A PROCEDURE FOR PREDICTING CONCENTRATIONS OF DISSOLVED SOLIDS AND SULFATE ION IN STREAMS DRAINING AREAS STRIP MINED FOR COAL

U.S. GEOLOGICAL SURVEY

WATER-RESOURCES INVESTIGATIONS

OPEN-FILE REPORT 80-764

Prepared in cooperation with the

Kansas Department of Health and Environment

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

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ABSTRACT

Current trends in increased coal production neccessitate the development of techniques to appraise the environmental degradation that results from strip mining. A procedure is introduced for the prediction of dissolved-solids and sulfate-ion concentrations in streams draining strip-mined areas as functions of the percentage of the drainage area that has been strip mined. These relationships are expressed by regression equations computed from data collected in streams draining strip-mined areas of Cherokee and Crawford Counties in southeast Kansas.

INTRODUCTION

The current shortage of petroleum resources is resulting in an increased demand for coal production to supply the energy requirements of industry and to generate electrical power. Coal production in Kansas reflects this trend.

Annual Kansas coal production peaked at approximately 7.0 million tons in 1917 and 1918 (Pierce and Courtier, 1937, p. 84). By 1975, annual production had declined to approximately 0.5 million tons due to concurrent increases in natural gas and petroleum production. In 1978, 19 permits for strip mining coal at 12 active mines, covering 1,077 acres in Cherokee, Crawford, Bourbon, Miami, and Linn Counties of southeast Kansas, were issued by the Kansas Mined Land Reclamation Board (Kansas Department of Health and Environment, 1979, p. III-14). Annual Kansas coal production is expected to increase to approximately 2.5 million tons by the early 1980's (Keystone Coal Industry Manual, 1978, p. 496-500).

Strip mining for coal often results in serious environmental degradation that includes contamination of streams draining the mined areas with increased concentrations of dissolved solids and sulfate ion. The purpose of this report is to present predictive equations relating the extent of strip mining in a drainage area to the stream contamination as evidenced by increased concentrations of dissolved solids and sulfate ion.

There are approximately 50,000 acres of abandoned strip mines in five counties of southeast Kansas. Previous reports of water-quality investigations in this area concluded that streams draining the strip-mined areas are contaminated by acid and iron compounds (Bailey, 1911, p. 349-361; and Metzler and others, 1958).

The water quality in streams draining strip-mined areas in Cherokee and Crawford Counties (fig. 1) is being investigated by the U.S. Geological Survey in cooperation with the Kansas Department of Health and Environment. Data are being collected at sites (figs. 2, 3, and 4) within the drainage basins of Lightning Creek, Deer Creek, Cherry Creek, and Cow Creek. Data from these sites, listed in table 1, were used to develop the relations in this report.

CONVERSION FACTORS

Factors for converting inch-pound units, used in this report, to the International System (SI) of Units and the respective abbreviations are given below:

Inch-pound units	Multiply by	SI units
acre	4.047×10^{-1}	square hectometer (hm^2)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
ton, short	9.072×10^{-1}	megagram (Mg)

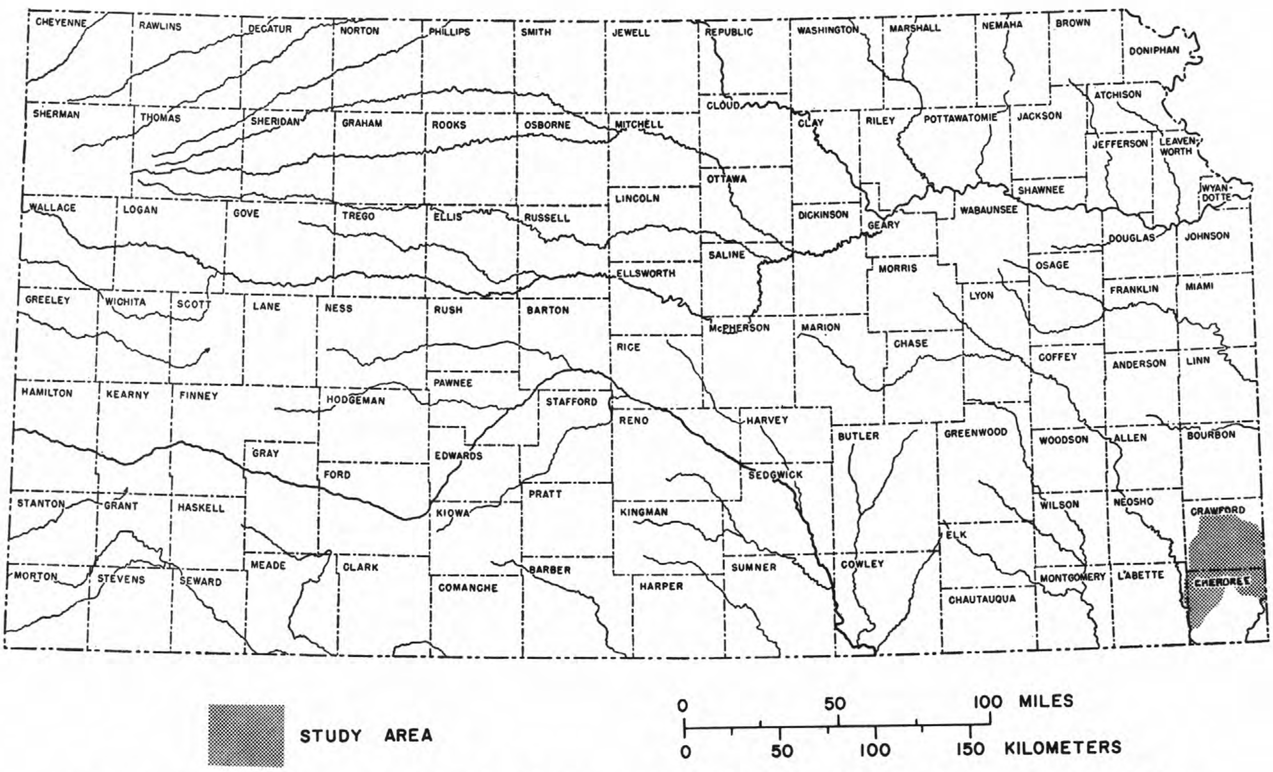

Figure 1.--Map of Kansas showing geographic location of the study area.

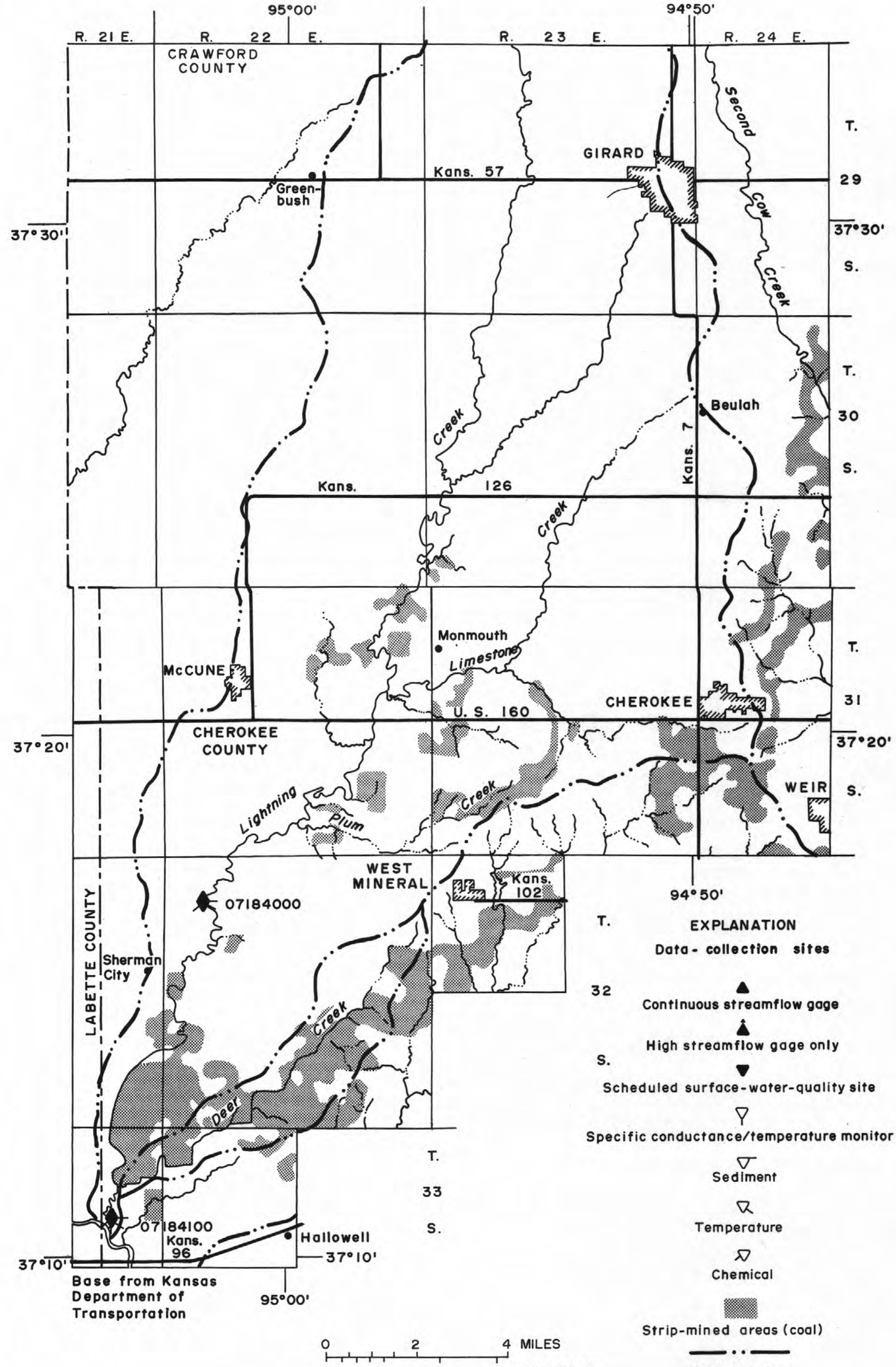

Figure 2.--Locations of data-collection sites in the Lightning Creek drainage basin.

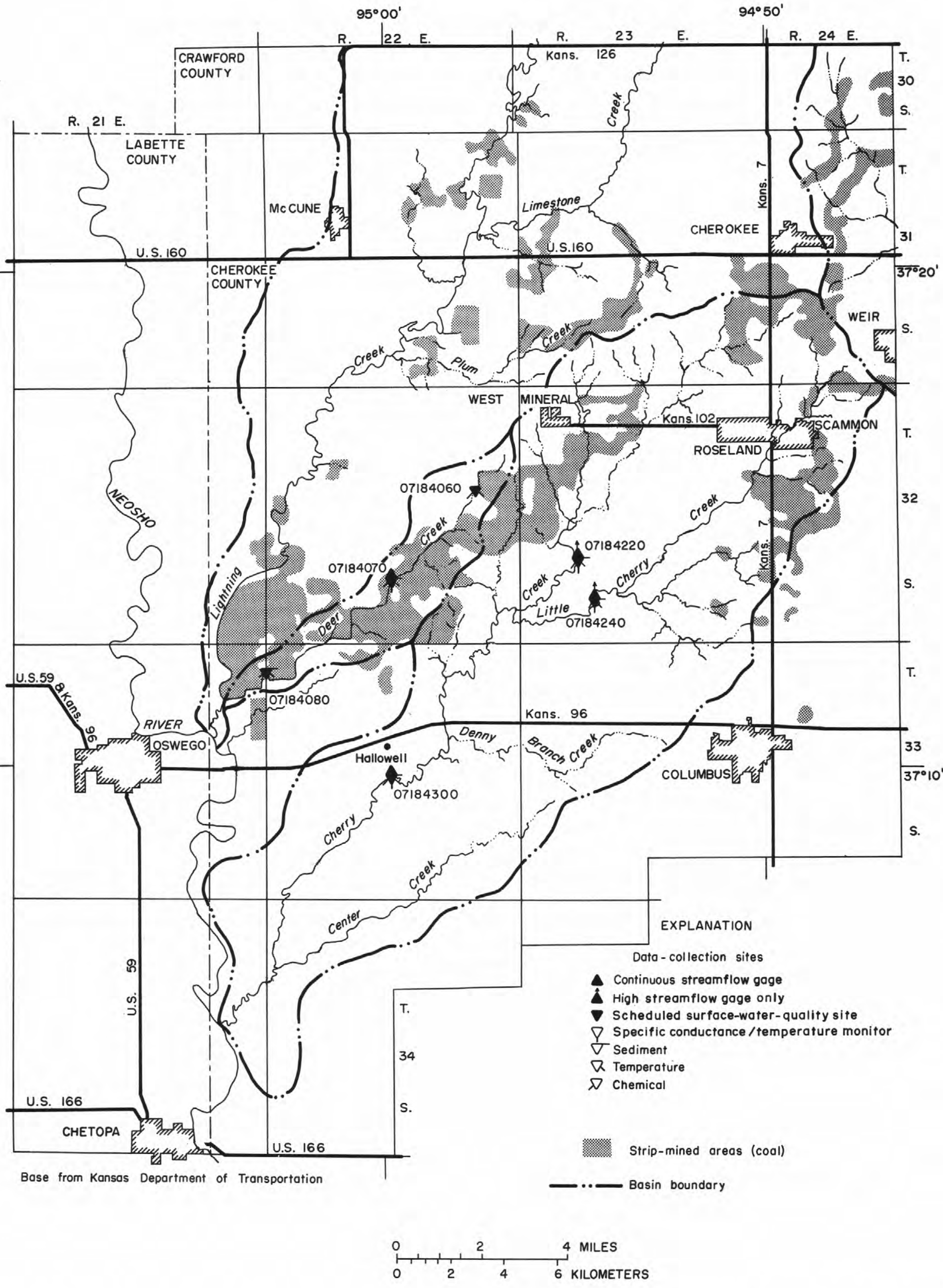

Figure 3.--Locations of data-collection sites in the Deer Creek and Cherry Creek drainage basins.

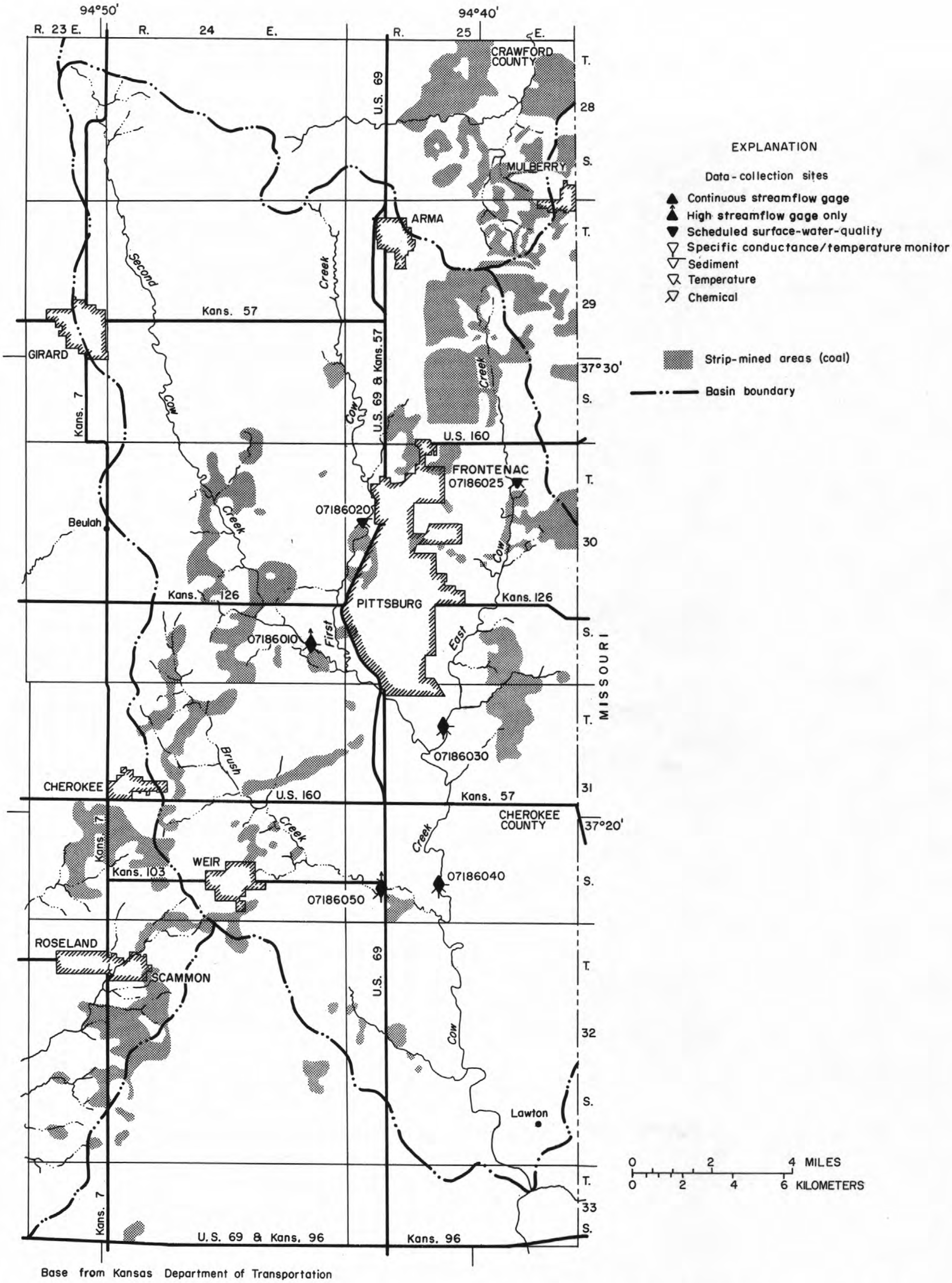

Figure 4.--Locations of data-collection sites in the Cow Creek drainage basin.

Table 1.--Data-collection sites located in the study area

Station no.	Station name
07184000	Lightning Creek near McCune, Kansas
07184060	Deer Creek near West Mineral, Kansas
07184070	Deer Creek near Hallowell, Kansas
07184080	Deer Creek near Oswego, Kansas
07184100	Lightning Creek near Oswego, Kansas
07184220	Cherry Creek near West Mineral, Kansas
07184240	Little Cherry Creek near West Mineral, Kansas
07184300	Cherry Creek near Hallowell, Kansas
07186010	Second Cow Creek at Pittsburg, Kansas
07186020	First Cow Creek at Pittsburg, Kansas
07186025	East Cow Creek at Frontenac, Kansas
07186030	East Cow Creek near Pittsburg, Kansas
07186040	Cow Creek near Weir, Kansas
07186050	Brush Creek near Weir, Kansas

CONTAMINATION OF STREAMS DRAINING AREAS STRIP MINED FOR COAL

Contamination of streams draining strip-mined areas generally results from overland rainfall runoff or ground-water seepage contacting iron-sulfur compounds or minerals and introducing deleterious chemicals into solution. Iron-sulfide minerals, primarily pyrite and marcasite, exposed in spoil piles and high walls of strip pits, react with water and oxygen as follows:

$$2FeS_2 + 7O_2 + 2H_2O \rightarrow 2FeSO_4 + 2H_2SO_4 . \qquad (1)$$

The iron is then oxidized from the ferrous to the ferric state:

$$4FeSO_4 + O_2 + 2H_2SO_4 \rightarrow 2Fe_2(SO_4)_3 + 2H_2O . \qquad (2)$$

Hydrolysis occurs, and ferric hydroxide is precipitated as a reddish-brown deposit commonly called "yellow boy":

$$Fe_2(SO_4)_3 + 6H_2O \rightarrow 2Fe(OH)_3\downarrow + 3H_2SO_4 . \qquad (3)$$

Reactions involving pyrite and marcasite in areas below the zone of saturation, where dissolved oxygen is minimal, could be reduction reactions as suggested by the following equation (Barnes and Clarke, 1964):

$$FeS_2 + 8H_2O \rightarrow Fe^{+2} + 2SO_4^{-2} + 2H^{+1} + 7H_2 . \qquad (4)$$

These reactions show that the concentration of sulfate ion in streams draining strip-mined areas is a principal indicator of chemical erosion resulting from strip-mining activities. Water-quality data collected from 1976 through 1978 in Cherokee and Crawford Counties, published in U.S. Geological Survey Water Resources Data for Kansas, show that high concentrations of dissolved solids, predominantly sulfate ion, are present during periods of low streamflow. During these periods, all or most of the flow is provided by groundwater seepage. As streamflow increases, due to rainfall runoff, the concentrations of dissolved solids and sulfate ion decrease significantly (figs. 5 and 6). This dilution effect indicates that the streams are being ion enriched by ground water in which reduction reactions, such as that shown in equation 4, may be dominant.

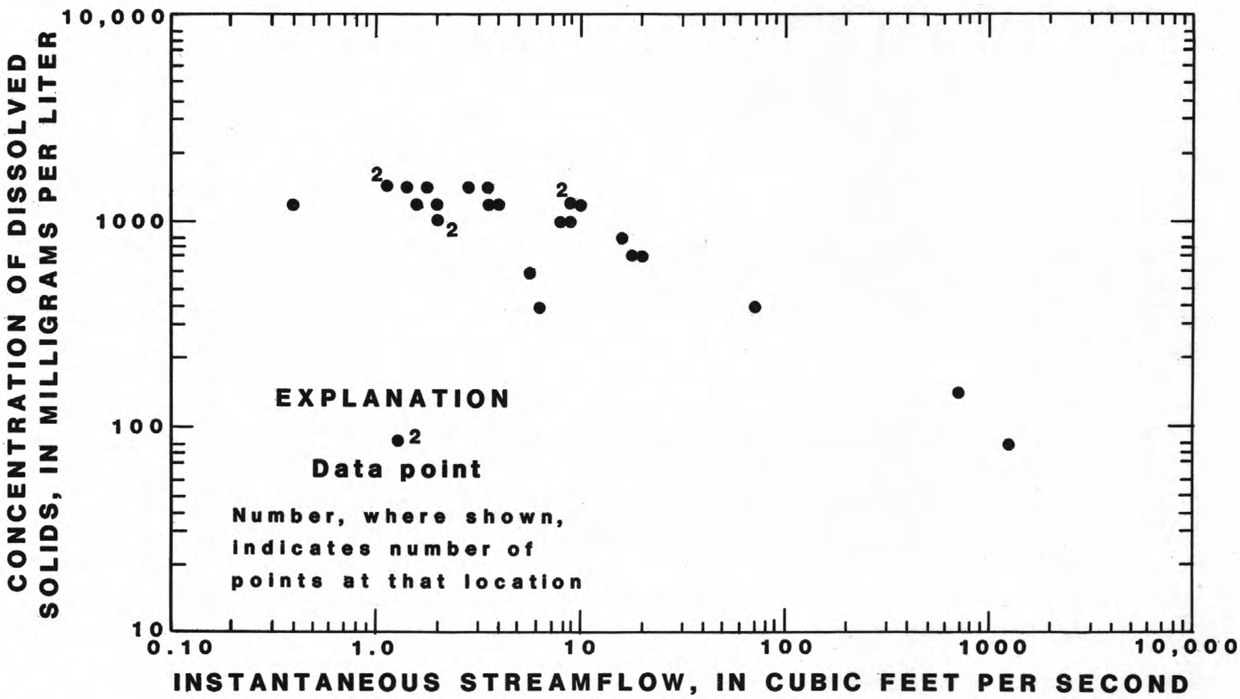

Figure 5.--Relation of instantaneous streamflow to concentration of dissolved solids in Little Cherry Creek near West Mineral, Kansas (07184240).

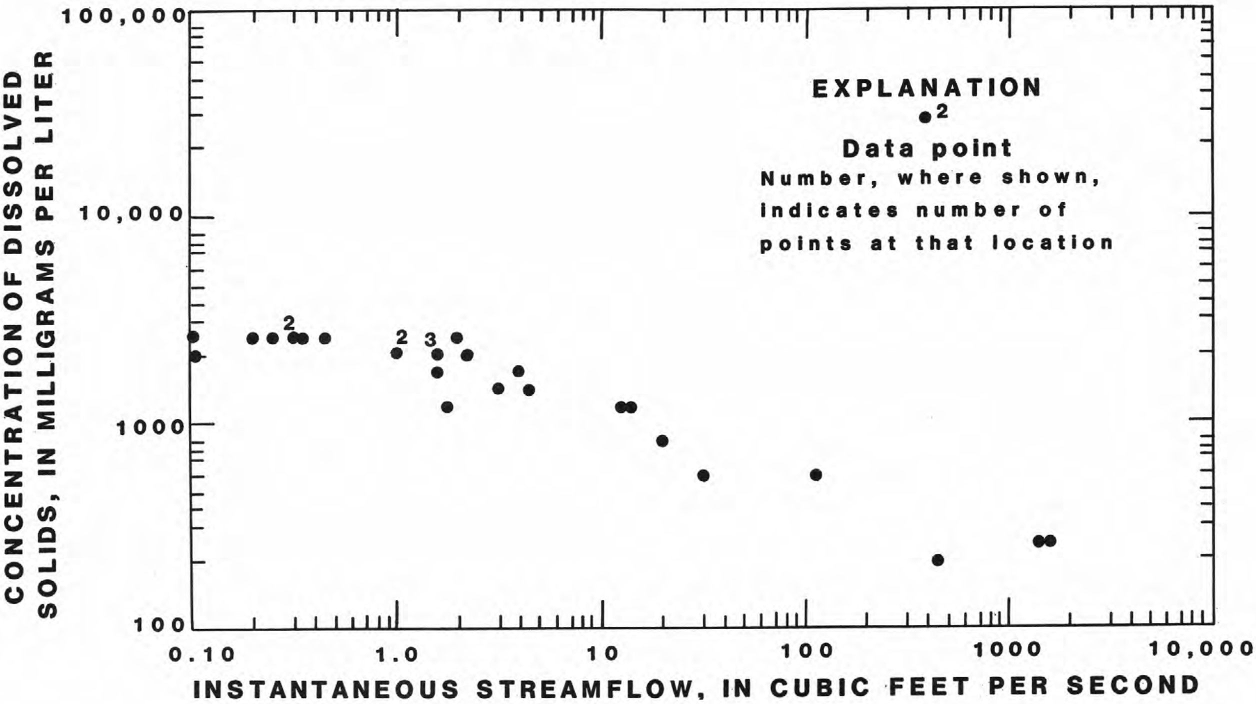

Figure 6.--Relation of instantaneous streamflow to concentration of dissolved solids in Cherry Creek near West Mineral, Kansas (07184220).

In the study area, strip mining was confined mainly to stream valleys because less overburden needed to be removed. In some parts of the study area, including the lower part of Lightning Creek and almost all of Deer Creek, the stream channels were included in the strip mines. Overburden was removed to depths approaching 90 feet in some areas. This material was broken into small fragments when removed and haphazardly piled into a previously mined pit adjacent to the one being mined. The mined areas contain many former strip pits filled with unconsolidated waste rock containing pyrite and marcasite. These former strip pits function as discontinuous alluvial aquifers that obtain water by percolation from the surface or from the coal seam, from thin sandstone lenses, and other local aquifers that were penetrated during the mining operation. During low stages of flow, these strip-mined areas discharge ground water containing high concentrations of dissolved solids and sulfate ion into the streams. Because similar depths of overburden were removed throughout the study area and the overburden was relatively uniform in composition, it is reasonable to expect that equal quantities of iron-sulfur compounds are in contact with ground water in strip-mined areas that are equal in areal extent. This is the basis for relating concentrations of dissolved solids and sulfate ion in the stream to the extent of strip mining in a drainage area.

PROCEDURE FOR PREDICTING CONCENTRATIONS OF DISSOLVED SOLIDS AND SULFATE ION

The suggested procedure for predicting concentrations of dissolved solids and sulfate ion in streams draining areas strip mined for coal relies on the development of linear least-squares regression equations. These regression equations are of the form (Blalock, 1972, p. 370):

$$Y_p = \alpha + Bx_i \ , \qquad (5)$$

where Y_p is the value of the dependent variable predicted by the regression equation; α is the Y-intercept value; B is the slope of the regression line; and x_i is the value of the independent variable.

A required assumption in using linear least-squares regression equations for prediction purposes is that all measurement error is assigned to the dependent variable. For the relations developed in this report, mean concentrations of dissolved solids and sulfate ion, in milligrams per liter (mg/L), are designated as the dependent variables, and percentage of the drainage area that has been strip mined is designated as the independent variable. Using percentage of the drainage area that has been mined allows comparisons between basins of different sizes.

The slope of the regression line, B, indicates the magnitude of the change in Y_p for a unit change in x_i. If B is positive, the relationship between the two variables is direct, but, if B is negative, the relationship is inverse (Blalock, 1972, p. 365).

The Y-intercept value, α, is the value of Y_p when x_i is equal to zero. This value can be interpreted as the background value of Y_p that is not related to x_i.

The correlation coefficient, r, ranges from -1 to +1. A value of r approaching -1 indicates a strong inverse linear relationship between x_i and Y_p; a value of r that approaches +1 indicates a strong direct linear relationship; and a value of r that approaches zero indicates no linear relationship (Blalock, 1972, p. 376).

The standard error of the estimate, $\hat{\sigma}_{Y/X}$, is equivalent to the standard deviation about the regression line. It is an estimate of the error likely to be encountered in making a prediction from the regression equation (Kendall and Buckland, 1960, p. 277).

Ninety-eight-percent prediction intervals are computed as bands about the regression line. Generally, these intervals can be expected to include the true value of the predicted variable about 98 percent of the time (Ostle, 1963, p. 172).

Mean values for sampled concentrations of dissolved solids and sulfate ion for each data-collection site in the study area were computed by the means procedure of the SAS system (Barr and others, 1976, p. 180). Descriptive statistics for the frequency distributions of these data are presented in "Statistical Summaries of Water-Quality Data for Streams Draining Coal-Mined Areas, Southeastern Kansas" (Bevans and Diaz, 1980).

The percentages of the drainage areas strip mined were computed with a Talos Model SBL-660B[1/] digitizer from U.S. Geological Survey 7 1/2-minute topographic maps of the study area. These maps were updated to include recent coal-mined areas.

The values of the dependent and independent variables used in computing the regression equations are presented in table 2.

Table 2.--Values for basin parameters and chemical constituents used to develop the regression equations

Station no.	Drainage area (mi^2)	Mined area (mi^2)	Independent variable (percentage of drainage area strip mined)	Dependent variables: Mean concentration of dissolved solids (mg/L)	Dependent variables: Mean concentration of sulfate ion (mg/L)
07184000	190	5.0	2.6	471	230
07184060	1.1	.46	42	3,070	2,100
07184070	6.5	3.7	57	2,620	1,800
07184080	12	6.6	55	2,460	1,700
07184100	220	17	7.7	1,030	690
07184220	23	4.8	21	1,750	1,200
07184240	31	3.4	11	1,040	760
07184300	83	9.7	12	878	640
07186010	56	4.3	7.7	989	690
07186020	28	4.6	16	968	560
07186025	6.9	2.6	38	1,580	1,100
07186030	43	9.5	22	1,070	770
07186040	170	20	12	656	380
07186050	29	3.6	12	807	570

[1/] The use of the brand name in this report is for identification purposes only and does not imply endorsement by the U.S. Geological Survey.

The regression equation relating the mean concentration of dissolved solids (Y_p), in milligrams per liter, to the percentage of the drainage area strip mined (x_i) is:

$$Y_p = 484 + 39.93\, x_i \;, \qquad (6)$$

with

$$r = .90 \quad \text{and}$$
$$\hat{\sigma}_{Y/x} = 367 \text{ mg/L} \;.$$

The scatter diagram, regression line, and prediction interval for the relation of the mean concentration of dissolved solids to the percentage of the drainage area strip mined are plotted in figure 7.

The regression equation relating the mean concentration of sulfate ion (Y_p), in milligrams per liter, to the percentage of the drainage area strip mined (x_i) is:

$$Y_p = 308 + 28.07\, x_i \;, \qquad (7)$$

with

$$r = .90 \quad \text{and}$$
$$\hat{\sigma}_{Y/x} = 260 \text{ mg/L} \;.$$

The scatter diagram, regression line, and prediction interval for the relation of the mean concentration of sulfate ion to the percentage of the drainage area strip mined are plotted in figure 8.

DISCUSSION

Contamination of streams draining areas strip mined for coal is often evidenced by increased concentrations of dissolved solids, with the sulfate ion being the principal dissolved constituent. Predictive equations relating concentrations of dissolved solids and sulfate ion to the percentage of a drainage area strip mined were developed using linear least-square regression procedures. Squaring the correlation coefficients, which were 0.90 for both relationships, gives 0.81 as the proportion of the variance in concentration of dissolved solids or sulfate ion that is explained by the percentage of the basin that has been strip mined (Blalock, 1972, p. 389). The remaining unexplained variance is probably due to a combination of the following factors: (1) measurement error in determining the mean concentration of dissolved solids or sulfate ion, (2) the presence of abandoned underground mines in some of the drainage basins, (3) the relative exposure time of the strip mines, and (4) local variation in subsurface geology, such as thickness and composition of overburden.

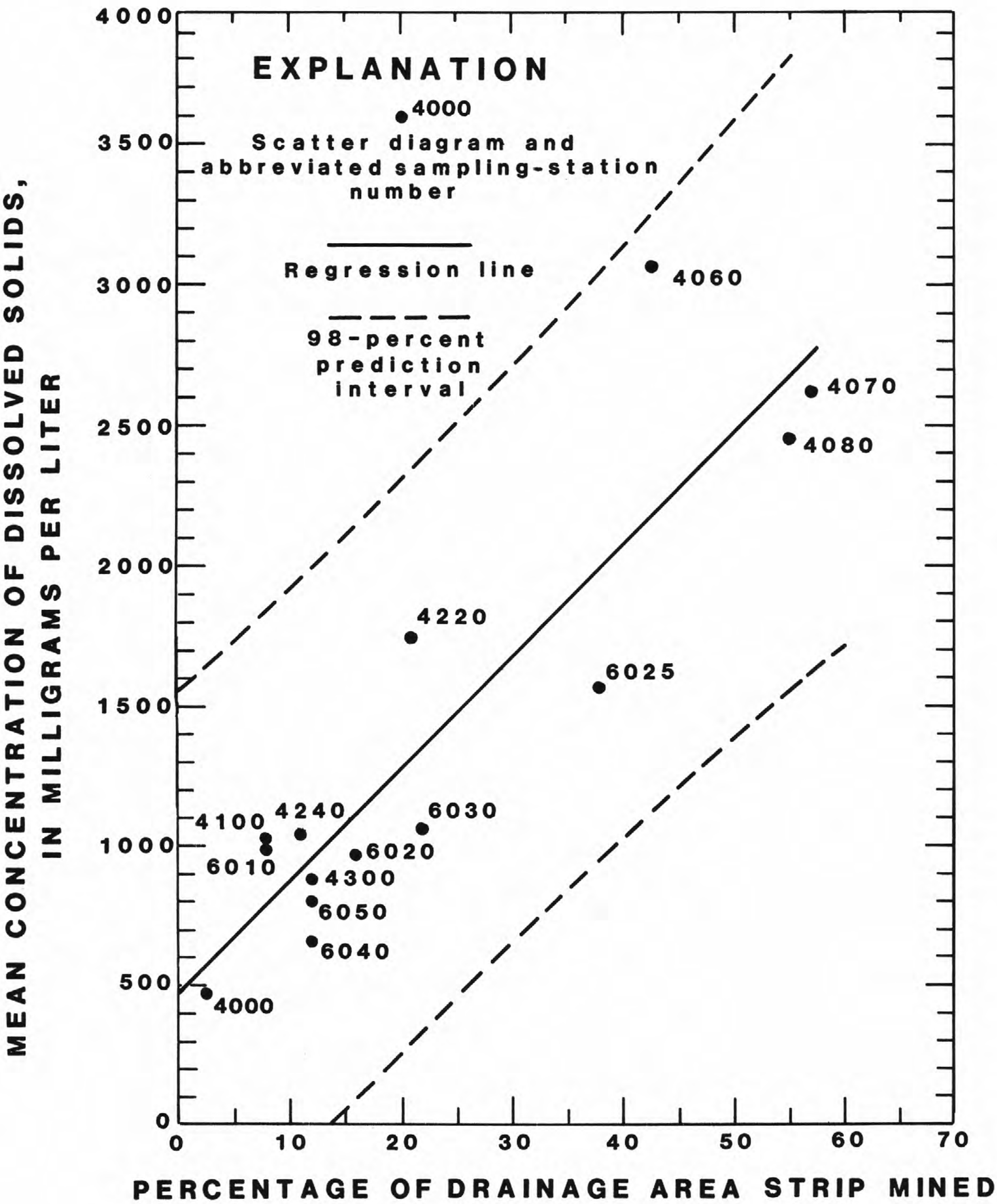

Figure 7.--Relation of mean concentration of dissolved solids to percentage of drainage area strip mined.

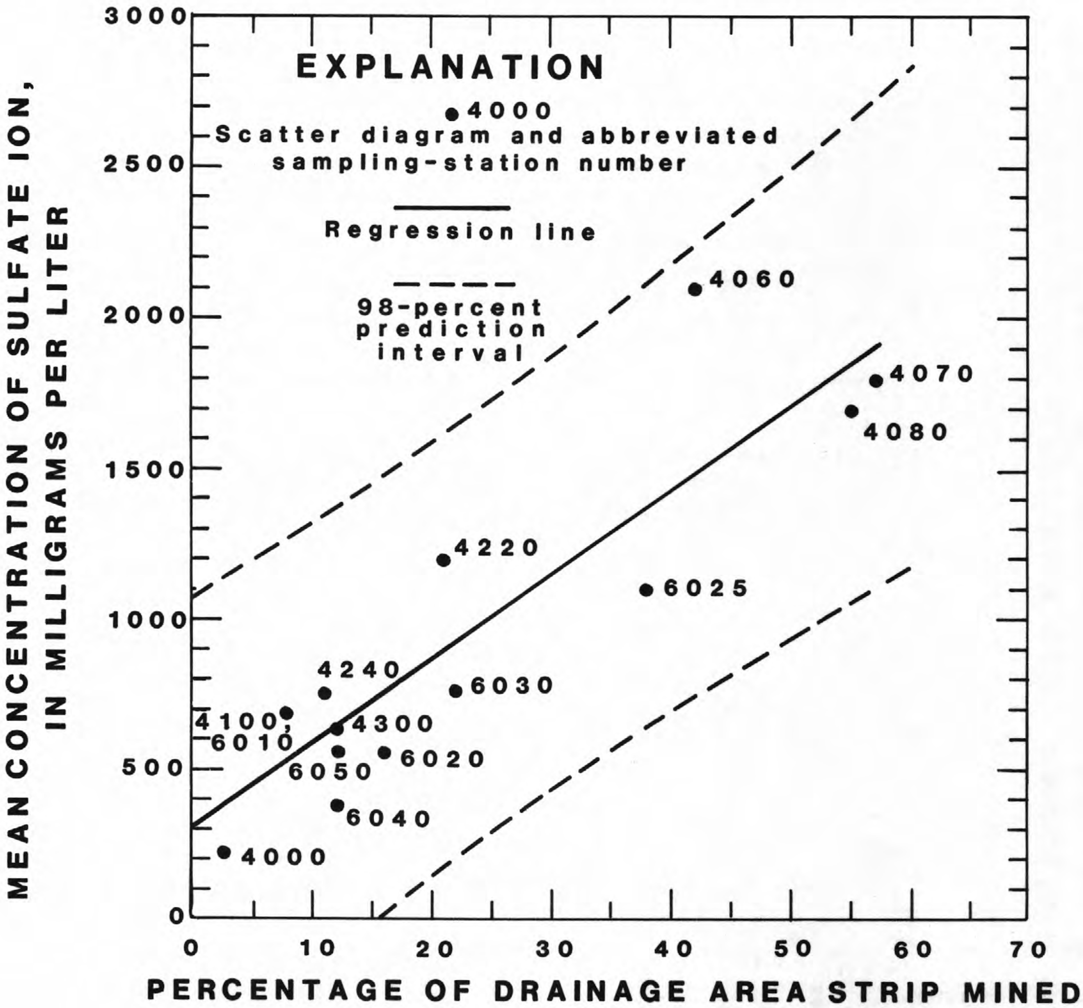

Figure 8.--Relation of mean concentration of sulfate ion to percentage of drainage area strip mined.

The strong correlations associated with these relationships and the reasonable standard errors of the estimates, which would be expected when applying them, indicate that the relations have excellent potential for predicting in-stream concentrations of dissolved solids and sulfate ion in strip-mined areas of eastern Kansas. These relationships could be utilized by planning agencies or coal companies to determine the extent to which a drainage basin could be strip mined without exceeding water-quality criteria for concentrations of dissolved solids and sulfate ion.

The long-term stream contamination, resulting from strip mining for coal and the lack of practical abatement procedures, leaves planning as the only feasible method for control. The relations presented in this report are adequate for prediction purposes and could be applied to planning future strip-mining activities in eastern Kansas, or other areas with similar geology and climate.

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