation of an area. Slides or the downslope movement of debris results in the loss of some trees. Additional losses are caused by burial with sediment eroded from mines (fig. 10). The impounding of water (fig. 20) or its diversion also destroys trees.

Some timber damage may not be evident until well after mining has ceased. This is particularly true in central Alabama. Damaged or uprooted conifers dissipate in vigor and, in their weakened state, attract a variety of insects including the Southern Pine Beetle. This infestation could spread to nearby conifers and cause tree kills over a large area.

RECREATION

Ideally, water-related recreation resources should be preserved and enhanced. The demand, use, and appreciation of these resources have never been greater and will increase in the future. Boating, skiing, swimming, fishing, and sightseeing are dependent on water resources and are major pastimes for a large percentage of the nation's population. Unfortunately, water resources can be degraded or rendered unfit for recreation by many mining activities.

The aesthetic degradation of the environment caused by mining is largely in the mind of the beholder. The scenery in a mining area might be offensive to one person and detract from his enjoyment, whereas it might be fascinating and enjoyable to another person. For most, the sight of unreclaimed strip mining with its barren, eroded slopes (fig. 21) is not considered to be as scenic as the natural environment.

Problems associated with coal mining do place restrictions on some forms of recreation such as swimming and fishing. Acidic water may cause eye irritation (Mood, 1968). In most bathing and swimming waters, eye irritation is minimized and recreational enjoyment enhanced by maintaining the pH within the range of 6.5 and 8.3 except for those waters with a low buffer capacity where a range of pH between 5.0 and 9.0 may be tolerated (Environmental Protection Agency, 1972, p. 33).

Acid mine drainage is detrimental to fish and other forms of aquatic life. The degradation of fish in streams associated with coal mining was recognized early in Alabama (Tutwiler Coal, Coke & Iron Co. v. Nichols, 1905). In Kentucky, the disappearance of fish due to acid mine drainage has been well documented (Collier and others, 1970). A pH of 3.0 to 3.5 was lethal to fish in one stream and less acidic water in another stream resulted in a decline in fish population. In one experiment, three different species

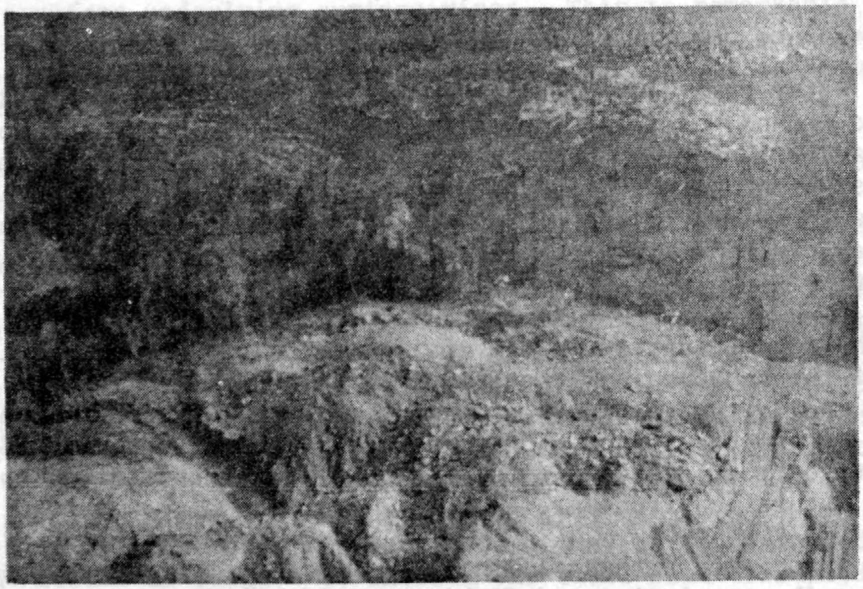


Figure 20.--Tree kill resulting from impounding of water.

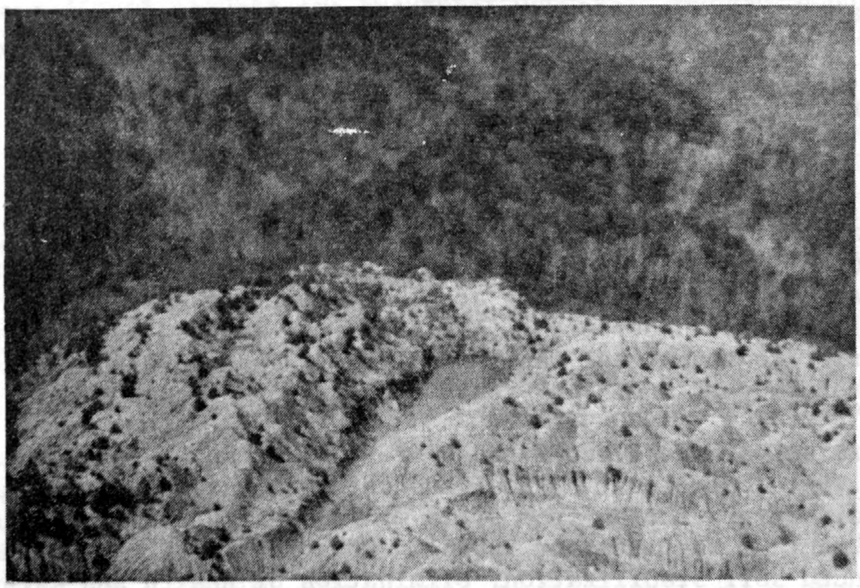


Figure 21.--Unreclaimed strip mining area in Tuscaloosa County.

placed in the more acidic stream died in 190 minutes or less (Collier and others, 1964). The effect of mine drainage on the fish population decreased in downstream reaches as the water was buffered by inflow from streams unaffected by mining. The downstream reaches of a stream not normally adversely affected by mine drainage is susceptible to major fish kills in some instances. For example, in one stream in Pennsylvania, 20 major fish kills resulted from the downstream transport of mine effluents by localized rains in the mining region (U.S. Army Corps of Engineers, 1962).

Mine drainage also adversely affects other forms of aquatic life. Significant reductions in the diversity of benthic microinvertebrate species due to mine drainage in Cane Creek in Walker County, Alabama, were described by Dills and Rogers (1972). The effect on stream-bottom fauna and the microbiology of a stream disturbed by mining in Kentucky has been described by Collier and others (1970). Among many changes noted was the establishment of the bacteria *Ferrobacillus ferrooxidans* which biologically contributes to the acidity of a stream. The effects of pH on aquatic organisms and fish are reviewed in detail in European Inland Fisheries Advisory Commission (1969) and Katz (1969). Interpretations and summaries of these reviews outlined in Environmental Protection Agency (1972, p. 141) are given in table 3.

RECLAMATION

Reclaiming of mined lands in Alabama, as in other states in Appalachia, has been and will be a difficult problem. The alteration of natural conditions by mining has been drastic in many areas and will increase greatly as additional coal mining is undertaken. Alabama first enacted reclamation controls in 1969. Prior to that time, many mines were abandoned with little or no effort to reclaim the land. Any reclamation effort was voluntary.

An appraisal of the effectiveness of reclamation in Appalachia prior to 1965 showed that control of physical and chemical water quality, as related to acid and sediment production from strip mines, was the most important problem (U.S. Department of the Interior, 1966). Other criteria used in making evaluations included soil stabilization, elimination of health and safety hazards, conservation and preservation of mineral resources, usability of reclaimed lands and watercourses, and restoration of aesthetic values. The appraisal also found that despite reclamation efforts, some mining had frequently resulted in acid-water drainage, soil erosion, and stream sedimentation.

Few records are readily available to determine the amount and degree of reclamation accomplished in Alabama prior to 1969. Alabama authorities reported that 18,900 acres (76 km2) of surface coal mining had been completed prior to January 1, 1965 (U.S. Department of the Interior, 1966). Of this, it was estimated that 2,200 acres (8.9 km^2) were unreclaimed, 11,700 acres (47.3 km^2) were partially reclaimed, and 5,000 acres (20.2 km^2) were completely reclaimed. Unfortunately, what constituted "partially reclaimed" land during the preceding years is not easily definable. The data indicate, however, that about 26 percent of the disturbed area had been completely reclaimed.

Table 3.--A summary of some effects of pH on freshwater fish and other aquatic organisms

pH	Known effects
11.5-12.0	Some caddis flies (Trichoptera) survive but emergence reduced.
11.0-11.5	Rapidly lethal to all species of fish.
10.5-11.0	Rapidly lethal to salmonids. The upper limit is lethal to carp (Cyprinus carpio), goldfish (Carassius auratus), and pike. Lethal to some stoneflies (Plecoptera) and dragonflies (Odonata). Caddis fly emergence reduced.
10.0-10.5	Withstood by salmonids for short periods but eventually lethal. Exceeds tolerance of bluegills (Lepomis macrochirus) and probably goldfish. Some typical stoneflies and mayflies (Ephemera) survive with reduced emergence.
9.5-10.0	Lethal to salmonids over a prolonged period of time and no viable fishery for coldwater species. Reduces populations of warmwater fish and may be harmful to development stages. Causes reduced emergence of some stoneflies.
9.0-9.5	Likely to be harmful to salmonids and perch (Perca) if present for a considerable length of time and no viable fishery for coldwater species. Reduced populations of warmwater fish. Carp avoid these levels.
8.5-9.0	Approaches tolerance limit of some salmonids, whitefish (Coregonus), catfish (Ictaluridae), and perch. Avoided by goldfish. No apparent effects on invertebrates.
8.0-8.5	Mobility of carp sperm reduced. Partial mortality of burbot (Lota lota) eggs.
7.0-8.0	Full fish production. No known harmful effects on adult or immature fish, but 7.0 is near low limit for Gammarus reproduction and perhaps for some other crustaceans.
6.5-7.0	Not lethal to fish unless heavy metals or cyanides that are more toxic at low pH are present. Generally full fish production but for fathead minnow (Pimephales promelas), frequency of spawning and number of eggs are somewhat reduced. Invertebrates except crustaceans relatively normal, including common occurrence of mollusks. Microorganisms, algae, and higher plants essentially normal.
6.0-6.5	Unlikely to be toxic to fish unless free carbon dioxide is present in excess of 100 ppm. Good aquatic populations with varied species can exist with some exceptions. Reproduction of Gammarus and Daphnia prevented, perhaps other crustaceans. Aquatic plants and microorganisms relatively normal except fungi frequent.
5.5-6.0	Eastern brook trout (Salvelinus fontinalis) survive at over pH 5.5. Rainbow trout (Salmo gairdneri) do not occur. In natural situations, small populations of relatively few species of fish can be found. Growth rate of carp reduced. Spawning of fathead minnow significantly reduced. Mollusks rare.

Table 3--Continued

pH	Known effects
5.0-5.5	Very restricted fish populations but not lethal to any fish species unless CO_2 is high (over 25 ppm), or water contains iron salts. May be lethal to eggs and larvae of sensitive fish species. Prevents spawning of fathead minnow. Benthic invertebrates moderately diverse, with certain black flies (Simuliidae), mayflies (Ephemerella), stoneflies, and midges (Chironomidae) present in numbers. Lethal to other invertebrates such as the mayfly. Bacterial species diversity decreased; yeasts and sulfur and iron bacteria (Thiobacillus-Ferrobacillus) common. Algae reasonably diverse and higher plants will grow.
4.5-5.0	No viable fishery can be maintained. Likely to be lethal to eggs and fry of salmonids. A salmonid population could not reproduce. Harmful, but not necessarily lethal to carp. Adult brown trout (Salma trutta) can survive in peat waters. Benthic fauna restricted, mayflies reduced. Lethal to several typical stoneflies. Inhibits emergence of certain caddis fly, stonefly, and midge larvae. Diatoms are dominant algae.
4.0-4.5	Fish populations limited; only a few species survive. Perch, some coarse fish, and pike can acclimate to this pH, but only pike reproduce. Lethal to fathead minnow. Some caddis flies and dragonflies found in such habitats; certain midges dominant. Flora restricted.
3.5-4.0	Lethal to salmonids and bluegills. Limit of tolerance of pumpkinseed (Lepomis gibbosus), perch, pike, and some coarse fish. All flora and fauna severely restricted in number of species. Cattail (Typha) is only common higher plant.
3.0-3.5	Unlikely that any fish can survive for more than a few hours. A few kinds of invertebrates such as certain midges and alderflies, and a few species of algae may be found at this pH range and lower.

In contrast, of the 3,170 acres (12.8 km^2) utilized in Alabama in 1971, 2,160 acres (8.7 km^2) or about 68 percent of the total was reportedly reclaimed (Paone and others, 1974).

The basic concept of reclamation is the restoring of mined land to a beneficial use. In Alabama, early attempts consisted chiefly of planting conifers. In recent years, grading or leveling of mined lands has been added to facilitate their growth and control drainage. This choice was natural because it ultimately would return the land to forest. Unfortunately, the time required for rooting sufficient to retard erosion can be years and the largest amount of erosion and sediment transport often occurs soon after mining. The feasibility of returning land to forest is dependent on many things including climate, topography, and the acidity of the soil. In many instances, vegetation other than conifers would be far more successful and beneficial. Reconnaissances of many old and new surface mines in Alabama have shown that reforestation, whether natural or man-related, has had a minimal effect on retarding erosion. In contrast, some recent mining areas observed on the ground and from the air (fig. 22) exhibit a dense vegetative cover capable of retarding erosion.

The reclamation process should concentrate on minimizing acid mine drainage and erosion regardless of the intended land use. This is necessary because the movement of water causes mine related problems many miles from mined areas. In many parts of Alabama these problems are considered more than localized. Therefore, reclamation is needed so that future mining activity will not seriously hinder other types of development in Alabama in the future.

Mining and reclamation techniques desired to minimize water problems have been utilized in Appalachia. Some recommended techniques have been defined (U.S. Department of the Interior, 1966) and are probably being used in Alabama. The largest problem regarding the evaluation of reclamation in Alabama is the lack of readily available information defining the techniques being used and their evaluation. The acquisition of data in future phases of the investigation will aid in this definition.

CONCLUSIONS

Surface and subsurface coal mining in Alabama has been accompanied by a variety of water-related problems such as erosion and sedimentation, flooding, diversion of drainage, decline in water level, land subsidence, and the degradation of water quality. The severity of individual problems at a particular site varies considerably. However, with additional development the principal problem will be the degradation of water quality. Surface mining, because of its extent, degrades the quality of water in many streams. The degradation is sufficient to limit the use of water and adjacent land for many purposes. The mineralization and acidity of mine drainage is generally diluted or buffered sufficiently in downstream areas to eliminate most of the objectionable properties. Because of the increase in the magnitude of mining, however, the buffering or neutralizing capacity of the larger streams may be

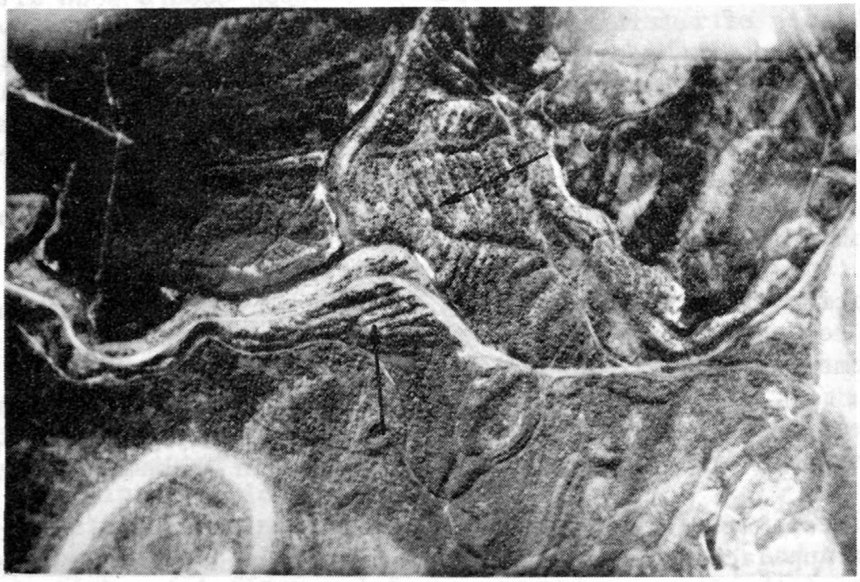


Figure 22.--Revegetated strip mines in Jefferson County.

less effective in the future. If this should occur, the quality of water in some reaches of major streams might deteriorate significantly.

Additional work to define and evaluate ground-water problems associated with mining is important because (1) most ground water available for use from the Pottsville Formation occurs at shallow depths and is prone to contamination, (2) the Pottsville is the only source of potable water available to many rural inhabitants, (3) when contamination does occur, it may persist for decades, and (4) reclamation efforts to minimize the problem would be extremely expensive and, in some instances, could aggravate the problem.

Unfortunately, of the hundreds of tributaries or basins affected by mining, the degree of water quality deterioration has been determined in only a few. In addition, the magnitude and distribution of mining activity and the extent to which streams have been affected by it has not been determined in a large part of the coal mine areas. If sufficient data were available, interpretation would be difficult because the changes in the hydrologic regimen due to mining and the time required for the dissipation of undesirable conditions have not been determined.

To adequately assess the overall problem or the effects of reclamation practices that may be instigated to minimize it, a considerable amount of information must be acquired. Data collection in the coal-mine areas should be a continuing process and should not be confined to a particular problem or to only one phase of mining. Data should be collected prior to and during mining, and throughout the reclamation process. The data collected should define recognized and potential problems. Without such a program, changes in the hydrologic regimen resulting from mining operations cannot be adequately evaluated. One of the greatest supplementary benefits to be gained from such a program is the evaluation of the transferability of hydrologic data from one mining area to another.

In summary, coal mining has affected the water resources of Alabama. Data are available to identify some specific problems such as water-quality deterioration, sedimentation, decline of ground-water levels, and land subsidence. The extent and severity of these problems, however, cannot be completely evaluated with existing data and the total effects in most places can only be generalized, extrapolated, or assumed. Since these problems and their related causes and effects will become more complicated and intensified, there is a growing need for a more thorough study and evaluation of the coal-mining operation and its relation to the hydrologic system in Alabama.

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