ASSESSMENT OF HYDROLOGIC CONDITIONS IN POTENTIAL COAL-LEASE TRACTS IN THE WARRIOR COAL FIELD, ALABAMA

By Celso Puente, J. G. Newton, and R. H. Bingham

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FACTORS FOR CONVERTING INCH-POUND UNITS TO INTERNATIONAL SYSTEM OF METRIC UNITS (SI)

For the convenience of readers who may want to use International System of Units (SI), the data may be converted by using the following factors:

Multiply inch-pound units	By	To obtain SI units
inch (in)	25.4	millimeters (mm)
foot (ft)	0.3048	meter (m)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
acre (A)	0.4047	hectare (ha)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer [$(m^3/s)/km^2$]
tons per square mile per year $(tons/mi^2)/y$	0.3503	metric tons per square kilometer per year $(metric\ t/km^2)/y$

ASSESSMENT OF HYDROLOGIC CONDITIONS IN POTENTIAL

COAL LEASE TRACTS IN THE WARRIOR COAL FIELD, ALABAMA

By Celso Puente, J. G. Newton, and R. H. Bingham

ABSTRACT

Assessing the hydrology of potential Federal coal-lease tracts, because of their dissemination and limited data, requires some predictive capability. Four tracts assessed were located in the outcrop of three coal groups and other relatively impermeable rocks in the Pottsville Formation. Physical settings of the tracts and most other areas in the Warrior coal field are similar. This results in similar ground-water and surface-water characteristics, in similar impacts resulting from surface coal mining, and in maximizing the transferability of data.

Assessments of the tracts reflected the small storage of water in underlying rocks and corresponding limited yields to wells and to the base flow of streams. Ground water and surface water in undisturbed areas are generally of good quality. Some subbasins in the tracts have already been impacted to some degree by mining.

Estimates of streamflow characteristics and the availability and quality of ground water in the tracts were made using available methodology or assessments based on local and regional data. Estimates of the degree of mineralization of surface-water quality were made using methodology developed from other coal hydrology work. Climatic, physiographic, hydrologic, and land-use data were analyzed by regressions to derive relations for assessing water quality in streams draining mined and unmined areas. In this approach, an equation was derived to estimate specific conductance. Additional equations, based on relations between specific conductance and other constituents, allow estimates of mine drainage indicators such as hardness, dissolved solids, and sulfate contents.

Hydrologic assessments of the tracts, based on limited verification data, proved to be reasonably accurate. Almost all ground-water verification data fall within estimated ranges and the remainder are close. Similarly, almost all surface-water quality data obtained fall within estimated ranges based on variations in discharge, and most of the remainder are close. Impacts that will result from future mining in tracts are defined. Methodology used to estimate future impacts on surface-water quality is described with examples.

INTRODUCTION

Maximum development of U.S. coal as a source of energy will require the mining of Federal reserves. In Alabama, these reserves underlie approximately 600,000 acres of which 70,500 acres are in the Warrior Coal Field (fig. 1). Most of the acreage is in small parcels disseminated in different parts of the coal field. In anticipation of mining these reserves, numerous tracts have been delineated for potential leasing. The U.S. Bureau of Land Management has the responsibility of assessing impacts that will result from the mining and for determining actions that will minimize problems.

The U.S. Geological Survey has the responsibility of collecting and providing baseline hydrologic information to the Bureau of Land Management to aid in preparation of environmental impact statements. An assessment of baseline hydrologic conditions, because of the short time available and fragmentary data resulting in part from the scattered nature of Federal coal reserves in a broad area, requires some predictive capability. This capability, based on other coal hydrology studies, requires some verification.

The purpose of this report is to describe hydrologic conditions in four widely separated potential coal lease tracts (fig. 1) of which two have already been impacted to some degree by surface mining. The descriptions include predictions where needed, estimating methods used, verification of estimates where feasible, and probable impacts of future mining.

PHYSICAL SETTING

The physical settings of the study areas (fig. 1) are similar to each other and to most other areas in the Warrior coal field. This is due to the similarity in topography and drainage, land use, climate, and, for the most part, geology. Variations in physical settings, where significant, will be discussed under descriptions of the individual tracts.

The Warrior coal field is in the Cumberland Plateau physiographic division which consists chiefly of a submaturely to maturely dissected upland developed largely on nearly flat-lying rocks (Johnston, 1933). Maximum relief generally is about 300 feet with numerous tributaries incised sharply into shale and sandstone that support ridges and steep slopes. Most basins are separated by sharp ridges. This is modified somewhat along southern and western boundaries of the coal field where unconsolidated sediments overlie the harder rocks. In these areas, hilltops and ridges tend to be less sharp and, in places, relatively flat. Most roads are on ridges and most land development is along the roads and in the flatter lowland areas. The remainder of the area is relatively undisturbed. Major land-use activities in a large part of the area are devoted to the timber industry and to surface coal mining.

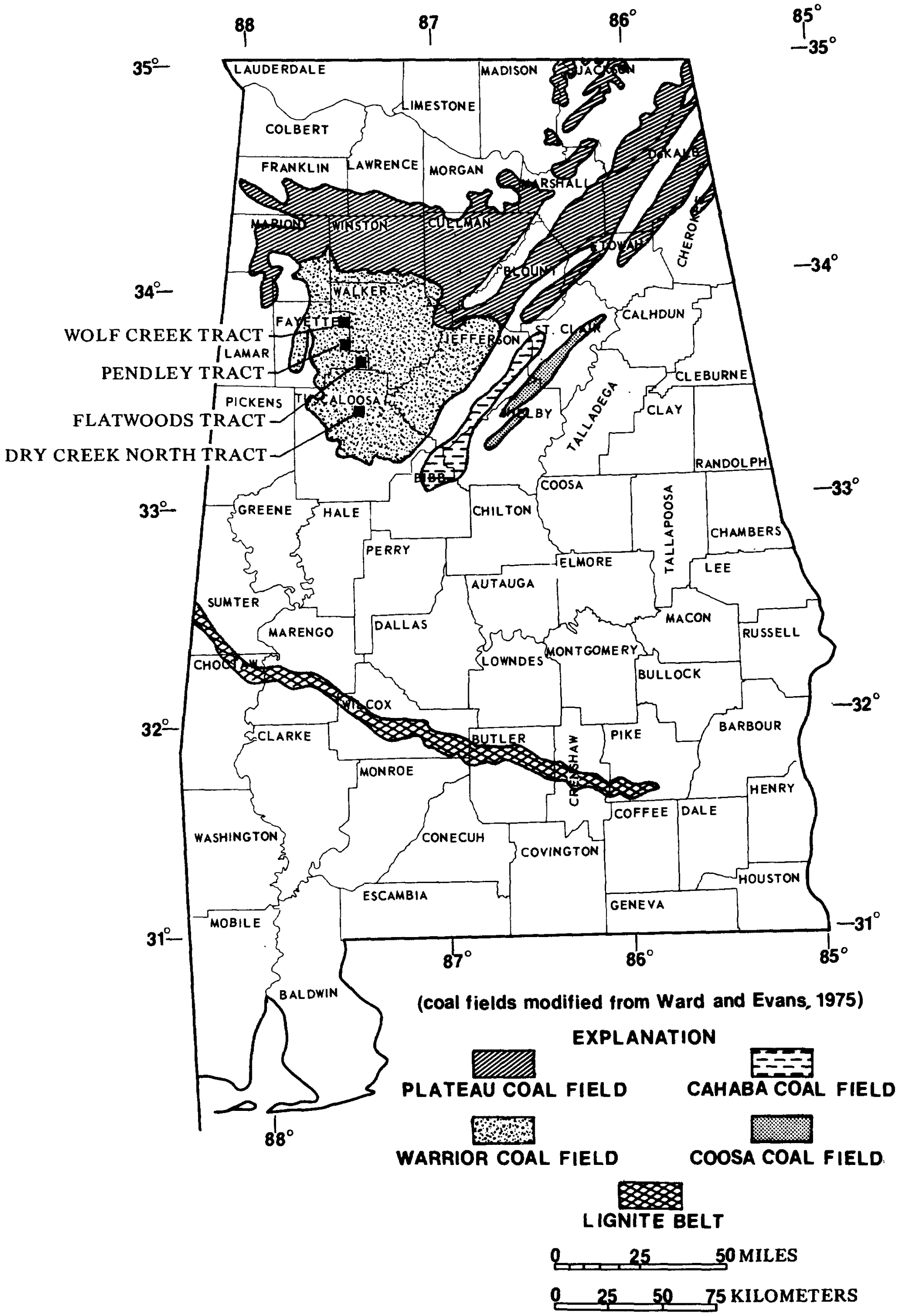

Figure 1.--Areas of study and principal coal fields in Alabama.

The study area has a subtropical climate characterized by warm and humid weather. According to U.S. National Weather Service records (Frentz and Lynott, 1978), the average annual temperature is about 17°C. January is generally the coldest month with an average temperature of 6.7°C, and July the hottest with an average temperature of 26.5°C. The average annual precipitation, almost all in the form of rain, is about 54 inches. Snowfall is very light and infrequent. During December through April, about 55 percent of the average annual precipitation occurs. The wettest month is March and the driest is October; drought conditions seldom occur.

The Warrior coal field is in the outcrop of the Pottsville Formation of Pennsylvanian age and the overlying Coker Formation of Late Cretaceous age. Significant deposits of the Coker are restricted to areas along the southern and western boundaries of the field. Regionally, strata in the Pottsville strike northwestward and dip southwestward 30 to 200 feet per mile (Culbertson, 1964). Strata in the Coker strike northwestward and dip southwestward 30 to 50 feet per mile.

The Pottsville Formation has a maximum thickness that exceeds 4,500 feet in the study area (Culbertson, 1964). The lower part consists predominantly of orthoquartzitic sandstone and conglomerate. Middle and upper parts consist chiefly of shale, sandstone and siltstone. These strata are generally medium- to dark-gray and carbonaceous, micaceous, and fossiliferous to some degree; some are calcareous. Shale is the dominant rock type. Several intervals in the Pottsville Formation contain beds of coal and underclay. The productive part of the formation contains 7 coal groups that contain 2 to 10 beds each (Culbertson, 1964). These groups are, in ascending order, the Black Creek, Mary Lee, Pratt, Cobb, Gwin, Utley, and Brookwood.

The Coker Formation in surface mine areas in the Warrior coal field rarely exceeds 100 feet in thickness, and generally consists of fine- to coarse-grained sand, gravelly sand, and sandy gravel separated in places by lenticular beds of gray sandy clay. One or more thin beds of ferruginous cemented sandstone or conglomerate are usually present near the base of the formation.

HYDROLOGY

Two hydrologic environments are present in the Warrior coal field. The physical setting of both, with the exception of their geology, is similar. The most extensive area of the environment is underlain by relatively impermeable rocks of the Pottsville Formation. The second environment, restricted to areas along western and southern boundaries of the field, is underlain by permeable strata of the Coker Formation that rest on the Pottsville Formation. The hydrology of basins within either of the environments is generally similar. The four tracts assessed are in the Pottsville environment. The Coker Formation is absent or is sufficiently limited in extent not to significantly influence hydrologic assessments of the tracts. For information pertaining to the Coker environment, the reader is referred to Puente and others (1980).

Ground Water

The Pottsville Formation is the mosts significant and, in many parts of the Warrior coal field, the only source of ground water available to wells. Recharge percolating downward into the formation is generally stored in and transmitted through openings along joints, fractures, and bedding planes. The water occurs under perched, water table, and artesian conditions; however, this study 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, generally conforms somewhat to the overlying topography. Perched bodies of water commonly occur where fractures and joints are absent or are sealed by underclay or soft shale. The movement of water, where these strata are present, is along bedding planes which, in the study area, generally dip southwestward. Water levels in nearby wells can vary greatly where they may reflect perched, water table, or artesian conditions or combinations of the different sources. These variations and the occurrence and movement of water, including that under perched conditions, is illustrated in figure 2. The depth to water levels in wells on hilltops generally range from 20 to 150 feet, those in lowland areas from 5 to 30 feet, and those on hillslopes between the two ranges given.

The Pottsville Formation is the source of water to most domestic wells in coal mine areas but does not generally yield large supplies. Yields from wells are generally less than 10 gal/min and many are less than 5 gal/min. Yields exceeding 25 gal/min are rare. Quantitative data are not available to determine specific aquifer characteristics; however, the small yield of wells and springs in such a broad area reflect limited storage and a low permeability. The small amount of water contributed to streams by Pottsville aquifers (base flow) also reflects the limited storage and low permeability.

Existing hydrologic conditions in the Warrior coal field and in some tracts assessed (fig. 1) include local modification of ground-water conditions. In some areas, existing aquifers have been removed or disturbed and, in many instances, have been replaced by spoil aquifers. These aquifers are created when accumulations of heterogeneous surface mine spoil (debris) are sufficiently large and permeable to store and transmit water. The amount of water stored in the spoil aquifers and their permeability generally exceed that of the undisturbed Pottsville aquifers. Consequently, water infiltrates downward and laterally from the spoil aquifers. This increases recharge to underlying aquifers and results in increased base flow to streams. Locally, streams have discharge during dry periods when they previously ceased to flow (Puente and Newton, 1979).

Surface Water

Streamflow characteristics are determined by climatic, physiographic, and geologic conditions, and by stream-regulating conditions imposed by man. Where these conditions are similar, basins may have similar streamflow characteristics. Streams in the Warrior coal field underlain by the Pottsville Formation, because of their similar physical setting, generally have similar low, median, and flood flow characteristics.

Relatively impermeable rocks in the Pottsville Formation result in poorly sustained low 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 to no flow between storms. Consequently, many streams in the area are intermittent; they generally flow from November through May and are frequently dry from June through October. Annual average discharge will vary considerably during extremely dry or wet years.

Annual discharges average about 40 percent of the average annual percipitation (54 inches). Annual streamflow, based on available data, generally ranges from 1.5 to 1.7 $(ft^3/s)/mi^2$.

The effects of existing mines on streamflow characteristics are difficult to assess. The effects are influenced by mining procedures and reclamation practices. Spoil aquifers and mine impoundments result in increased water storage. During periods of little precipitation, the augmentation to base flow from this storage locally results in discharges exceeding those prior to mining. The magnitude of increase resulting from the augmentation cannot be readily determined. The effects on flooding will vary with the magnitude of flood flows. The 2-year flood (Q_2) might increase initially as a result of vegetation removal. The increase, however, is expected to be short term and rapidly approach, or decrease below, premining flooding conditions because of reclamation and changes in permeability of overburden. Effects of mining and reclamation on the magnitude of the 25-, 50-, and 100-year floods are probably negligible.

Streamflow characteristics of the various tracts, including some at selected recurrence intervals and methods used in determining them, are given in following sections of this report.

Water Quality

The quality of ground water and surface water in undisturbed areas in the Pottsville environment is generally good, being suitable for most uses. Water in some areas disrupted by surface coal mines has become sufficiently mineralized to affect its use for some purposes.

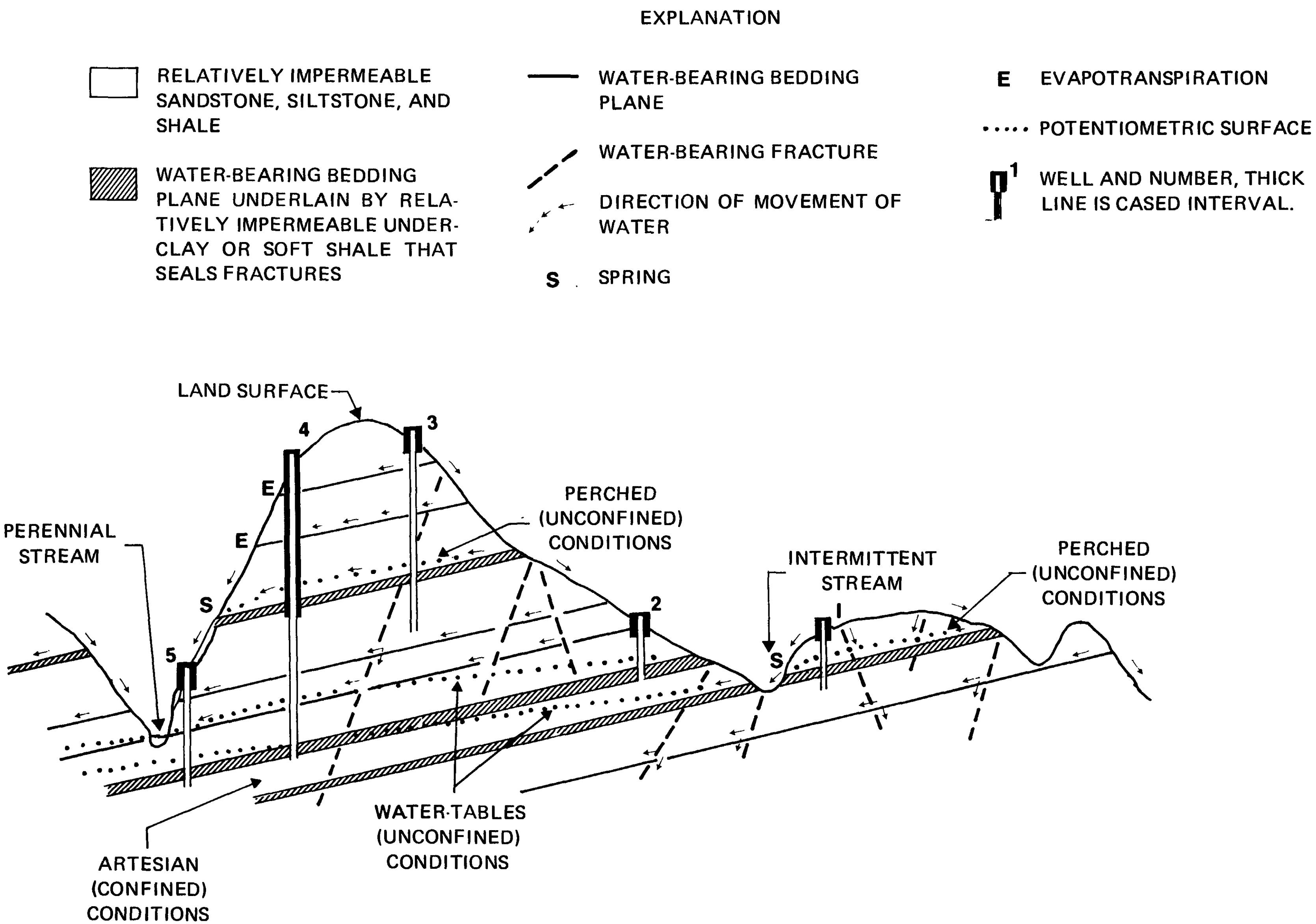

Figure 2.--Schematic diagram showing occurrence and movement of water in the Pottsville Formation.

Measurable characteristics that may be used to define water quality can be classified into three major groups: (1) chemical, (2) physical, and (3) biological. Chemical constituents and physical characteristics are used in this report because they are easily measured and can be related to water-use requirements. Specifically, these constituents and physical characteristics are specific conductance, pH, sediment, iron, bicarbonate, sulfate, hardness, and dissolved solids. Definitions of some of these are:

Dissolved solids.--Consist mainly of the dissolved mineral constituents in water and are 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

Total recoverable iron and manganese concentrations.--Is the amount of a given constituent that is in solution after a representative water-suspended sediment sample has been digested by a method (usually using a dilute acid solution) that results in dissolution of only readily soluble substances. Complete dissolution of all particulate matter is not achieved by the digestion treatment, and thus the determination represents something less than the "total" amount (that is, less than 95 percent) of the constituent present in the dissolved and suspended phases of the sample. To achieve comparability of analytical data, equivalent digestion procedures would be required of all laboratories performing such analyses because different digestion procedures are likely to produce different analytical results.

pH.--A measure of the hydrogren-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 units, acid water has a smaller pH and alkaline water a large 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, and land use, and quantity and intensity of precipitation.

Specific conductance.--A measure of the ability of water to conduct an electrical current and is expressed in micromhos per centimeter at 25°C. Because the specific conductance is related to the number of 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 centimeter at 25°C). This relation is not constant from stream to stream, and may vary within the same stream.

Mineralization of ground water in the Pottsville Formation increases with its time in contact with soluble minerals. This generally results in an increase in mineralization with depth from a common datum plane. The specific conductance of water at depths of less than 50 feet will generally be less than 150 umhos (micromhos per centimeter at 25°C) and, at a depth of 250 feet, may be as much as 800 umhos or more. Water in most wells generally ranges in dissolved solids from 20 to 500 mg/L, and in pH from 5.5 to 8.5 units and generally exceeds 7.0 units. Bicarbonate concentrations generally range from 20 to 450 mg/L and generally exceeds 100 mg/L; hardness ranges from 10 to 400 mg/L and generally exceeds 60 mg/L. Other constituents are usually present in low quantities. Most specific ranges in constituents and properties, based on available data, are given in descriptions of tracts in this report.

Available data allow estimates of ranges for some water-quality parameters that are expected to occur at depths of 50 to 250 feet. A specific estimate for a specific depth at a specific site or small area cannot be made accurately because secondary porosity (joints, fractures, and bedding planes) allows vertical and near horizontal movement to different depths (fig. 2). Shallow wells, because of geology and topography, can also yield more mineralized water than deeper wells where movement is controlled by bedding planes. Water in a shallow well (well 5 on fig. 2), based on the distance it has moved, would have been in contact with rocks longer and be more mineralized than water in nearby deeper wells (wells 3 and 4).

Surface water in undisturbed streams draining the Pottsville Formation is generally soft, acidic, and low in dissolved-solids content. Specific conductance generally ranges from 20 to 100 umhos, dissolved solids from 20 to 60 mg/L, and pH from 5.5 to 7.8 units. Only limited concentrations of other dissolved constituents are usually present. More specific ranges in constituents and properties, based on available data, are given in descriptions of tracts in this report.

Degradation of the quality of ground water and surface water has resulted from surface coal mining in parts of some of the tracts to be assessed and other areas in the Warrior coal field. Mine drainage is alkaline or acidic depending on the presence or absence of carbonate minerals in the strata disrupted. Some excellent indicators of mine drainage include specific conductance, dissolved solids, sulfate, iron, manganese, total hardness, and noncarbonate hardness where it approaches or exceeds 50 percent of the total hardness (Knight and Newton, 1977). Water in streams and aquifers impacted by mining is similar in quality, but the impact on water in aquifers is more localized.

TRACT EVALUATION

Federal coal reserves are disseminated in small parcels over a broad area in the Warrior coal field. The four tracts assessed were selected because they are in the outcrop of surface-minable coal beds in three different coal groups. Because the tracts are in outcrop areas of different coal groups, the study is regional in scope and allows additional evaluations of the transferability of hydrologic data in mining areas and the regional value of assessment methods utilized. The study areas and their respective coal group assessed, from north to south, are the Wolf Creek (Pratt), Pendley (Cobb), Flatwoods (Utley), and Dry Creek North (Utley) tracts (fig. 1).

Assessment Methods

Regression equations were derived to estimate regional variations in streamflow and water quality as functions of climate, basin characteristics, and land use. Models used in the regression analyses to derive the equations are of the form,

$$Y = ax_1^{b_1} X_2^{b_2} \ldots\ldots X_n^{b_n}$$

where $\underline{Y}$ (dependent variable) represents streamflow or water quality characteristics, $\underline{X}$'s (independent variables) are climate, basin characteristics, and land use, $\underline{a}$ is the regression constant, $\underline{b}$'s are regression coefficients, and $\underline{n}$ is the total number of independent variables. Dependent variables (Y's) are estimated from a combination of known independent variables (X's).

Regression analyses by Olin and Bingham (1977) provide equations for estimating flood magnitudes in small streams for selected recurrence intervals. Drainage area and main channel slope are the most significant characteristics affecting flood frequency and magnitude. Errors associated with use of the equations to estimate flood magnitudes in ungaged streams are unknown. Verification of flood magnitudes for streams in the coal-lease areas (table 1) will require collection of streamflow data for several years. Eight of the sites have drainage areas smaller than the minimum limit (1 mi^2) used to derive the equations. Flood magnitudes given in Table 1, however, appear to be reasonable.

Estimates of 7-day 2-year ($7Q_2$) and 7-day 10-year ($7Q_{10}$) low flows in ungaged streams are determined using methods derived by Bingham (1979). The methods consist of regression equations using a base flow recession index, drainage area, and mean annual precipitation as independent variables. The base flow recession index systematically relates the effects of geology underlying stream basins to the rate of low flow. Verification of low flow estimates for ungaged streams in the coal-lease areas (table 1) will require collection of streamflow data for several years. All sites have drainage areas smaller than the minimum limit (5 mi^2) used to derive the equations. However, all low flows given in table 1 are zero.

Climatic, physiographic, hydrologic, and land-use data for 67 basins in the Warrior coal field were analyzed by regressions to derive relations for assessing water quality in streams draining mined and unmined areas. Other investigators (Lystrom and others, 1979) have successfully used the same approach in similar studies. The regional data-collection network and a diagram illustrating the regression approach are shown on figure 3. Mineralization of mine drainage varies as functions of the quantity of water leaving the mined area, the presence of reactive minerals in spoil materials, and the period of time during which the reactive minerals have been exposed to weathering. In the regression approach, the selected dependent variable representing mineralization of mine drainage is specific conductance. Independent variables include streamflow, percent of basin mined, channel distance between stream sampling site and mined area, and the relative age of mined areas.

The equation for estimating specific conductance of water in streams draining mined areas is:

$$\text{SP. COND.} = 28.84 \frac{(\text{PBM})^{0.407} (\text{MAF})^{0.476}}{(\text{Q/A})^{0.369} (\text{CL})^{0.381}}$$

where SP. COND. is specific conductance, in micromhos per centimeter at 25°C,

<u>PBM</u> is percent of basin mined, in percent,

<u>Q/A</u> is streamflow, in cubic feet per second per square mile,

<u>CL</u> is averaged channel length or distance between stream sampling site and mined area, in miles, and

<u>MAF</u> is a mine age-weight factor. It is a numerical value based on observed increases in mineralization of mine drainage with time. The numerical values are:

Relative mine age in years after mine starting	MAF
1	2
2	3
3	7
4	10
5	15
6	18
7	20
8	20
9	20
10	19
11	15
12	9
13	6
14	4
15	3

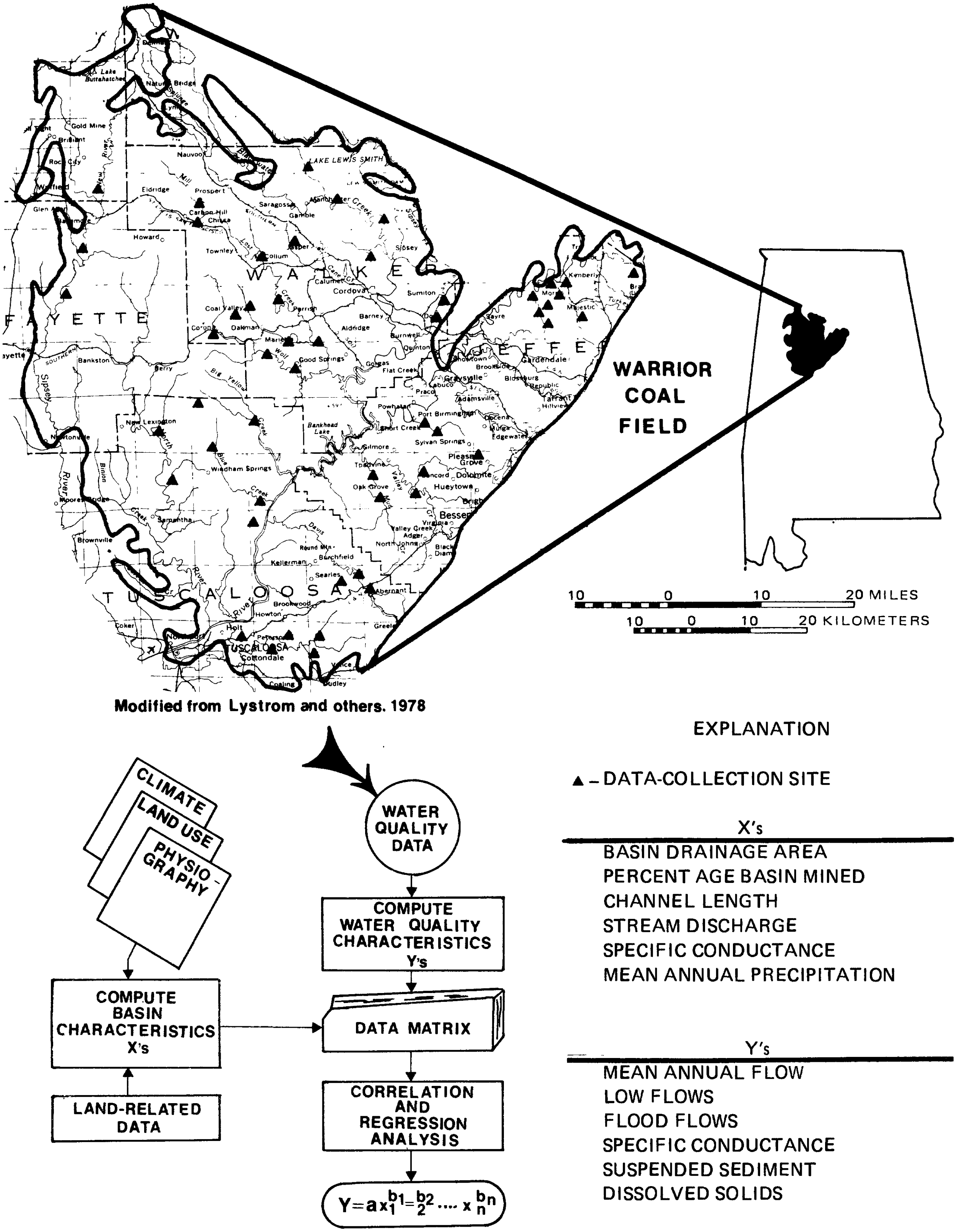

Figure 3.--Regional data collection network and a schematic diagram of hydrologic assessment approach.

Mine age-weight factors (MAF) were determined from plots of specific conductance versus stream discharge based on the relative age of surface mines contributing drainage to streams sampled. The preceeding table represents an interpolation of a bar graph where MAF = 2 when mine age is less than 3 years; MAF = 10 when mine age is 3 but less than 6 years. MAF = 20 when mine age is 6 but less than 12 years; and MAF = 5 when mine age is 12 or more years.

Graphical solution of the specific conductance equation is shown in figure 4. Estimates of specific conductance greater than 3,000 umhos exceed the range of observed data and should be set equal to 3,000. The equation is applicable only for ranges of data defined by the family of curves.

Specific conductance is directly related to dissolved solids concentrations in water, and is frequently used to estimate other ion concentrations. Relations between specific conductance versus ion concentrations commonly used as indicators of coal-mine drainage are given in table 2 and shown in figures 5, 6, and 7.

Relations for estimating total recoverable iron and manganese concentrations are based on suspended-sediment concentrations observed during medium and high flow. The equations for suspended-sediment concentrations versus total recoverable iron and manganese concentrations are given in table 2 and the relations are shown in figures 8 and 9.

Estimates of surface water quality parameters, such as specific conductance for streams draining unmined basins, pH, and annual sediment yields, are based on data reported elsewhere (Harkins and others, 1980), and on data collected in nearby areas with similar geology, basin characteristics, and land use.

Individual water quality parameters vary with stream discharge. Those in solution are generally inversely related to discharge; the larger concentrations generally occur during low flow. Because of this variability, estimates of concentrations represent ranges based on variations in discharge (0.5 to 5.0 ft^3/s). Verification of estimates was accomplished by sampling at the various sites. The accuracy of an estimate was indicated by the position of the verification datum in the estimated range as related to discharge during sampling.

Ground-water assessments for the various tracts are based on data available for wells in or near the tracts, on a regional assessment, or combinations of both where sufficient data are not locally available. The regional assessment is given in the section on hydrology in this report. Reconnaissance-type inventories were made in and near tracts during the verification stage of the study to substantiate the transferability of the data used.

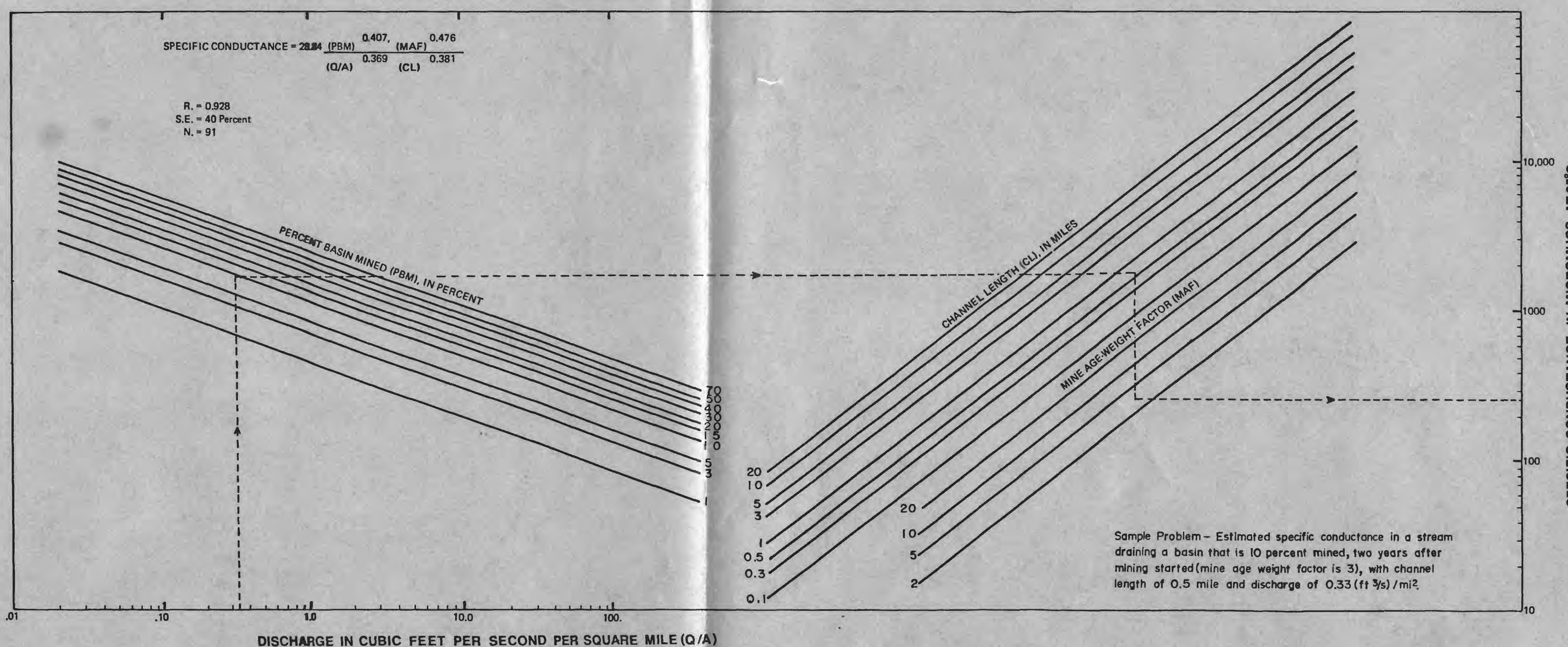

Figure 4.—Graphical solution for specific conductance.

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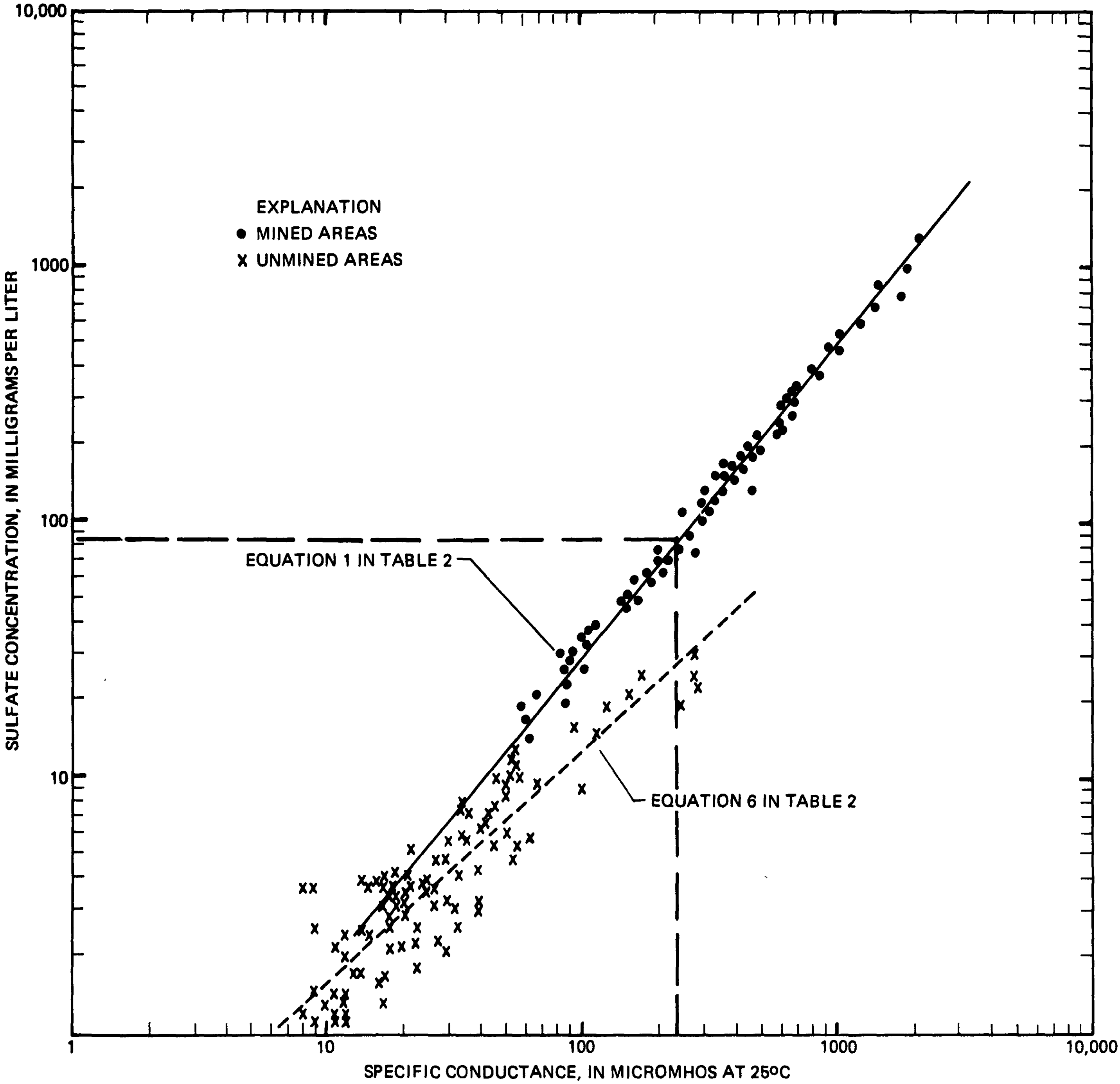


Figure 5.--Relation between specific conductance and sulfate concentration for streams draining the Warrior coal field.

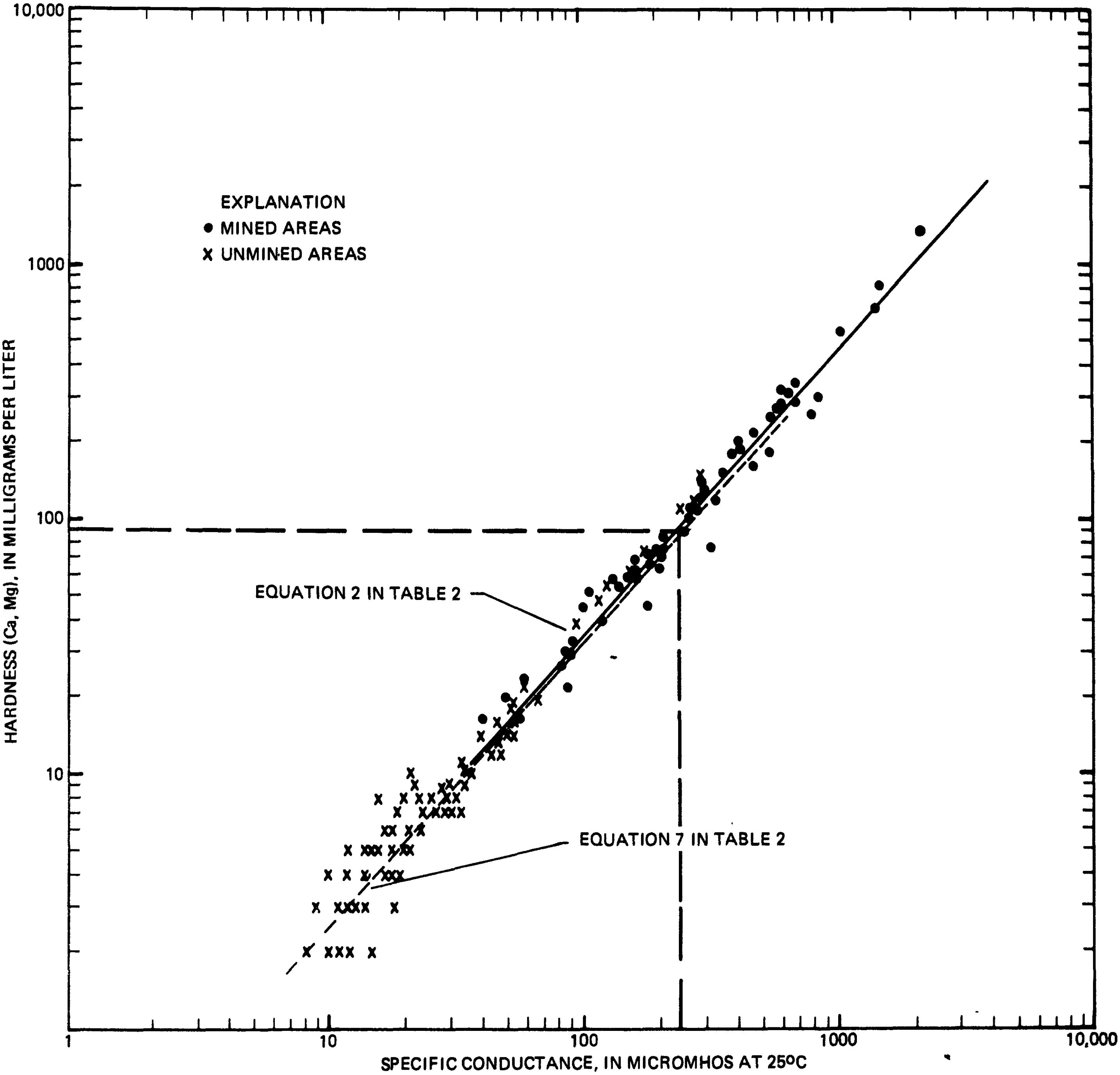


Figure 6.--Relation between specific conductance and hardness (Ca, Mg) for streams draining the Warrior coal field.

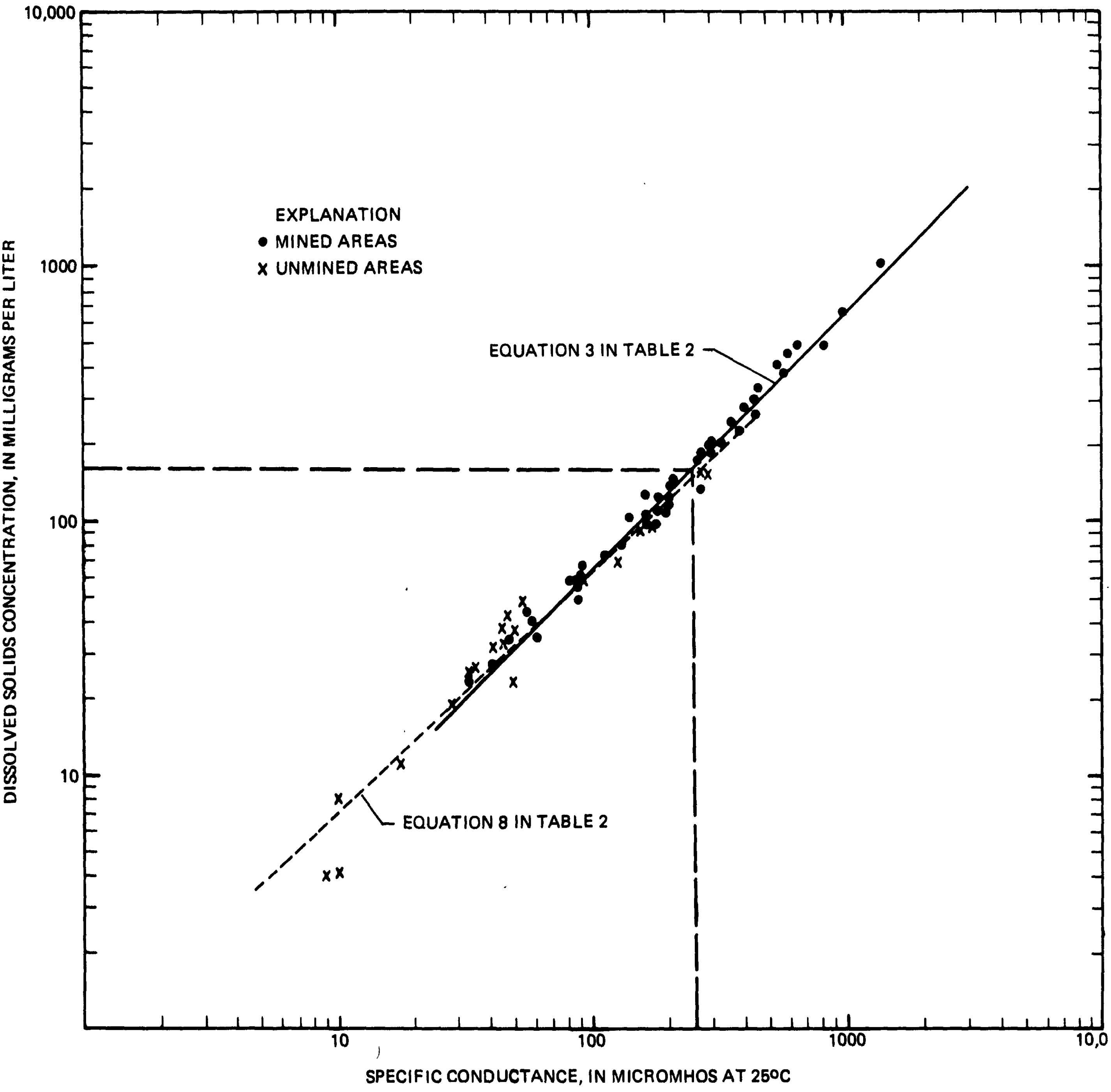


Figure 7.—Relation between specific conductance and dissolved solids concentration for streams draining the Warrior coal field.

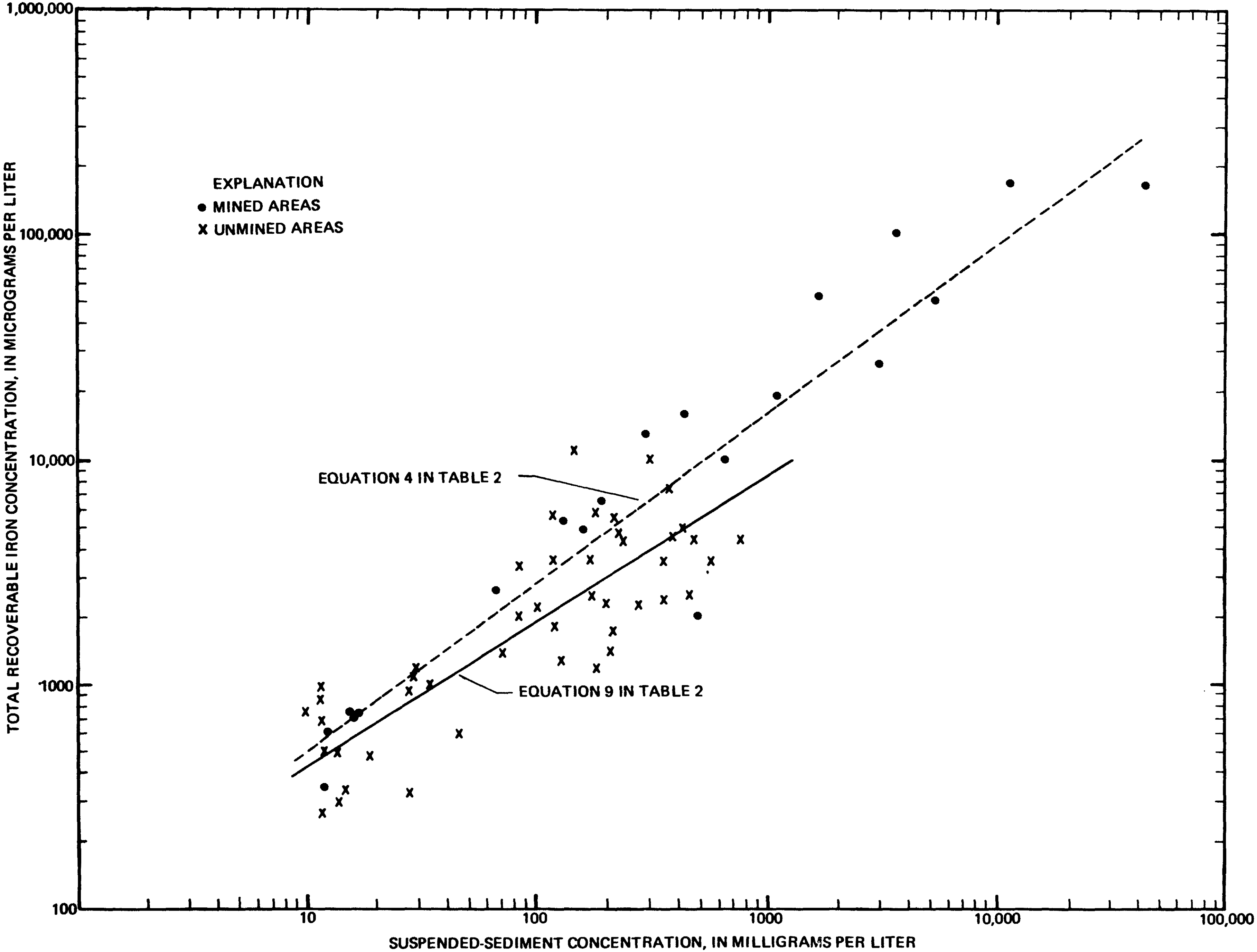


Figure 8.--Relation between suspended-sediment and total recoverable iron concentrations.

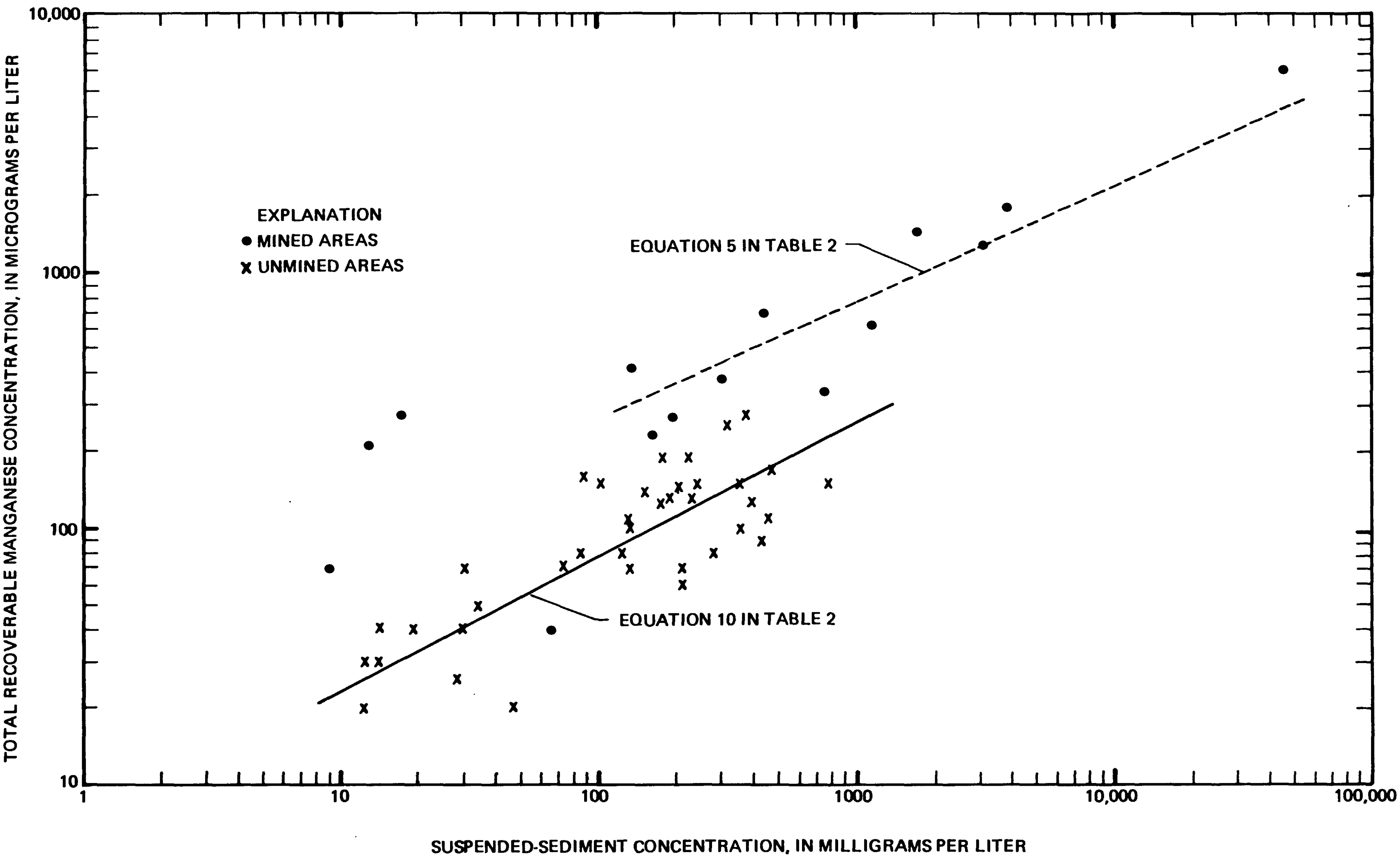


Figure 9.--Relation between suspended-sediment and total recoverable manganese concentrations.

Wolf Creek Tract

The tract, located in Fayette County (fig. 1), is uninhabited and mostly in timber. The surface is dissected with slopes ranging from 33 percent on hillsides to about 1 percent on hilltops. Maximum topographic relief is about 300 feet. The tract is drained by Allen, Cranford, Wolf, and Boxes Creeks and their tributaries (fig. 10).

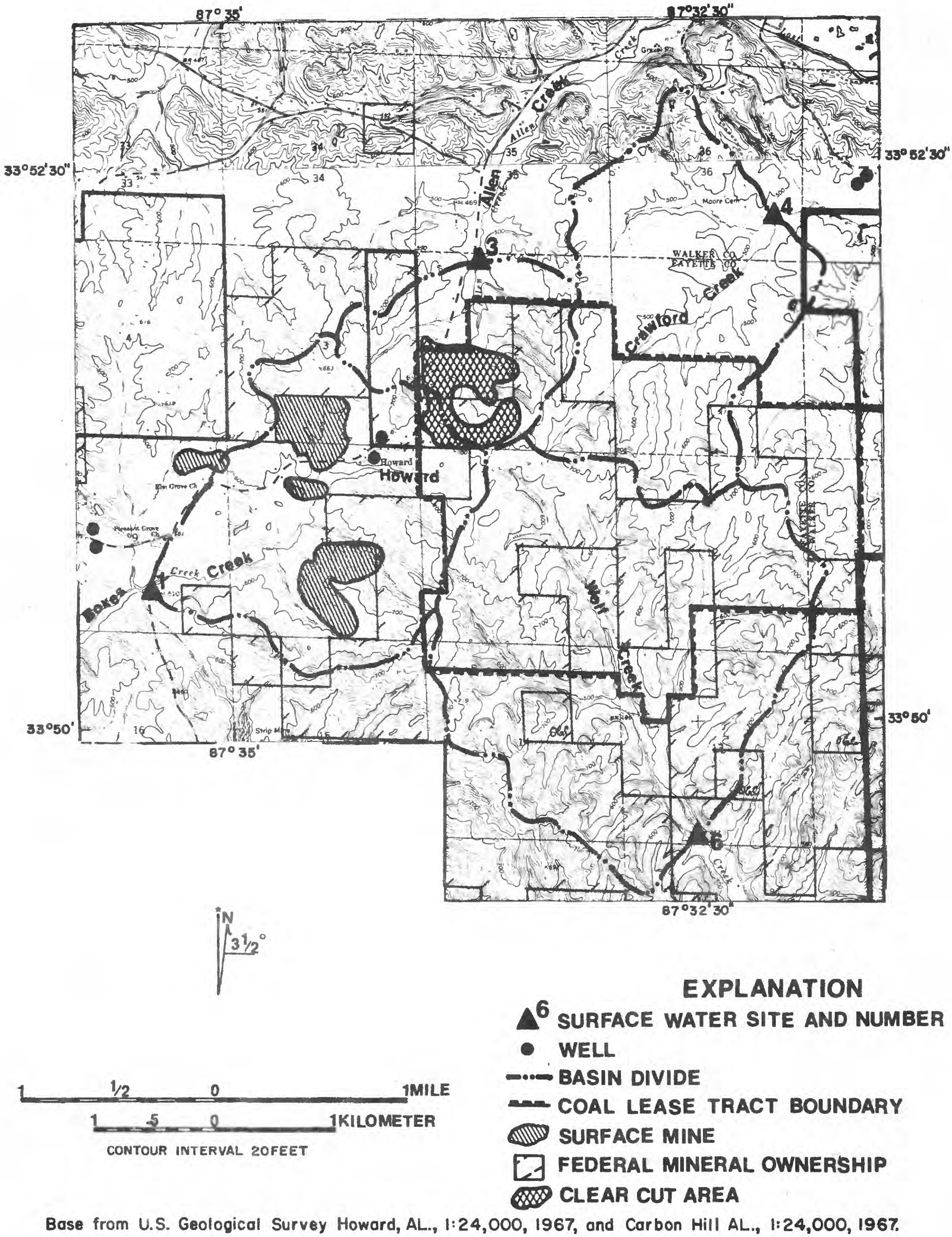
The Pottsville Formation crops out in most of the tract. Thin, small outliers of the Coker Formation cap some of the higher hills. The Pottsville consists chiefly of alternating beds of sandstone, shale, and siltstone with a few thin beds of limestone, coal, and underclay. The coal beds are in the Pratt coal group. The Coker Formation consists of sand and gravel with some thin beds of clay. The Pottsville Formation dips southward about 60 feet per mile and the Coker Formation dips southwestward about 30 feet per mile.

Assessment

The Pottsville Formation, the only available source of ground water, is not tapped by wells in the tract. Aquifers are expected to have water-bearing characteristics similar to those in nearby areas and in other coal mine areas in the Warrior coal field. The quality of water is also expected to be similar, for the most part, to that available at comparable depths in nearby areas.

Yields available for water-bearing openings at depths less than 250 feet are generally expected to be less than 10 gal/min. Water levels are expected to range in depth from 5 feet in lowland areas to 150 feet in highland areas. Specific conductance of water in aquifers at depths less than 50 feet is generally expected to be less than 150 umhos, and at depths of 50 to 250 feet, is expected to generally range from 150 to 800 umhos. Dissolved solids concentrations are expected to range from 20 to 500 mg/L and pH from 5.5 to 8.5 units with most exceeding 7.0 units. In all but the shallowest wells, the water is expected to be moderately hard to very hard and have a bicarbonate concentration ranging from 20 to 450 mg/L. Only low concentrations of other constituents are expected. Calcium, magnesium, and sulfate concentrations are each expected to range from 1 to 50 mg/L. Locally, dissolved iron and manganese concentrations may exceed 300 and 50 ug/L (micrograms per liter), respectively.

All streams within the tract are intermittent. Because of steep topographic relief and underlying relatively impermeable rocks, runoff is expected to be very rapid with discharge receding quickly to low or no flow. Basin characteristics including estimates of low flow and flood flow for sites on four streams draining the tract (fig. 10) are given in table 1. The sites, with the exception of site 1, drain unmined areas in and near the tract. Site 1 on Boxes Creek receives drainage from some surface mined areas west of the tract (fig. 10). Site 3, based on 1980 aerial photography, drains an area in the northwest part of the tract where clear-cutting of timber has occurred (fig. 10).



Base from U.S. Geological Survey Howard, AL., 1:24,000, 1967, and Carbon Hill AL., 1:24,000, 1967.

Figure 10.--Wolf Creek Tract and data collection sites.

Water in streams draining undisturbed areas (sites 4 and 6 on fig. 10) is expected to be of good chemical quality. Water draining the area in which clear-cutting has occurred (site 3) is expected to be of similar quality but slightly more mineralized than that at sites 4 and 6. Water draining mining areas (site 1) is expected to be significantly mineralized. Estimates of ranges of selected physical properties and concentrations of chemical constituents given in tables 3 and 4 reflect the varying degree of mineralization expected at the sites.

Water at sites 4 and 6 draining undisturbed areas, based on discharges of 0.5 and 5.0 ft^3/s, had estimated ranges in specific conductance of 20 to 90 umhos, in hardness from 5 to 30 mg/L, in sulfate from 3 to 12 mg/L, and in dissolved solids from 14 to 56 mg/L (table 3). The estimates for the same parameters at site 3 more than doubled at comparable low flow (0.5 ft^3/s). This reflects the expected increase in water mineralization resulting from minerals exposed to weathering by the disruption of the land surface caused by clear-cutting of timber. Estimated values for site 1 draining mined areas were about six times greater than those for undisturbed areas (sites 4 and 6) at the comparable low flow (0.5 ft^3/s).

Verification

A reconnaissance inventory of six wells adjacent to the tract, because of the absence of wells in it, was made in May 1980. Some additional wells visited were not used for verification because they were affected by mining and not related to undisturbed conditions in the tract. Inventoried wells, most of which are located in or near Howard (fig. 10), tap the same sequence of strata that underlies the tract. Well depths ranged from 43 to 435 feet, and measured depths to water levels ranged from 6.0 to 61.1 feet. Water levels, based on topography (wells were located on lower slopes and lowlands), were in the lower half of the range predicted and water levels nearest land surface generally occurred in wells in lowland areas. Information pertaining to well yields was not available. Water quality data obtained to verify assessments were limited to field determinations (pH, specific conductance, and bicarbonate concentration). Based on the field determinations, specific conductances ranged from 138 to 740 umhos, pH from 6.4 to 8.8 units with most exceeding 7.0 units, and bicarbonate from 46 to 550 mg/L with all exceeding 100 mg/L except for one determination for a shallow dug well. The data obtained, though limited, indicate that the ground-water assessment was reasonably accurate.

Selected chemical and physical characteristics of water in streams draining the tract during the verification phase in April-May 1980, are given in tables 3 and 4. Determinations for sites draining unmined areas (sites 3, 4, and 6) were well within estimated ranges (table 3). Specific conductance ranged from 16 to 139 umhos and pH from 6.3 to 7.3 units. Sulfate concentrations ranged from 3 to 36 mg/L, hardness from 4 to 48 mg/L, and dissolved solids from 26 to 80 mg/L.

Water at site 3 draining an area in which clear-cutting of timber has occurred, was slightly more mineralized than that in sites 4 and 6 draining undisturbed basins. Water at site 1, draining a mined area, was highly mineralized. Although the pH and the sulfate concentration of water at site 1 were within estimated ranges, actual specific conductance and dissolved solids concentration exceeded estimates by about 22 percent or 150 umhos and 98 mg/L, respectively. Observed hardness exceeded the estimated range by about 33 percent or 110 mg/L. A point estimate of specific conductance, based on the measured discharge of 0.37 ft^3/s at site 1 was 580 umhos. The point estimate was about 15 percent or 100 umhos less than the observed specific conductance. Differences between observed and estimated water quality parameters at site 1 probably results largely from the presence of significant amounts of limestone and other calcareous minerals not normally found in mined areas. Observed total recoverable iron and manganese concentrations at all sites were within estimated ranges (table 4). Based on the data obtained, the water-quality assessment for streams draining the tract was reasonably accurate.

Pendley Tract

The tract, located in Fayette and Walker Counties (fig. 11), is sparsely inhabited and mostly in timber. About 13 percent of the tract area consists of reclaimed surface mines. The surface is dissected, and slopes range from 45 percent on hillsides to about 5 percent on the hilltops. Maximum topographic relief is about 300 feet. The tract is drained by Cane and Pendley Creeks and their tributaries (fig. 11).

The tract is underlain by the Pottsville Formation. The Pottsville consists chiefly of alternating beds of sandstone, shale, siltstone, and thin beds of coal and underclay. The coal beds are in the Cobb coal group. Strata in the Pottsville strike northwestward and dip southwestward about 50 to 60 feet per mile.

Assessment

The Pottsville Formation is the only source of ground water in the tract. Well depths, water levels, yields, and ground-water quality in unmined areas are expected to be similar to those in unmined areas in the Wolf Creek Tract. A detailed chemical analysis was available for a test well (well 1, fig. 11) in the tract prior to the assessment. The well had a depth of 207 feet. Water from it had a specific conductance of 370 umhos, a pH of 6.5 units, and a bicarbonate concentration of 170 mg/L. The total hardness was 150 mg/L of which 7 mg/L was noncarbonate hardness. Dissolved calcium, magnesium, and sulfate concentrations were 27, 19, and 39 mg/L, respectively. Dissolved iron and manganese concentrations were 20 and 80 ug/L, respectively.

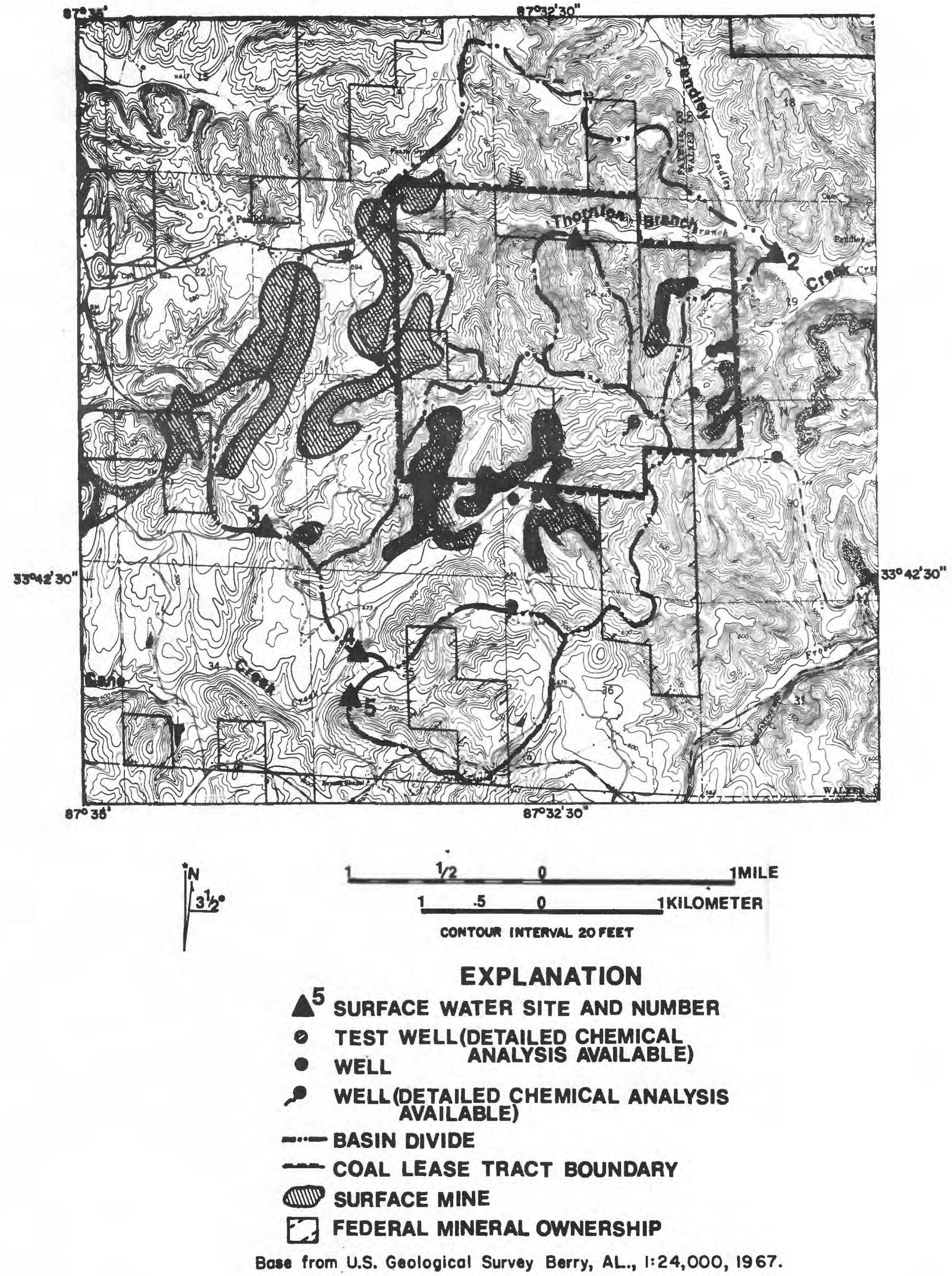


Figure 11.--Pendley Tract and data collection sites.

Aquifers underlying and adjacent to mined areas have probably been impacted to some degree by recharge from surface mine drainage. The quality of ground water affected by recharge from mines is expected to be characterized by increases in specific conductance and hardness and in sulfate and dissolved solids concentrations. Sulfate concentrations are expected to exceed 50 mg/L and the pH is expected to remain similar to that of ground water in unmined areas (5.5-8.5 units). Dissolved iron and manganese concentrations are expected to exceed 300 and 50 ug/L, respectively. In general, the quality of ground water affected by mining is expected to be similar to that of mine drainage in streams.

All streams within the tract are expected to be intermittent. During low flow, streams draining mined areas are expected to have larger discharges, per unit area, than those in unmined areas because of increased water storage in spoil areas and mine impoundments. Resulting increases in base flow from these sources of storage are expected to shorten periods of no flow. Because of steep topographic relief and the relative impermeability of underlying rocks, runoff is expected to be very rapid with discharge receding quickly to low or no flow. Basin characteristics, including estimates of low flow and flood flow, for sites draining the tract and for site 5 which lies outside the tract (fig. 11) are given in table 1. Sites 1 and 5 drain undisturbed areas, but sites 2, 3, and 4 receive drainage from reclaimed surface-mined areas (fig. 11). Water at sites 1 and 5 is expected to be of good chemical quality and similar to that assessed for streams draining undisturbed areas in the Wolf Creek Tract. Water at sites 2, 3, and 4 is expected to be significantly more mineralized. Estimates of ranges in selected physical properties and concentrations of chemical constituents at different discharges are given in tables 3 and 4. They reflect the contrast in mineralization of water expected between mined and unmined basins. The estimated specific conductance at site 3, based on a discharge of 0.5 ft^3/s, is 740 umhos. This is about eight times greater than those estimated for streams draining undisturbed areas (sites 1 and 5) during comparable low flow.

Verification

An inventory of 13 wells in and adjacent to the tract was made in May 1980. The wells tap the Pottsville Formation and range in depth from 26 to 209 feet. Measured depths to water levels ranged from 15.5 to 100 feet; water levels shallower than 40 feet generally occurred in wells in lowland areas or in shallow wells (less than 100 feet) at higher altitudes. Data on their yields were not available.

Water quality data obtained to verify assessments consisted of field determinations (pH, specific conductance, and bicarbonate concentration) for all wells and detailed chemical analyses for two wells.

Water in wells unaffected by mining ranged in specific conductance from 59 to 560 umhos and in pH from 6.1 to 7.3 units. Bicarbonate concentrations ranged from 10 to 320 mg/L. Bicarbonate concentrations less than 100 mg/L and specific conductance values less than 150 umhos were generally from wells less than 40 feet deep. Water from one well (well 2, fig. 11) with a depth of 102 feet and a water level of 42.2 feet, based on a detailed analysis, had a specific conductance of 410 umhos, a pH of 7.2 units, and a bicarbonate concentration of 200 mg/L. The total hardness was 190 mg/L of which the noncarbonate hardness was 39 mg/L. Dissolved calcium, magnesium, and sulfate concentrations were 46, 18, and 38 mg/L, respectively. Dissolved iron and manganese concentrations were 80 and 70 ug/L, respectively.

Wells affected by mine drainage were identified by field determinations of sulfate. Based on these determinations, water in wells affected by mine drainage generally had sulfate concentrations exceeding 200 mg/L. Specific conductance ranged from 630 to 1360 umhos. The pH ranged from 6.1 to 7.3 units and bicarbonate concentrations from 124 to 300 mg/L. Water from one well (well 3, fig. 11) with a depth of 101 feet and a reported water level of 40 feet, based on detailed chemical analysis, had a specific conductance of 1360 umhos, a pH of 7.3 units, and a bicarbonate concentration of 250 mg/L. Dissolved calcium, magnesium, and sulfate concentrations were 180, 64, and 556 mg/L, respectively. The total hardness was 720 mg/L of which the noncarbonate hardness was 520 mg/L. Dissolved iron and manganese concentrations were 1200 and 260 ug/L, respectively.

The ground water data obtained, though limited, indicate that the ground-water assessment was reasonably accurate.

Estimated and observed chemical and physical characteristics of water in streams draining the tract are given in tables 3 and 4. Water-quality determinations for all sites draining the tract, with the exception of some total recoverable manganese concentrations, were well within estimated ranges. Water at sites 2, 3, and 4 draining mined areas was significantly more mineralized than water at sites 1 and 5 draining unmined areas. Point estimates of specific conductance, based on observed discharges at sites 2, 3, and 4 (1.80, 1.50, and 1.50 ft^3/s) were 110, 480, and 310 umhos, respectively. The point estimates were 2, 8, and 24 percent less, respectively, than observed specific conductances (table 3). Total recoverable manganese concentrations for streams draining unmined areas were within estimated ranges; however, those for streams draining mined areas were less than or greater than the estimated ranges. Differences between observed and estimated values probably resulted from the high variability of dissolved manganese concentrations in water during low flow. Total manganese concentrations during low flow mainly consists of dissolved concentrations and are not generally related to suspended-sediment concentrations. Based on the data obtained, the water quality assessment for streams draining the tract were reasonably accurate.

Flatwoods Tract

The tract, located in Fayette County (fig. 1), is sparsely inhabited and mostly in timber. About 10 percent of the tract has been surface mined. The surface is dissected with slopes ranging from 50 percent on hillsides to about 10 percent on the hilltops. Maximum topographic relief is about 240 feet. The tract is drained by Little Yellow and Big Yellow Creeks and their tributaries (fig. 12).

The Pottsville Formation crops out in most of the tract, but thin, small outliers of the Coker Formation cap some of the higher hills. The Pottsville consists chiefly of alternating beds of sandstone, shale, siltstone, and a few thin beds of coal and underclay. The minable coal beds are in the Utley coal group. The Coker Formation consists of sand and gravel with some thin beds of clay. Strata in the Pottsville generally strike eastward and dip southward from 10 to 40 feet per mile. Beds in the Coker strike northwestward and dip southwestward about 30 feet per mile.

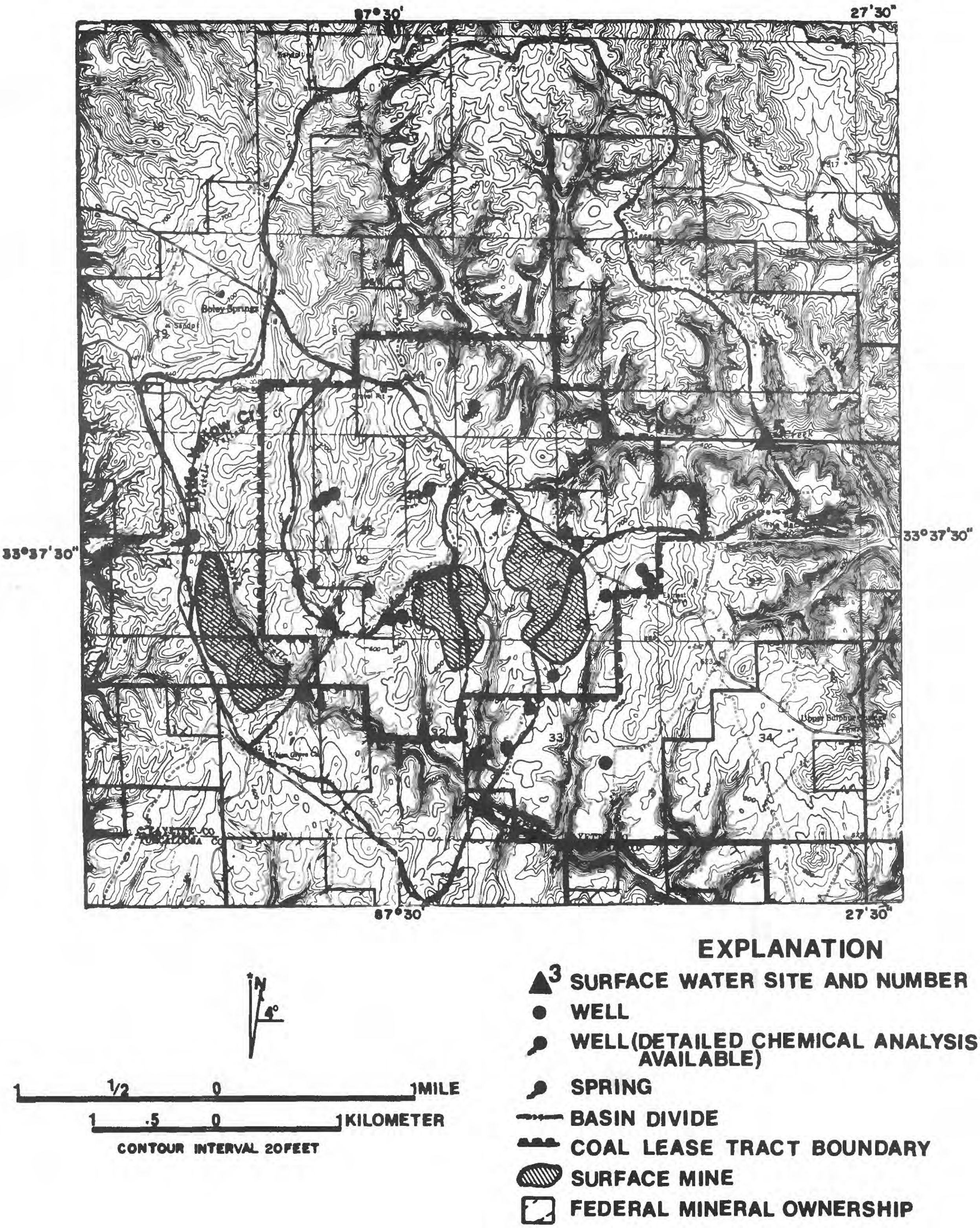
Assessment

The Pottsville Formation is the principal source of ground water in the tract. Its water-bearing characteristics, well depths, water levels, yields, and water quality in undisturbed areas are expected to be similar to those described in the previous tract assessments. Ground-waters quality affected by recharge from surface mine drainage is expected to be similar to that described in the assessment of the Pendley tract.

The Coker Formation is a minor source of ground water in the northwestern part of the tract. Yields from wells are expected to be less than 10 gal/min and depths to water levels less than 40 feet. Water in the Coker Formation is generally much less mineralized than that in the Pottsville Formation. The specific conductance of water in the Coker Formation is expected to range from 10 to 40 umhos, and the pH from 4.0 to 6.5 units. Bicarbonate and dissolved solids concentrations are generally less than 15 and 30 mg/L, respectively. Locally, dissolved iron and manganese concentrations may exceed 300 and 50 ug/L, respectively.

All streams within the tract are expected to be intermittent. Streamflow characteristics and variability are expected to be similar to those described in the assessment of the Pendley tract. Basin characteristics including estimates of low flow and flood flow for select sites draining the tract (fig. 12) are given in table 1. Sites 1 and 5 drain undisturbed areas, but sites 2, 3, and 4 receive drainage from surface mined areas.

Water in streams at sites 1 and 5 is expected to be of good chemical quality and, similar to that described in assessments of streams draining undisturbed areas in the preceding tracts. Water at sites 2, 3, and 4 draining mined areas is expected to be significantly mineralized. Estimates of ranges of selected physical properties and concentrations of chemical constituents given in tables 3 and 4 reflect the varying degrees of mineralization expected at the sites.



Base from U.S. Geological Survey Oakman, AL., 1:24,000, 1951; Wiley, AL., 1:24,000, 1951, Berry SE, AL., 1:24,000, 1967, and Berry, AL., 1:24,000, 1967.

Figure 12.—Flatwoods Tract and data collection sites.

Verification

An inventory of 21 wells and one spring in and adjacent to the tract was made in April 1980. All wells tap the Pottsville Formation and range in depth from 18 to 300 feet. The spring discharges from the Coker Formation. Measured depths to water levels in the wells ranged from 13 to 43 feet. Water levels less than 20 feet generally occurred in wells in lowland areas and in shallow wells (less than 75 feet) on hilltops. Information pertaining to their yields was not available.

Water quality data obtained for verification consisted of field determinations (pH, specific conductance, and bicarbonate and sulfate concentrations) for all wells and a detailed chemical analysis for one well (well 1, fig. 12) with a depth of 61 feet and a water level of 24.2 feet. Water from wells in unmined areas ranged in specific conductance from 43 to 520 umhos and in pH from 5.4 to 8.1 units. Bicarbonate concentrations ranged from 12 to 290 mg/L. Bicarbonate concentrations less than 100 mg/L and specific conductance less than 200 umhos were generally from relatively shallow wells. Based on the one detailed analysis, dissolved calcium, magnesium, and sulfate concentrations were 23, 6.5, and 19 mg/L, respectively, and dissolved iron and manganese concentrations were 790 and 280 ug/L, respectively. The quality of water in wells adjacent to mined areas was similar to that in wells in unmined areas. The absence of highly mineralized water adjacent to the mines is probably due to the relatively young age of the mines (less than 3 years).

Water from one spring discharging from the Coker Formation was sampled. Specific conductance, pH, and bicarbonate concentration determinations were 18 umhos, 5.3 units and 2 mg/L, respectively.

Based on the data obtained, the ground-water assessment in the tract was reasonably accurate.

Selected chemical and physical characteristics of water in streams draining the tract during April 1980 are given in tables 3 and 4. Water quality determinations for sites 1 and 5 draining undisturbed areas were generally within estimated ranges (table 3). Water at sites 2, 3, and 4 draining mined areas was not nearly as mineralized as expected, and was similar to water at sites draining undisturbed areas. All pH and most total recoverable iron and manganese concentrations were within estimated ranges, but observed specific conductance and other chemical constituents averaged about six times less than estimated values at comparable discharges. For example, the estimated specific conductance (180 umhos) at site 4 during a dishcarge of 5.0 ft^3/s is about six times greater than the observed specific conductance (31 umhos) at a discharge of 4.28 ft^3/s (table 3). The small amount of mineralization generated by the young mines during the verification phase undoubtedly resulted from extreme flushing from unusually excessive precipitation prior to sampling. Exceptionally high monthly rainfall totals (greater than 17 inches) were recorded in the area during March 1980. Additional water-quality sampling at a nearby downstream site on Little Yellow Creek during August 1980 indicated a return to significantly more-mineralized water (specific conductance of 300 umhos at a discharge of 0.2 ft^3/s) draining from mined areas in the tract. Considering this unusual occurrence and the return of mineralization to estimated levels, the water quality assessment for streams draining the tract was reasonably accurate.

Dry Creek North Tract

The tract, located in Tuscaloosa County (fig. 1), is sparsely inhabited and mostly in timber. The surface is dissected with slopes ranging from 50 percent on hillsides to about 3 percent on hilltops. Maximum topographic relief is about 160 feet. The tract is drained by Cripple, Little, and Dry Creeks and their tributaries (fig. 13).

The Pottsville Formation underlies and crops out in most of the tract; some thin, small outliers of the Coker Formation cap the higher hills. The Pottsville consists chiefly of alternating beds of sandstone, shale, siltstone, and some thin beds of coal and underclay. The coal beds are in the Utley coal group. The Coker Formation consists of sand and gravel with some thin beds of clay. The Pottsville and Coker Formations strike northwestward and dip southwestward. Strata in the Pottsville dip about 30 feet per mile and those in the Coker about 35 feet per mile.

Assessment

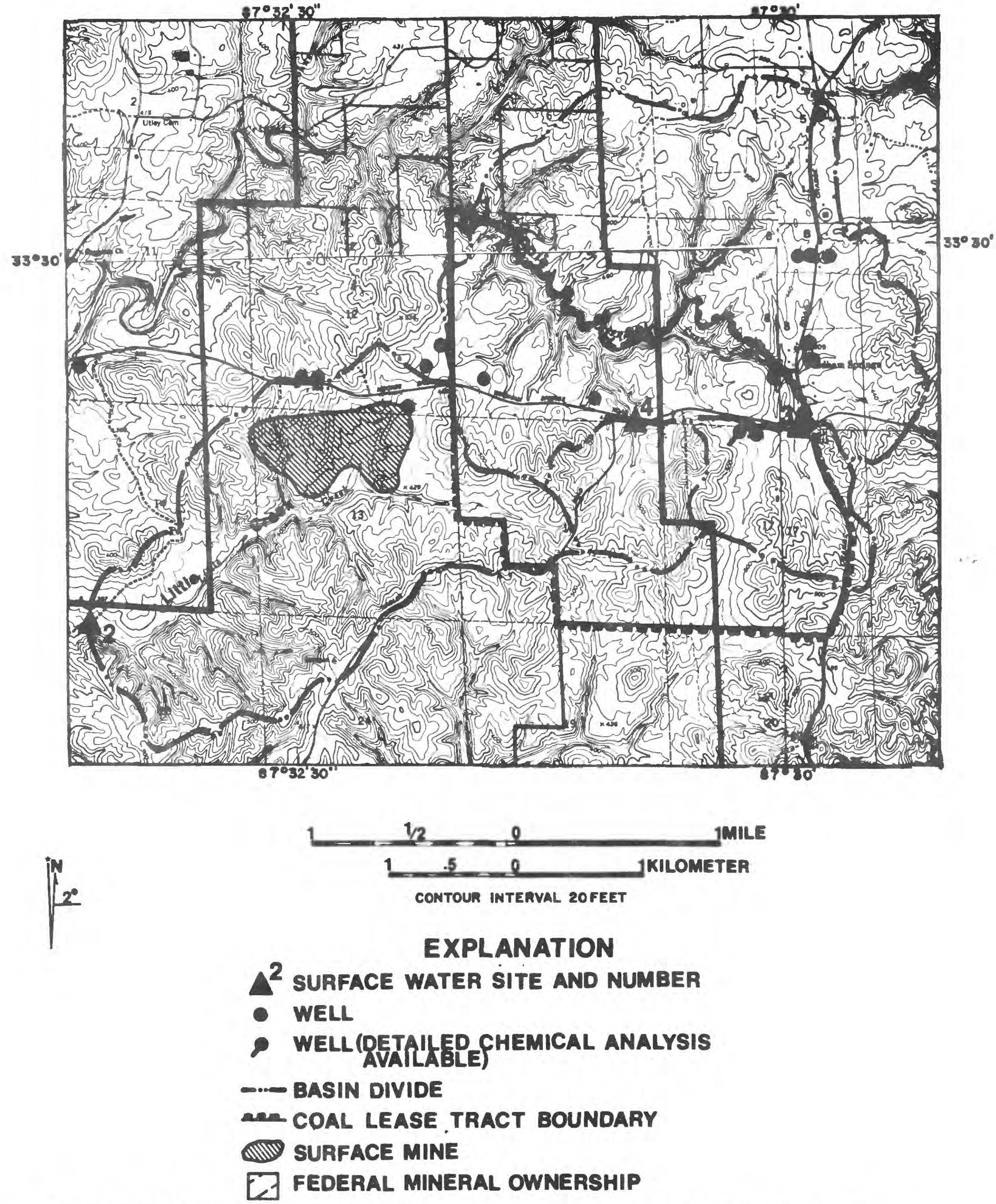
The Pottsville Formation is the principal source of ground water in the tract. In the southern part, the Coker Formation is a minor source of ground water. Water-bearing characteristics, well depths, water levels, yields, and water quality are expected to be similar to those described for unmined areas in the previous tract assessments.

All streams within the tract are intermittent. Streamflow characteristics and variability are also expected to be similar to those described in previous assessments. Basin characteristics including estimates of low flow and flood flow for select sites draining the tract (fig. 13) are given in table 1. Sites 1, 3, and 4 drain undisturbed areas, but site 2 on Little Creek receives drainage from surface mined areas west of the tract (fig. 13).

Water at sites 1, 3, and 4 is expected to be of good quality being similar to that described in unmined basins in previous assessments. Water at site 2 draining mined areas is expected to be significantly mineralized. Estimates of ranges in physical properties and concentrations of chemical constituents expected are given in tables 3 and 4.

Verification

An inventory of 18 wells in and adjacent to the tract was made in May 1980. The wells tap the Pottsville Formation and range in depth from 22 to 270 feet. Measured depths to water levels ranged from 6 to 14 feet. Information pertaining to well yields was not available.



Base from U.S. Geological Survey Lake Tuscaloosa North, AL., 1:24,000, 1978; Berry SE, AL., 1:24,000, 1967; Windham Springs, AL., 1:24,000, 1974; and Wiley, AL., 1:24,000, 1951.

Figure 13.—Dry Creek North Tract and data collection sites.

Water quality information obtained to verify assessments included selected field determinations for all wells and a detailed chemical analysis for one well (well 1, fig. 13). Based on field determinations, specific conductances ranged from 85 to 582 umhos and pH ranged from 5.4 to 8.7 units. Values of pH less than 6.0 units were obtained from wells at depths of 33 feet or less. Bicarbonate concentrations ranged from 8 to 280 mg/L. Bicarbonate concentrations less than 100 mg/L and specific conductances less than 150 umhos were generally from wells at depths less than 100 feet. A detailed chemical analysis for well 1 with a depth of 91 feet and a reported water level of 30 feet showed dissolved calcium and magnesium concentrations of 14 and 9.2 mg/L and dissolved iron and manganese concentrations of 1500 and 210 ug/L, respectively. Based on the data obtained, the ground-water assessment in the tract was reasonably accurate.

Selected chemical and physical characteristics of water in streams draining the tract during April 1980 are given in tables 3 and 4. Determinations for sites 1, 3, and 4 draining undisturbed areas were generally well within estimated ranges (table 3). Water at site 2 draining mined areas was slightly less mineralized than expected. The pH and hardness were within estimated ranges, but specific conductance and dissolved solids concentrations were about 12 percent (22 umhos and 10 mg/L, respectively) less than estimates made for comparable flows of 5.0 ft^3/s. Observed and estimated sulfate concentrations were nearly the same. A point estimate of specific conductance, based on the measured discharge of 7.0 ft^3/s at site 2, was 150 umhos or about 5 percent (8 umhos) less than the observed specific conductance. The total recoverable iron concentration was within the estimated range, but the total recoverable manganese concentration exceeded the estimated range. The water-quality assessment for streams draining the tract appear to be reasonably accurate.

IMPACTS OF FUTURE MINING

Future mining in the tracts assessed will affect existing hydrologic conditions. The effects, some of which are discussed in preceding parts of this report, are declines in ground-water levels, creation of spoil aquifers, changes in streamflow characteristics, increased erosion and sedimentation, and increases in mineralization of ground water and surface water. The increase in mineralization of surface water is the most significant because surface water will flow to receiving streams outside mining areas. It is also the only hydrologic change for which sufficient data are available to quantitatively predict the degree of change.

Ground Water

The intersection of a surface mine with water-bearing openings results in draining of the openings and a corresponding decline in water level adjacent to the mine. Where the openings intersected by the mine are tapped by nearby wells, the decline can result in dewatering of the wells or in smaller available yields. The declines can be short-term (recovering or partially recovering after mining), or they can be permanent (Knight and Newton, 1977). The declines generally are restricted to the immediate vicinity of the mines and their magnitude decreases with distance from the mine.

Surface mining will remove large segments of the Pottsville Formation and, in many areas, will disrupt Pottsville aquifers. These segments will be replaced by broken spoil material that will become spoil aquifers. Spoil aquifers may be created where no Pottsville aquifer occurred. Based on available information and observation, spoil aquifers are expected to store and transmit larger quantities of water than the original aquifers. Water moving through leached spoil commonly becomes highly mineralized and may be transmitted to underlying aquifers as recharge or to streams as base flow.

Degradation of ground-water quality is expected where mines are sources of recharge to underlying aquifers. Sources of recharge include settling ponds or other impoundments, ponded water on mine floors, and spoil drainage. The mineralization will be characterized by increases in hardness, dissolved solids, and sulfate concentrations. Noncarbonate hardness is expected to approach or exceed 50 percent of the total hardness and large increases in dissolved iron and manganese (exceeding 300 and 50 ug/L, respectively) concentrations will probably occur. Recharge from mined areas to Pottsville aquifers may be acidic or alkaline depending on the chemistry of rocks in mines. Where the recharge is acidic, it is generally neutralized by calcareous minerals in the subsurface and the alkalinity of natural ground water in the Pottsville Formation.

The degradation of ground-water quality is usually restricted to the general vicinity of mining areas. The degree of mineralization is expected to decrease with distance from the mine due to increased mixing with recharge from undisturbed areas. The movement of most of the mineralized ground water is expected to be downdip (south or southwest); however, the movement can be in any direction where water-bearing fractures, joints, or faults are present that penetrate impermeable strata. Because most mining in the tracts will be on elevated hillslopes, a significant amount of the impacted water will probably discharge eventually as base flow to nearby streams.

Surface Water

Impacts of mining on streamflow characteristics are difficult to assess. Streamflow is generally influenced by mining procedures and reclamation practices because spoil aquifers and mine impoundments result in increased water storage. During period of little precipitation, the augmentation to base flow from this storage results in low flows that exceed those prior to mining, and periods of no flow will be shorter. Base flow augmentation may vary from near zero to 10 ft^3/s depending on the location and method of mining, spoil area size and distribution, and number of impoundment in the mine.

Effects of mining on floods will probably vary with the magnitude of flood flows. The timing response and volume of the 2-year flood (Q_2) is expected to increase initially as a result of vegetation removal. The increase in the volume of flow however, is expected to be short term and to rapidly decrease to or below the premining Q_2 because of revegetation and increased infiltration due to the creation of spoil aquifers. Effects of mining and reclamation on the 25-, 50-, and 100-year floods will probably be negligible because of the magnitude of the floods.

The water in streams receiving surface mine drainage will become more mineralized in a relatively short period of time. It will become moderately hard to very hard and change from a calcium-magnesium-bicarbonate type water to a magnesium-sulfate type water. Ranges in physical properties and chemical constituents, based on all available analyses of water in streams draining mined areas in the Warrior coal field, are expected to be:

specific conductance:	100-3,000 umhos
pH:	2.5-8.8 units
sulfate:	15-1,800 mg/L
hardness ($CaCO_3$):	50-1,800 mg/L
noncarbonate hardness:	20-1,800 mg/L
bicarbonate:	0-450 mg/L
dissolved solids:	60-2,000 mg/L

Water affected by mine drainage may become more acidic or more alkaline depending on the chemistry of the rocks disturbed. Calcareous minerals occur in significant quantities in many areas. Acidic mine drainage will probably occur if water has long residence time in mine areas with limited calcareous minerals. Locally, large increases in iron and manganese concentrations are expected to occur. Aeration of mine drainage in streams, however, causes the formation of insoluble iron and manganese precipitates called "Yellow Boy" in the streambed near the mined area. Dissolved manganese concentrations are expected to remain relatively high in acidic or near neutral mine drainage. Sorption of iron and manganese precipitates on stream sediments will result in increased total recoverable iron and manganese concentrations.

Water-quality changes may become readily apparent within months after mining starts. The degree of degradation will continue to increase for about 8 to 10 years after mining begins, and will gradually decrease after that period. Barring other disturbance in the mined area, water in streams will gradually become less mineralized and eventually approach its original quality after many years.

Surface mining activities also degrade water quality by exposing large volumes of soil and overburden that are subject to erosion and transport by surface runoff. Annual sediment yields may increase from a natural range of 20 to 800 (tons/mi^2)/y to 1,000 to 20,000 (tons/mi^2)/y without preventative measures. The expected increase in sediment yield can occur soon after mining is initiated.

Water Quality Projections

Future water-quality changes in streasms draining mined areas may be estimated by using the equation for estimating specific conductance given in figure 4 and the equations given in table 2. Estimates may be made under various conditions imposed by the user. These conditions include variable mining progression rates, the amount of streamflow draining from mined areas, the downstream distance between sampling point and mined areas, and the mine age. The following example is given to illustrate the use of the equation for estimating specific conductance (fig. 4) and for estimating hardness and the sulfate and dissolved solids concentrations (table 2).

The example is a new surface mining operation in a small basin with a drainage area (A) of 3.0 mi^2. The rate of mining is expected to be 100 acres (0.156 mi^2) per year for 5 years. The problem is to estimate the specific conductance and the hardness, sulfate, and dissolved solids concentrations in water in a stream draining the area for the following time frames and conditions:

(1) at the start of mining and 2, 5, 10, and 15 years after mining is initiated,
(2) at a constant streamflow (Q) of 1.0 cubic foot per second, and
(3) at a downstream sampling distance (CL) of 0.5 mile.

The estimating procedure is as follows:

(1) determine unit area discharge (Q/A),
(2) determine percent basin mined, PBM=(Area disturbed/A) X100,
(3) select mine age factor (MAF) based on relative mine age,
(4) use downstream sampling distance (CL) directly,
(5) enter above values into the equation (fig. 4) and compute specific conductance values,
(6) computed specific conductance values are entered into equations 1, 2, and 3 in table 2 for computation of sulfate, hardness, and dissolved-solids concentrations.

The equations in table 2 have been reduced to graphical form as shown in figures 4, 5, 6, and 7, respectively. To illustrate the use of the curves, the dotted lines on the figures correspond to estimated values after 2 years of mining using data in the preceding example.

$$Q/A = \frac{1.0\ 10\ ft^3/s}{3.0\ mi^2} = 0.33\ (ft^3/s)/mi^2$$

$$PBM = \frac{\text{Area disturbed}}{A} X100 = \frac{0.31\ mi^2}{3.0\ mi^2} X100 = 10 \text{ percent}$$

$$CL = 0.5 \text{ mi}$$

$$MAF = 3. \text{ based on mine age of 2 years.}$$

Enter in figure 4 (Q/A) along bottom scale. Move upward to the PBM curves to 10. Move horizontally to the CL curves to 0.5. Move downward to the MAF curves to 3. Move horizontally to the specific conductance scale. The following results were obtained for this example:

from figure 4, specific conductance = 240 umhos,
from figure 5, sulfate = 85 mg/L,
from figure 6, hardness = 92 mg/L, and
from figure 7, dissolved solids = 155 mg/L.

A summary of the problem conditions and estimated water quality parameters is given in table 5.

The preceding methodology can also be utilized to make similar estimates where a new mine is located in a basin in which another mine exists. In this instance, based on the previous example,

Q/A - would remain the same,
PBM - would be the total area disturbed by both mines at a given time,
CL - would be the average distance of both mines from the sampling site, and
MAF - would be computed by weighting the MAF's and areas disturbed by the respective mines to the total area disturbed. For instance, if 50 percent of the area disturbed has a MAF of 10 and 50 percent has a MAF of 2, the MAF used for both would be 6.

SUMMARY AND CONCLUSIONS

Federal coal reserves underlie approximately 70,500 acres in the Warrior coal field. Most of the acreage is disseminated in small parcels in the Warrior coal field. In anticipation of mining these reserves, numerous tracts have been delineated for potential leasing. Assessing hydrologic conditions in tracts, because of their dissemination in a broad area and the limited time and data available, requires some predictive capability. This capability, resulting from other coal studies, requires some verification.

Physical settings of tracts assessed are similar to each other and to most other areas in the Warrior field. This is due to similarities in topography and drainage, land use, climate, and for the most part, geology. Four widely separated tracts located in the outcrop of three different coal groups were selected to assure that findings were regional in scope.

Almost all surface coal mine areas in the Warrior field are underlain by relatively impermeable rocks in the Pottsville Formation that, with the similar physical settings, results in similar aquifer and streamflow characteristics. The Pottsville is the source of water for most wells but does not generally yield large supplies. Most yields are less than 10 gal/min. Most streams have poorly-sustained low flows. Streamflow recedes from sharply concentrated flood peaks to low flows, or to no flow between storms. Average annual streamflow generally ranges from 1.5 to 1.7 $(ft^3/s)/mi^2$. The quality of ground water and surface water in unmined areas is generally good. Surface coal mining, including mining in some of the tracts selected for study, has effected hydrologic conditions to some degree.

Climatic, physiographic, hydrologic, and land-use data for 67 basins in the Warrior field were analyzed by regressions to derive relations for assessing water quality in streams draining mined and unmined areas. In this approach, an equation was developed to estimate specific conductance. Additional equations, based on relations between specific conductance and other constituents, allow estimates of mine drainage indicators such as hardness, dissolved solids, and sulfate concentrations. Streamflow characteristics were estimated utilizing existing methodology and estimates of ground-water availability and quality were based on local and regional assessments of available data.

Assessments of the hydrology of the four tracts studied, based on limited verification data, proved to be reasonably accurate. Almost all ground-water quality determinations obtained during the verification phase of the study fell within estimated ranges. Most determinations outside estimated ranges were close and were for very shallow wells. Data were not available to verify predicted yields. Similarly, almost all surface-water quality data obtained fell within estimated ranges based on variations in discharge. These data were for mined and unmined subbasins. Estimated changes in streamflow characteristics could not be verified because of the long period of record required.

Hydrologic changes that will result from future mining of the tracts include declines in water levels, creation of spoil aquifers, changes in streamflow characteristics, increased erosion and sedimentation, and degradation of ground-water and surface-water quality. Methodology developed using available data allows estimates of future degradation of surface-water quality, the most important hydrologic change because it extends outside of the mined areas. The methodology utilized is the same as that used to make projections for mined areas in tracts studied. The magnitude of most changes other than surface-water quality cannot be estimated prior to mining.

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Table 1.--Basin characteristics, low flow, and flood magnitudes for selected small streams draining coal-lease tracts

Tract	Site number	Streamflow recession index (days/log cycle)	Mean annual precipitation (inches)	Drainage area (mi^2)	Channel slope (ft/mi)	Estimated low flow (ft^3/s) $7Q_2$	Estimated low flow (ft^3/s) $7Q_{10}$	Flood magnitudes recurrence interval in years (ft^3/s) 2	50	100
Wolf Creek 1/	1	32	56	1.52	83	0	0	347	930	1060
	3	32	56	.81	154	0	0	267	630	707
	4	32	56	.90	96	0	0	256	645	733
	6	32	56	2.22	95	0	0	457	1240	1420
Pendley 2/	1	32	56	.25	286	0	0	145	290	315
	2	32	56	1.97	112	0	0	440	1160	1320
	3	32	56	1.31	108	0	0	335	860	975
	4	32	56	1.80	90	0	0	395	1060	1210
	5	32	56	.65	159	0	0	235	540	600
Flatwoods 3/	1	32	56	.82	145	0	0	266	630	710
	2	32	56	.58	90	0	0	190	465	530
	3	32	56	3.52	47	0	0	520	1610	1870
	4	32	56	1.73	81	0	0	375	1020	1160
	5	32	56	4.25	111	0	0	720	2030	2310
Dry Creek	1	32	54	3.43	47	0	0	512	1580	1830
North 4/	2	32	54	2.47	76	0	0	464	1310	1500
	3	32	54	.51	123	0	0	188	440	494
	4	32	54	.45	182	0	0	190	418	467

1/ Location of sites shown on figure 10.
2/ Location of sites shown on figure 11.
3/ Location of sites shown on figure 12.
4/ Location of sites shown on figure 13.

Table 2.--Regression equations and variables for selected water quality parameters

Equation number	Equation	R [1]	Standard error[2] (percent)	Range of dependent variable: Variable	Range of dependent variable: Range	Range of independent variable: Variable	Range of independent variable: Range	Dependent Variable	Independent variable	N [3]
				STREAMS DRAINING MINED AREAS						
1	$SO4 = 0.10\ SP.\ COND.^{1.23}$	0.989	17	SO4	4.5-1300	SP. COND.	40-2160	SO4 = Dissolved sulfate concentration in mg/L.	SP. COND. = Specific conductance, in micromhos per centimeter at 25°C.	94
2	$HD = 0.20\ SP.\ COND.^{1.12}$	.989	16	HD	9-1400	SP. COND.	34-2160	HD = Hardness as calcium, magnesium, carbonate, in mg/L.	........do..........	75
3	$DS = 0.57\ SP.\ COND.^{1.02}$	.992	11	DS	23-1060	SP. COND.	34-1410	DS = Dissolved solids concentration, in mg/L.	........do..........	55
4	$FE = 97.10\ SS^{0.73}$	.931	74	FE	350-160,000	SS	12-44,500	FE = Total recoverable iron concentration, in ug/L.	SS = Suspended-sediment concentration, in mg/L.	18
5	$MN = 29.00\ SS^{0.47}$	.870	70	MN	70-6100	SS	9-44,500	MN = Total recoverable manganese concentration, in ug/L.	........do..........	15
				STREAMS DRAINING UNMINED AREAS						
6	$SO4 = 0.19\ SP.\ COND.^{0.92}$	.861	45	SO4	0.2-31	SP. COND.	8-290	SO4 = Dissolved sulfate concentration in mg/L.	SP. COND. = Specific conductance, in micromhos per centimeter at 25°C.	136
7	$HD = 0.19\ SP.\ COND.^{1.11}$	.929	37	HD	1.0-150	SP. COND.	8-290	HD = Hardness as calcium, magnesium, carbonate, in mg/L.	........do..........	138
8	$DS = 0.83\ SP.\ COND.^{0.94}$	.964	24	DS	4-153	SP. COND.	9-290	DS = Dissolved solids concentration, in mg/L.	........do..........	29
9	$FE = 99.34\ SS^{0.64}$	.815	58	FE	270-11,000	SS	10-792	FE = Total recoverable iron concentration, in ug/L.	SS = Suspended-sediment concentration, in mg/L.	39
10	$MN = 7.06\ SS^{0.52}$	.800	46	MN	10-280	SS	12-792	MN = Total recoverable manganese concentration, in ug/L.	........do..........	37

1/ R - Correlation coefficient.
2/ Standard error expressed in terms of percent of mean of dependent variable.
3/ N - Number of data observations for each regression.

Table 3.--Estimated and observed water quality characteristics for selected small streams draining coal lease tracts

Tract	Site number	Percent basin mined	Estimated: pH (units)	Estimated: Specific conductance (umhos)	Estimated: Hardness as $CaCO_3$ (mg/L)	Estimated: Sulfate (mg/L)	Estimated: Dissolved solids (mg/L)	Observed: Discharge (ft^3/s)	Observed: pH (units)	Observed: Specific conductance (umhos)	Observed: Hardness as $CaCO_3$ (mg/L)	Observed: Sulfate (mg/L)	Observed: Dissolved solids (mg/L)
Wolf Creek 1/	1	22	5.5-7.5	230-520	90-220	80-220	150-340	0.36	7.4	670	330	220	438
	3	0	5.5-7.5	20-200	5-75	3-70	14-130	.34	7.3	139	48	36	80
	4	0	5.5-7.5	20-90	5-30	3-12	14-56	1.11	7.3	58	15	6.8	26
	6	0	5.5-7.5	20-90	5-30	3-12	14-56	.18	6.7	45	9	10	31
Pendley 2/	1	0	6.0-7.8	20-90	5-30	3-12	14-56	.03	6.9	44	14	13	36
	2	4	6.0-7.8	75-170	25-64	20-56	46-110	1.80	6.8	112	44	40	72
	3	32	5.8-7.8	320-740	130-320	120-330	210-430	1.50	7.4	521	250	210	336
	4	20	5.8-7.8	190-460	72-190	64-190	120-300	1.50	6.8	406	180	190	273
	5	0	6.0-7.8	20-90	5-30	3-12	14-56	.72	7.1	24	8	5.3	26
Flatwoods 3/	1	0	6.0-7.5	20-80	5-27	3-11	14-48	1.8	6.3	16	4	3.0	---
	2	40	5.5-7.5	120-300	42-120	35-110	70-200	.81	6.0	60	18	16	36
	3	15	5.5-7.5	120-270	42-100	35-100	70-170	6.68	6.0	34	10	9.8	26
	4	12	5.5-7.5	180-450	64-190	60-190	110-280	4.28	6.7	31	9	7.7	24
	5	0	6.0-7.5	20-80	5-27	3-11	14-48	5.81	6.5	24	7	4.0	22
Dry Creek North 4/	1	0	5.5-7.5	20-80	5-27	3-11	14-48	10.1	7.0	21	6	3.9	---
	2	13	5.0-7.5	180-450	66-190	60-180	115-290	7.0	7.2	158	70	58	105
	3	0	5.5-7.5	20-80	5-27	3-11	14-48	.82	6.4	23	9	3.9	22
	4	0	5.5-7.5	20-80	5-27	3-11	14-48	1.48	6.5	17	6	3.4	---

Estimated values: physical and major dissolved constituents at 5.0 and 0.5 ft^3/s.

1/ Locations of sites shown on figure 10.
2/ Locations of sites shown on figure 11.
3/ Locations of sites shown on figure 12.
4/ Locations of sites shown on figure 13.

Table 4.--Estimated and observed total recoverable iron and manganese concentrations for selected small streams draining coal lease tracts

Tract	Site number	Percent basin mined	Annual suspended sediment yield range $(tons/mi^2)/y$	Estimated Total recoverable trace element concentration ranges in ug/L at suspended-sediment concentration of 10 and 1000 mg/L: iron		manganese		Stream discharge (ft^3/s)	Suspended sediment concentration (mg/L)	Observed Total recoverable trace element concentration (ug/L): iron	Manganese
Wolf Creek 1/	1	22	500-3000	200-1200	6000-40,000	50-500	400-1500	1.67	6	220	340
	3	0	500-3000	200-1200	4000-15,000	10-50	120-600	.34	4	250	10
	4	0	100-700	200-1000	4000-15,000	10-50	120-600	1.10	4	390	20
	6	0	50-600	200-1000	4000-15,000	10-50	120-600	.18	6	700	20
Pendley 2/	1	0	50-400	200-1000	4000-15,000	10-50	120-160	.03	4	440	10
	2	4	400-1000	200-1200	6000-40,000	50-500	400-1500	1.80	9	330	20
	3	32	500-2000	200-1200	6000-20,000	50-500	400-1500	1.50	7	240	1400
	4	20	300-1500	200-1200	6000-40,000	50-500	400-1500	1.50	28	750	2500
	5	0	50-400	200-1000	4000-15,000	10-50	120-600	.72	5	280	10
Flatwoods 3/	1	0	300-1000	200-1000	400-15,000	10-50	120-600	1.80	5	220	40
	2	40	1000-5000	200-1200	6000-40,000	50-500	400-1500	.81	9	260	460
	3	15	1000-5000	200-1200	6000-40,000	50-500	400-1500	6.68	15	650	440
	4	12	1000-8000	200-1200	6000-40,000	50-500	400-1500	4.28	11	640	530
	5	0	50-400	200-1000	4000-15,000	10-50	120-600	5.81	5	480	60
Dry Creek North 4/	1	0	150-800	200-1200	4000-15,000	10-50	120-600	10.1	5	410	20
	2	13	800-5000	200-1200	6000-40,000	50-500	400-1500	7.00	9	730	1600
	3	0	100-700	200-1000	4000-15,000	10-50	120-600	.82	2	610	30
	4	0	50-400	200-1000	400-15,000	10-50	120-600	1.50	1	340	20

1/ Locations of sites shown on figure 10.
2/ Locations of sites shown on figure 11.
3/ Locations of sites shown on figure 12.
4/ Locations of sites shown on figure 13.

Table 5.-- Estimated water quality parameters in a hypothetical stream draining a mined area

Mining progression (years)	Given				Estimated			
	Q/A 1/ $(ft^3/s)/mi^2$	PBM 2/ (percent)	CL 3/ (mi)	MAF 4/ (unit)	Specific conductance (umhos)	Hardness (mg/L)	Sulfate (mg/L)	Dissolved solids (mg/L)
0	0.33	0	0.5	--	50 5/	16	7	32
2	.33	10	.5	3	240	93	85	153
5	.33	26	.5	15	770	342	355	501
10	.33	26	.5	19	860	387	407	561
15	.33	26	.5	3	360	146	139	231

1/ Discharge per unit area.
2/ Percent of basin mined.
3/ Channel length.
4/ Mine age factor.
5/ Estimate based on data for streams draining undisturbed areas.