RUNOFF AND WATER-QUALITY CHARACTERISTICS OF

SURFACE-MINED LANDS IN ILLINOIS

By Timothy P. Brabets

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WILLIAM P. CLARK, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

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FACTORS FOR CONVERTING INCH-POUND UNITS TO INTERNATIONAL SYSTEM 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 unit	By	To obtain SI unit
inch (in.)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
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)
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]
ton per square mile (ton/mi^2)	0.3503	metric ton per square kilometer (metric ton/km^2)
ton, short	0.9072	megagram (Mg)
cubic yard (yd^3)	0.7646	cubic meter (m^3)
ton per day (ton/day)	0.9072	metric ton per day (metric ton/day)

Degree Fahrenheit (°F) can be converted to degree Celsius (°C) by using

$$°C = 5/9 \ (°F-32)$$

Annual yields in this report are in units of tons per square mile and are computed as follows:

Yield = Sum of the 365 daily products of concentrations, in milligrams per liter, and runoff, in cubic feet per second-days, times 0.0027, divided by the drainage area, in square miles.

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ABSTRACT

Seven watersheds--three in western Illinois (Fulton County), two in south-western Illinois (St. Clair County), and two in southern Illinois (Williamson County)--were selected to assess the effect of surface mining on the quality and quantity of surface runoff. Each area had one site draining an unmined basin and a nearby site(s) draining a partly surface-mined basin. Data from the literature, file data collected prior to 1979, and streamflow and water-quality data collected from 1977 to 1979 as part of this study, were used to assess runoff characteristics.

Flow-duration curves for streams draining surface-mined land had lower variability than those for streams draining unmined land. By adjusting an index of variability, according to the percentage of surface-mined land in a basin, conventional techniques can be used to develop synthetic flow-duration curves. Surface mining changes basin characteristics such that peak flows are decreased and low flows are increased. Regression equations were developed that relate storm runoff volume and peak discharge to basin characteristics and climatologic data.

Concentrations of dissolved solids, sulfate, and calcium were higher in streams draining areas that were extensively mined than in streams draining areas where mining has been minimal. Different mined areas in Illinois yield different concentrations of these substances. Harmonic analyses of stream temperatures showed higher harmonic means and lower amplitudes in surface-mined basins. Surface-mined basins had lower suspended-sediment yields than unmined basins. Trace-element concentrations were similar in streams in mined and unmined basins provided in-place neutralization by alkaline material had taken place in mined basins.

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1.0   Introduction
  1.1   Coal Reserves in Illinois

ILLINOIS HAS VAST COAL RESERVES

Illinois is underlain by vast quantities of coal.
Illinois has the largest reserve of bituminous
coal in the United States.

The energy problem in the United States requires alternatives to the use of oil. One alternative is to increase use of the Nation's vast coal reserves. Coal production is expected to increase, and more than 50 percent of this coal production during the rest of the century may be by surface mining methods.

The coal reserves of Illinois are in the Eastern Interior Coal Field, which also includes parts of Indiana and Kentucky (fig. 1.1-1). Estimated coal reserves in Illinois (as of January 1975, with revisions in 1980) are 161.6 billion tons or 15.1 percent of the total demonstrated coal reserves in the United States (Nawrot and others, 1980). Illinois ranks first among the States in total bituminous coal reserves. Only Montana has larger total coal reserves (Rickert and others, 1979). Illinois' reserves also have the highest total heat content of any reserves in the Nation. About 12.1 percent of Illinois' reserves is considered surface minable (coal seams more than 18 inches thick and less than 150 feet deep), but currently only about 3.6 percent is economically and legally recoverable (Nawrot and others, 1980).

In 1979, 40 surface mines in operation in the State produced 26,856,897 tons of coal, and 31 underground mines produced a total of 32,681,230 tons (Illinois Department of Mines and Minerals, 1980).

Rickert and others (1979) have shown that Illinois' coal resources are among those most likely to be used for synthetic fuel production because of the large amount of coal available, plentiful water supplies, and a favorable geologic environment.

2
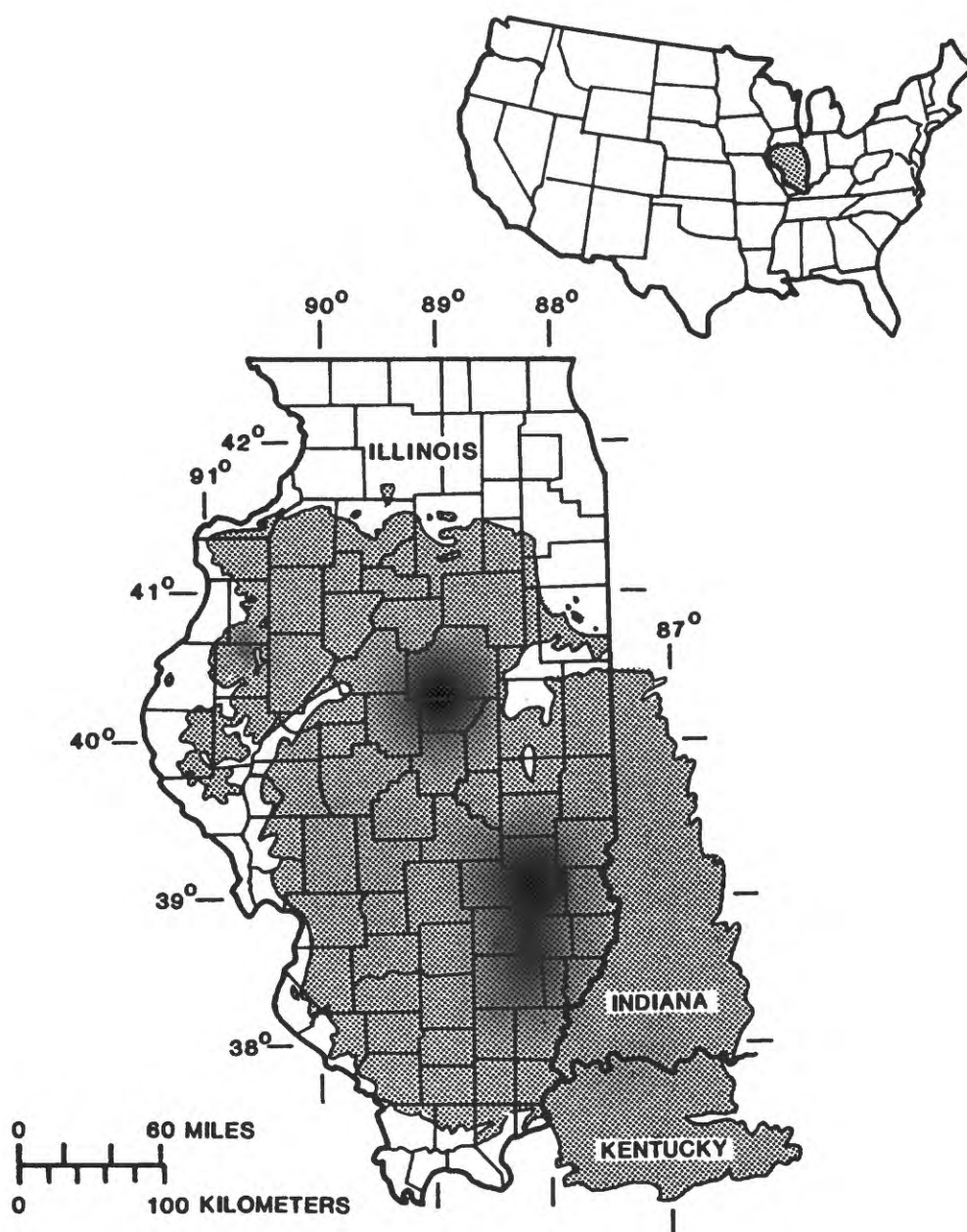
Figure 1.1-1.--Location of Eastern Interior Coal Field.

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TWO PRIMARY COAL FORMATIONS--THE SPOON FORMATION
AND THE CARBONDALE FORMATION

*Coals of economic importance lie in the Spoon and
the Carbondale Formations.*

Coals of the Spoon Formation (fig. 1.2-1) are the earliest widely dis-
tributed coals of Pennsylvanian (Des Moinesian) age in Illinois. Coals of
economic importance are:

(a) New Burnside Coal Member - well developed coal, but outcrops are
    scattered. It is up to 5 feet thick.

(b) Murphysboro Coal Member - is present in southeastern Illinois and is
    up to 7 feet thick.

(c) De Long Coal Member - more than 2 feet thick in a few places. This
    coal is present at various locations throughout southern Illinois, but
    is more extensive in western Illinois.

(d) Wise Ridge Coal Member - widely distributed. It is too thin to be
    mined economically in most of southern Illinois.

(e) Davis Coal Member - a major coal in southern Illinois. It averages
    about 4 feet in thickness and is prevalent in southeastern Illinois,
    where it has been extensively mined.

(f) De Koven Coal Member - is present from 3 to 40 feet above the Davis
    coal, and the two coal members commonly are mined together. The
    De Koven coal averages 3 feet in thickness and is present mainly in
    southeastern Illinois.

Coals of the Carbondale Formation are defined as those between the base of
the Colchester (No. 2) Coal Member and the top of Danville (No. 7) Coal Member.
The principal coals of the Carbondale Formation are:

(a) Colchester (No. 2) Coal Member - coal that has a maximum thickness of
    18 inches. It is present throughout Illinois.

(b) Shawneetown Coal Member - generally thin but has been reported as up
    to 8 feet thick in a few scattered drill holes in southeastern
    Illinois.

(c) Summum (No. 4) Coal Member - generally thin throughout Illinois. The
    coal is reported to have maximum thickness of 3 feet.

(d) Harrisburg-Springfield (No. 5) Coal Member - second in commercial importance in Illinois. It lies 50 to 80 feet above the No. 4; the lower end of this range is more common in southwestern Illinois. The coal may be more than 7 feet thick and is present throughout Illinois.

(e) Briar Hill (No. 5A) Coal Member - thin, discontinuous coal of little commercial importance. It is present only in southeastern and eastern Illinois.

(f) Herrin (No. 6) Coal Member - bright-banded coal, which ranks first in commercial importance in the State. The coal ranges from 4 to 9 feet in thickness.

Series	Fm		SOUTHWESTERN AND SOUTHEASTERN	NORTHERN AND WESTERN	EASTERN
DESMOINESIAN	Carbondale		Danville (No.7) C. Golum Ls. Allenby C. Bankston Fork Ls	Danville (No.7) C.	Danville (No.7) C. Bankston Fork Ls.
			Anvil Rock Ss.	Copperas Creek Ss. Lowson Sh.	
			Conant Ls. Jamestown C. Brereton Ls. Anna Sh. Herrin (No.6) C.	Brereton Ls. Anna Sh. Herrin (No.6) C. Spring Lake C. Big Creek Sh. Vermilionville Ss.	Conant Ls. Jamestown C. Brereton Ls. Anna Sh. Herrin (No.6) C.
			Briar Hill (No.5A) C.		Briar Hill (No.5A) C.
			Canton Sh. St. David Ls. Dykersburg Sh. Harrisburg (No.5) C.	Canton Sh. St. David Ls. Springfield (No.5) C.	Canton Sh. St. David Ls. Harrisburg (No.5) C.
			Hanover Ls. Excello Sh. Summum (No.4) C.	Covel Cgl. Hanover Ls. Excello Sh. Summum (No.4) C. Breezy Hill Ls.	Excello Sh. Summum (No.4) C.
			Roodhouse C. Pleasantview Ss.	Kerton Creek C. Pleasantview Ss. Purington Sh.	Pleasantview Ss.
			Shawneetown C.	Lowell C.	Shawneetown C.
			Oak Grove Ls. Mecca Quarry Sh.	Oak Grove Ls. Mecca Quarry Sh. Jake Creek Ss. Francis Creek Sh. Cardiff C.	Mecca Quarry Sh.
			Colchester (No.2) C.	Colchester (No.2) C.	Colchester (No.2) C.
	Spoon		Palzo Ss.	Browning Ss. Abingdon C. Isabel Ss.	
			Seelyville C.		Seelyville C.
			De Koven C.	Greenbush C.	
			Davis C. Seahorne Ls. Vergennes Ss.	Wiley C. Seahorne Ls.	
			Stonefort Ls. Wise Ridge C.	(Cheltenham Clay)	
			Mt. Rorah C.	De Long C.	
			Creal Springs		
			Murphysboro C. Granger Ss.		
			New Burnside C. Bidwell, O'Nan C. Curlew Ls. Litchfield, Assumption C.	Brush C. Herman C. Seville Ls. Rock Island (No.1) C.	

Scale: 0 — 50 — 100 ft.

Rocks present only in subsurface. Local oil-field names have been used informally.

Figure 1.2-1.--Stratigraphy of the Spoon and Carbondale
Formations in Illinois (from Willman and
others, 1975, p. 166).

1.0 Introduction
    1.3 History and Laws

SURFACE MINING IN ILLINOIS DATES BACK
TO 1866 - LEGISLATION BEGAN IN 1962

Illinois lands have been surface mined since 1866.
The first Illinois mining law was passed in 1962.

Illinois coals have been surface-mined since 1866. By 1898, 889 mines
were in operation throughout 52 counties, with an annual production of 23
million tons. According to the 1979 Illinois Bureau of Mines and Minerals
Annual Coal Report, 71 mines that were operated in 1979 produced over 59
million tons of coal.

Most coal in Illinois is mined with draglines and shovels. The capacities
of the equipment range from 10 to 185 cubic yards per bucket. Coal seams are
uncovered by removing successive strips of overburden; the strips are 40 to
200 feet wide and 20 to 100 feet thick. Successive cuts are made, resulting
in the deposition of overburden in long parallel ridges. The process con-
tinues until the overburden becomes so thick that coal can no longer be mined
economically. The final cut leaves an open trench that can be made into a
water impoundment.

No regulatory statutes were applicable to surface-mined lands until
January 1, 1962, when the Illinois General Assembly produced the Open Cut Land
Reclamation Act. The Act imposed some modest requirements for reclamation;
however, plans for reclamation were not required until long after the mining
began. Performance bonds were low and were often forfeited in preference to
reclaiming the land.

In 1971, the Surface-Mined Land Conservation and Reclamation Act was
passed by the State. This Act strengthened standards, involved local govern-
ments in planning reclamation, increased bonds and fees, and provided for
reclamation to row-crop agricultural land. Complete reclamation plans and
environmental impact statements were required before mining began.

With the passage of the Surface Mining Control and Reclamation Act of 1977
(Public Law 95-87) on August 3, 1977, mining companies were "required to mini-
mize the disturbance to the prevailing hydrologic balance at the mine site and
in associated offsite areas and the quality and quantity of water in surface-
and ground-water systems both during and after surface coal-mining operations."

1.0 Introduction
   1.4 Problem and Purpose

FEW DATA AVAILABLE TO ASSESS RUNOFF
FROM SURFACE-MINED AREAS

*Few data are available to assess the quantity and quality
of runoff from surface-mined land in Illinois.*

Few data are available to assess the effects of surface mining on runoff. It is a common belief that changes in the topography and physical characteristics of the disturbed overburden tend to dampen extreme-flow characteristics of surface runoff. The effect of mining on flow extremes needs to be evaluated.

Similarly, the chemical constituents in runoff could be different in areas affected by mining. Some minerals that are stable in the subsurface environment become unstable when exposed to weathering agents and thus have greater potential to become dissolved in runoff.

The U.S. Geological Survey began an intensive program in 1977 to evaluate the effects of surface mining in selected watersheds. The purpose of this program was: (1) to determine the differences in stream runoff caused by surface mining, and (2) to define chemical concentrations and loads contributed to surface runoff by surface-mined areas.

Runoff characteristics such as peak flows, mean daily flows, mean daily dissolved solids loads, and annual suspended-sediment yields were determined for small streams and basins in the Illinois coal-mining areas. These characteristics were then compared to characteristics of streams and basins in unmined areas and were quantified based on the percentage of surface-mined land in each stream basin.

2.0 Areas of Study
    2.1 Western Illinois

                        FULTON COUNTY

        *Three watersheds were selected in Fulton County. One watershed
        was unmined, one had 29 percent of the land in surface mining,
        and one had 90 percent of the land in surface mining.*

        The area of Fulton County is 874 square miles. As of 1967, land use con-
sisted of 57.1 percent cropland, 17.9 percent pasture, 17.2 percent forest,
and 7.8 percent other uses (Nawrot and others, 1980, p. 50). The topography
of Fulton County consists of level to rolling uplands, ravines, and flood
plains. Soils of the Clary-Clinton-Keomah, Joy-Tama-Muscatine-Ipava-Sable,
and Seaton-Fayette-Stronghurst soil associations developed primarily from
loess.

        There are 366 abandoned underground mines and over 73 square miles of
surface-mined lands in Fulton County. Three surface mines were active in the
county in 1980.

        Four major coal seams that have been mined in Fulton County are No. 1
(Rock Island), No. 2 (Colchester), No. 5 (Harrisburg-Springfield), and No. 6
(Herrin). The No. 5 seam is the principal coal seam and has an average thick-
ness of 56 inches. Estimated coal reserves of the county exceed 2.2 billion
tons, of which 89 percent is considered minable by surface methods.

        Three watersheds were selected for study in Fulton County (fig. 2.1-1).
All three watersheds are in the Spoon River basin. Turkey Creek drains an
unmined watershed of 11.5 square miles. Most of the watershed is farmland
(87 percent), and the remainder is forest. West Branch Big Creek near Canton
has a drainage area of 4.31 square miles. Twenty-nine percent of its area was
surface mined from 1970 to 1975. The remainder of the watershed is farmland.
The third site, Slug Run near Bryant, drains 7.12 square miles. Ninety per-
cent of its area was mined by surface methods before 1962.

        Gaging stations on Turkey Creek and West Branch Big Creek were equipped
to obtain records of streamflow, rainfall, water temperature, and specific
conductance. At both stations, water samples were collected monthly and more
frequently during high flows. Two additional rain gages were located within
Turkey Creek watershed to define the distribution of rainfall. Records of
streamflow, water temperature, specific conductance, and water quality have
been collected at a gaging station on Slug Run since 1975.

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TYPICAL GEOLOGICAL LOG
(provided by Consolidation Coal Co.)

DEPTH BELOW LAND SURFACE, IN FEET

Depth	Layer
0	Surface
5	Soft Pan
21	Brown Clay
24	Gray Clay
34	Brown Clay
56	Gray Shale–Sandstone
84	Dark Gray Shale–Limestone
86	Anna Shale
92	No. 5 Coal

NOTE.-- Canton Illinois is 17mi west of east and 22mi south of north border of Fulton County.

EXPLANATION

▲ --- Gaging Station
■ --- Raingage
▨ --- Strip-Mined Land
⸺·⸺ --- Drainage Basin Boundary

Figure 2.1-1.--Fulton County study area.

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2.0 Areas of Study
    2.2 *Southwestern Illinois*

ST. CLAIR COUNTY

*St. Clair County has more than 20 square miles of surface-mined
land. Two stream basins were chosen: one stream drained
an unmined area and the other stream had 50 percent
of its drainage area surface mined.*

The area of St. Clair County is 670 square miles. Land use includes crop-
land (61.2 percent), pasture (5.2 percent), forest (13.6 percent), and other
uses (20.0 percent). The topography consists of level to rolling uplands,
flood plains, river bluffs, and ravines. Soils in the county, which developed
primarily from loess, form the Stookey-Alford-Muren, Hosmer-Stoy-Weir,
Oconee-Cowden-Piasa, and Harrison-Herrick-Virden soil associations.

More than 20 square miles of land have been surface mined in St. Clair
County. There was one active surface mine in 1980. All surface-mining
operations extracted the Herrin (No. 6) coal at depths less than 100 feet.
Estimates of coal reserves exceed 2.9 billion tons, of which 36.2 percent is
considered minable by surface methods.

Two watersheds in St. Clair County were selected for hydrologic monitoring
(fig. 2.2-1). Both sites are in the Kaskaskia River basin. South Branch Doza
Creek near Lenzburg drains an unmined basin of 7.9 square miles. Land use is
primarily farmland (96.0 percent), and the remainder is forest. Doza Creek
near Lenzburg drains 18.4 square miles. Fifty percent of this watershed was
surface mined from 1963 to 1973. Gaging stations on both streams were
equipped with recorders to obtain water discharge, rainfall, water temperature,
and specific conductance. Water samples were collected monthly and during high
flows. Three additional rain gages were placed within the basins to monitor
the distribution of rainfall.
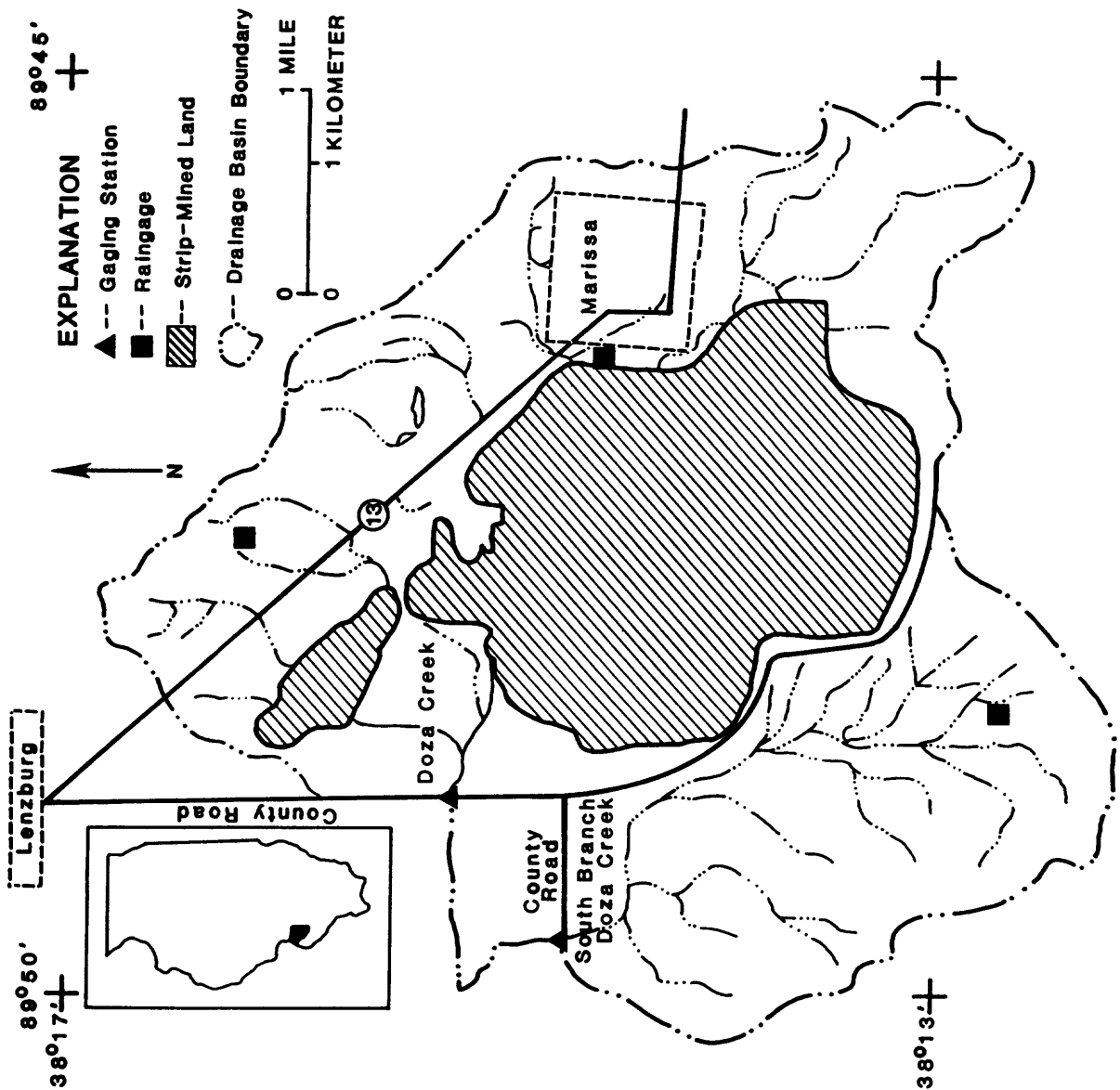
TYPICAL GEOLOGIC LOG
(provided by Peabody Coal Co.)

DEPTH BELOW LAND SURFACE, IN FEET

Surface-Clay and Drift	0
Limestone	32
Smut Coal	40
	41
Fire Clay-Shale	42
Limestone	48
Gray Shale	52
Limestone	60
Anna Dark Shale	68
No. 6 Coal	73
	78

NOTE.-- Marissa, Illinois is located 7mi northwest of southeast corner of St. Clair County.

EXPLANATION

▲ -- Gaging Station
■ -- Raingage
▨ -- Strip-Mined Land
⊙ -- Drainage Basin Boundary

0   1 MILE
0   1 KILOMETER

N

Lenzburg

County Road

Doza Creek

Marissa

13

South Branch Doza Creek

89°45'

89°50'

38°17'

38°13'

Figure 2.2-1.--St. Clair County study area.

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WILLIAMSON COUNTY

*Twenty-three square miles, more than 5 percent of the land in
Williamson County, has been surface mined. Two watersheds
were studied; one was an unmined area of 1.46 square miles,
and the other an area of 1.9 square miles, of which
99 percent has been surface mined.*

The area of Williamson County is 424 square miles. Land use consists of
cropland (28.6 percent), pasture (18.7 percent), forest (23.3 percent), and
other uses (29.4 pecent). Topographical features include a rolling till
plain, ravines, and flood plains. Loess and outwash material developed into
soils of the Ava-Bluford-Wynoose, Hosmer-Stoy-Weir, Hoyleton-Cisne-Huey, and
Grantsburg-Robbs-Wellston soil associations.

More than 23 square miles of land has been surface mined in Williamson
County and as of 1978, there were 15 active surface mines. The Harrisburg-
Springfield (No. 5) and Herrin (No. 6) coal seams have been surface mined.
The Danville (No. 7) and Davis-De Koven seams have also been mined at depths
less than 75 feet. Estimates of coal reserves are 3.1 billion tons, of which
17.9 percent is considered minable by surface methods.

Two hydrologic monitoring sites were established in Williamson County
(fig. 2.3-1), both in the Saline River basin. Little Cana Creek near Creal
Springs drains a 1.46-square-mile watershed. Most of the area is farmland (80
percent); the remainder is forest. Bankston Fork near Crab Orchard drains
1.90 square miles. Ninety-nine percent of the drainage area was surface mined
between 1944 and 1958.

Both sites were equipped to obtain records of streamflow, rainfall, water
temperature, and specific conductance. An additional rain gage was placed in
the Bankston Fork watershed to help define the distribution of rainfall.
Water samples were taken monthly and during periods of high flow.

Table 2.3-1 summarizes the land uses for the seven study watersheds.
Data for all sites were published in Water Resources Data Report for Illinois,
Volumes 1 and 2, water year 1980 (U.S. Geological Survey, 1981).
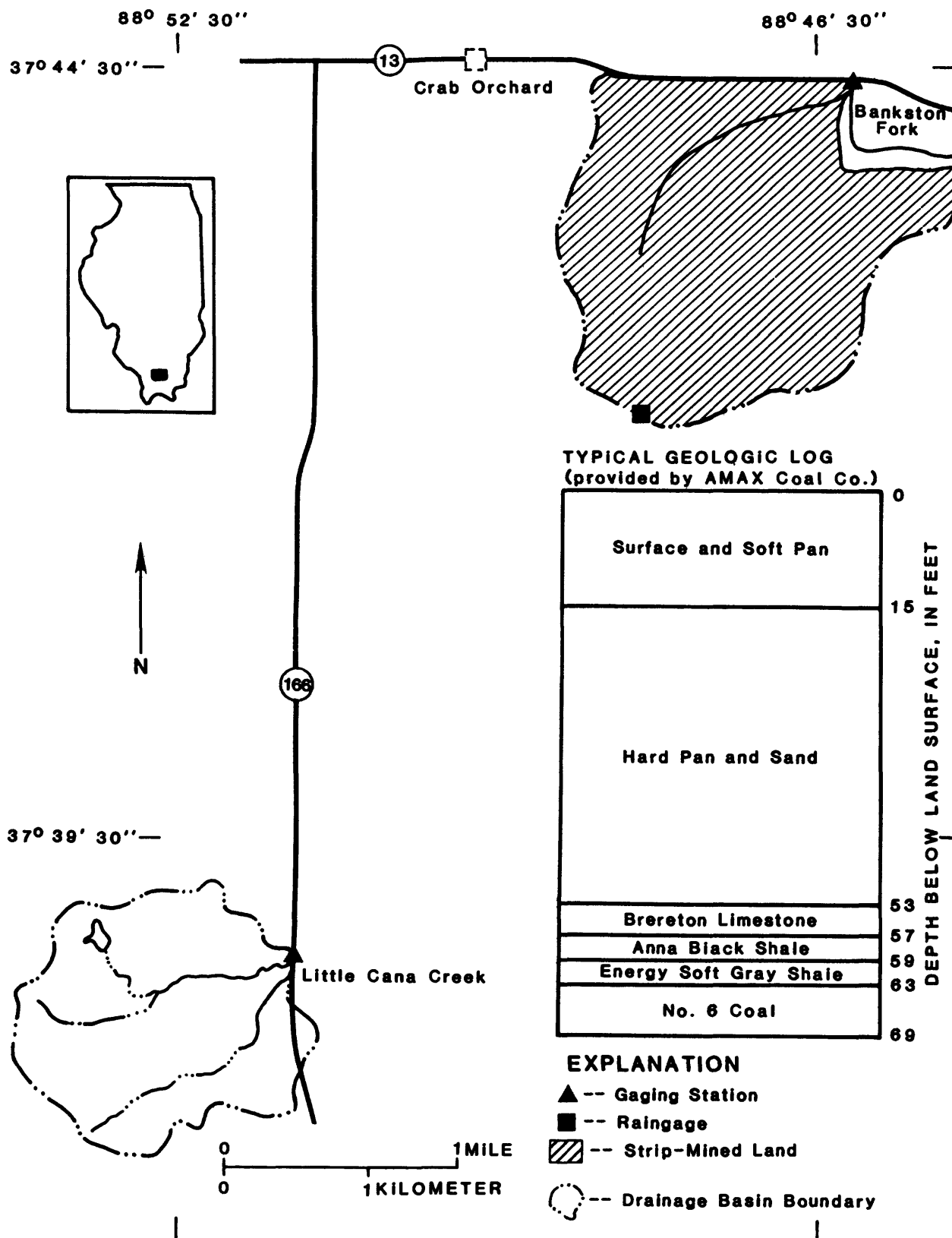
Figure 2.3-1.—Williamson County study area.

Table 2.3-1 Summary of land uses for the seven study sites

| USGS station number | Stream name | Drainage area (mi^2) | Land use, in percent | | |
			Farm land	Forest	Surface mined
03382045	Little Cana Creek near Creal Springs	1.46	80	20	0
03382160	Bankston Fork near Crab Orchard	1.90	0	1	99
05569968	Turkey Creek near Fiatt	11.5	87	13	0
05570330	West Branch Big Creek near Canton	4.31	71	0	29
05570380	Slug Run near Bryant	7.12	5	5	90
05595226	Doza Creek near Lenzburg	18.4	50	0	50
05595228	South Branch Doza Creek near Lenzburg	7.90	96	4	0

3.0 Surface Water
   3.1 Streamflow Characteristics

STREAMFLOW CHARACTERISTICS VARIED

*Discharge hydrographs show many differences in streamflow
characteristics between unmined and mined lands.*

The discharge hydrographs for the 1979 water year for two streams in
Williamson County (fig. 3.1-1) show differences in flow characteristics of
mined and unmined watersheds. Unmined watersheds such as Little Cana Creek
have comparatively high and sharp peak discharges, whereas mined basins, such
as Bankston Fork, have comparatively low peak discharges. In most unmined
basins, flow approaches zero or is extremely low during the summer; most of
the mined basins have higher flows during the summer than do unmined basins.

High flows, low flows, and other discharge characteristics were studied in
detail for all sites. This section presents the results of these studies, and
discusses the differences and similarities of the streamflow characteristics
between mined and unmined agricultural basins. Some techniques are presented
that may be useful in estimating changes in runoff characteristics influenced
by surface mining.
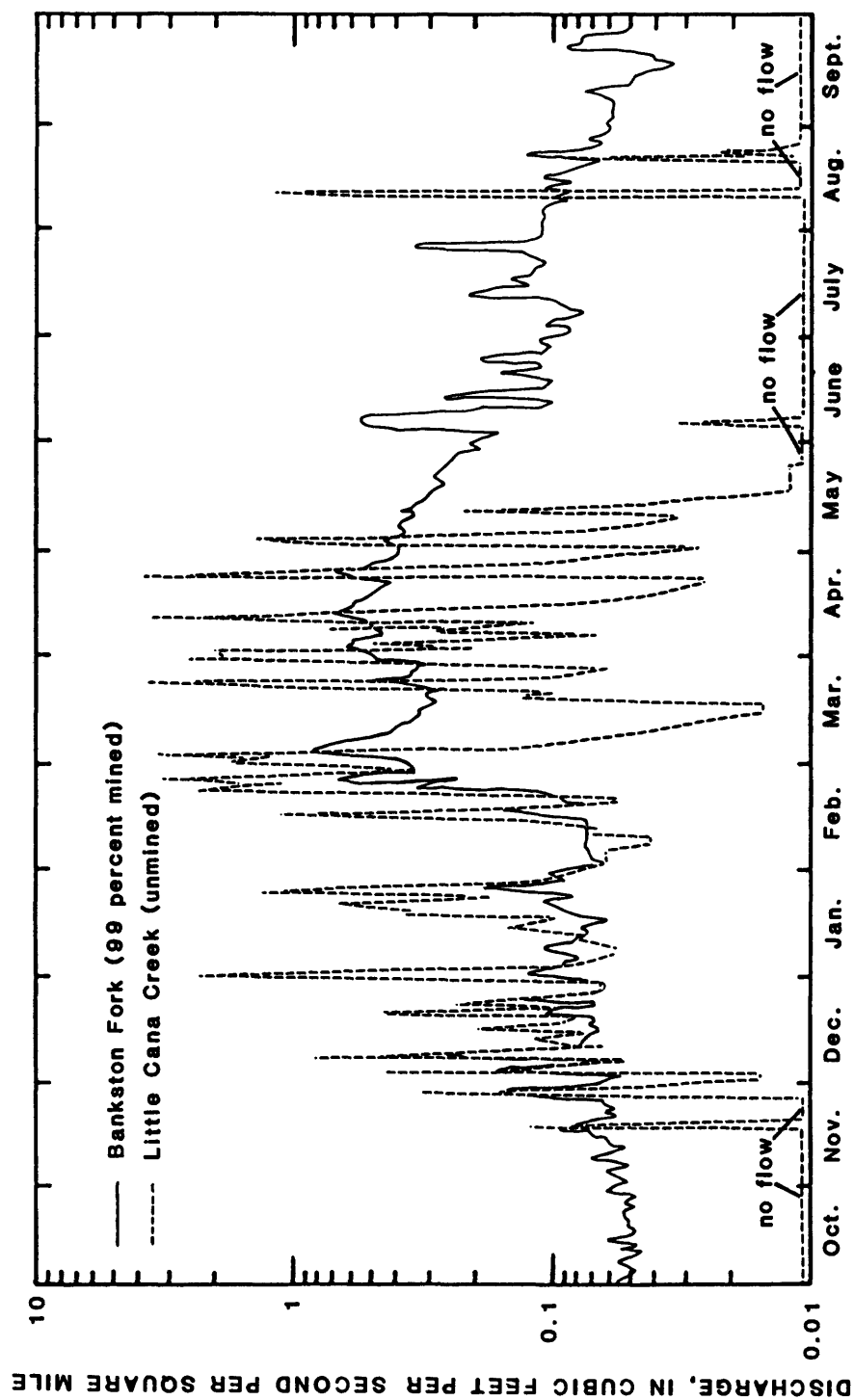
Figure 3.1-1.--Hydrographs for Little Cana Creek and Bankston Fork for 1979 water year.

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VOLUME OF RUNOFF DIFFERS BETWEEN MINED BASINS
AND UNMINED AGRICULTURAL BASINS

*Although monthly precipitation was nearly equal in both
mined and unmined basins, differences in monthly
runoff between basins are noticeable.*

Monthly precipitation data (table 3.2-1) in the Bankston Fork (mined) and
Little Cana Creek (unmined) basins in Williamson County (southern Illinois)
were fairly uniform from May 1978 to April 1980. Notable exceptions are June
and August of 1979, when storms affected only the Little Cana Creek basin.
Runoff from Bankston Fork totaled 17.13 inches from May 1978 to April 1979,
and 12.22 inches from May 1979 to April 1980. Runoff from Little Cana Creek
totaled 22.72 inches from May 1978 to April 1979 and 11.09 inches from May
1979 to April 1980.

For the sites in St. Clair and Fulton Counties (southwestern and western
Illinois) precipitation was evenly distributed over the mined and unmined
basins. Precipitation totaled 40 inches from June 1978 to May 1979 and 29
inches from June 1979 to May 1980 for the sites in St. Clair County (south-
western Illinois), and 38 inches from April 1978 to March 1979 and 25 inches
from April 1979 to March 1980 for the sites in Fulton County (western
Illinois). In southwestern Illinois, runoff from the mined basin (Doza
Creek) was greater (20 inches total for 2 years) than the unmined basin
(South Branch Doza Creek, which had 14 inches total for 2 years). In western
Illinois, all three basins had nearly equal runoff (Turkey Creek--19 inches
total for 2 years, West Branch Big Creek--21 inches total for 2 years, and
Slug Run--18 inches total for 2 years).

Although no differences were apparent in yearly runoff between mined and
unmined basins, notable differences in monthly runoff were observed. Figure
3.2-1 shows a graph of monthly runoff for Little Cana Creek and Bankston Fork.
Runoff during the summer and fall months was higher for the mined basin
(Bankston Fork). During the spring and winter months the unmined basin
(Little Cana Creek) had more runoff. Similar differences were also noted in
the other two study areas. The unmined basins consist primarily of farmland;
thus, differences in runoff patterns could result from the difference between
mining and agricultural practices rather than being typical of unmined versus
mined lands.
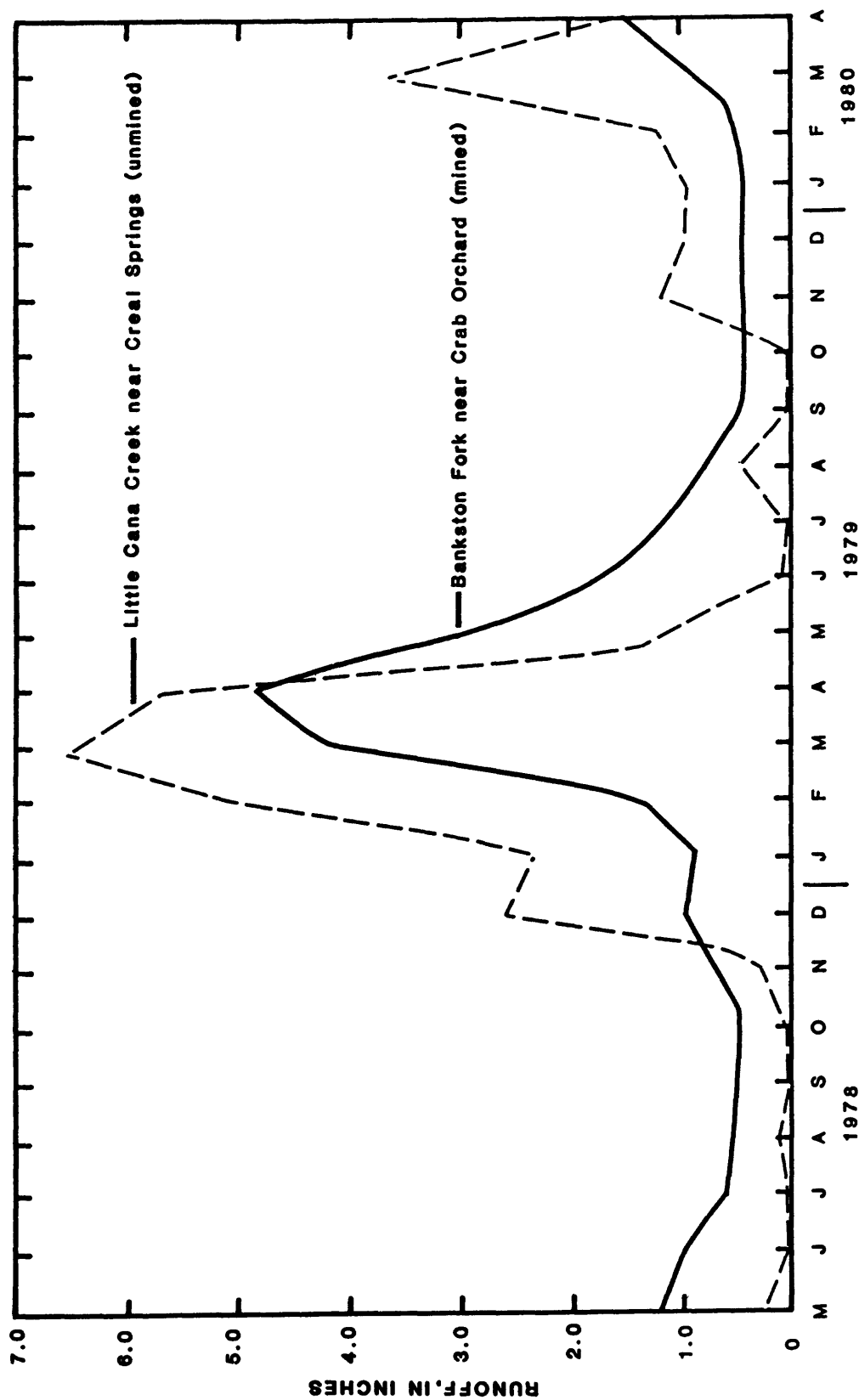
Figure 3.2-1.--Monthly runoff for Little Cana Creek and Bankston Fork.

Table 3.2-1 Monthly precipitation and runoff, in inches, for Bankston Fork and Little Cana Creek basins

| Month and year | Bankston Fork | | | | Little Cana Creek | |
| | Precipitation[1] | | | Runoff | Precipitation | Runoff |
	Gage 1	Gage 2	Average		Gage 1	
1978						
May	2.12	--	2.12	1.18	2.23	0.30
June	.93	--	.93	1.00	.91	.00
July	1.90	--	1.90	.60	1.65	.00
August	6.07	6.15	6.11	.57	6.27	.14
September	.70	.88	.79	.54	.68	.00
October	1.20	1.25	1.22	.51	1.13	.00
November	5.46	5.73	5.60	.77	5.35	.28
December	5.49	6.41	5.95	.94	5.61	2.60
1979						
January	1.27	--	1.27	.91	1.38	2.40
February	3.87	--	3.87	1.31	4.16	4.80
March	5.48	5.72	5.60	4.00	6.06	6.50
April	6.81	6.86	6.83	4.80	6.89	5.70
TOTAL			42.19	17.13	42.32	22.72
May	2.78	2.68	2.73	3.00	3.52	1.20
June	3.68	3.66	3.67	1.80	6.12	.02
July	4.33	4.56	4.44	1.20	4.13	.00
August	2.98	3.73	3.35	.80	5.70	.47
September	1.32	1.43	1.38	.50	.30	.00
October	1.98	2.10	2.04	.45	2.35	.00
November	6.00	5.91	5.95	.44	5.77	1.17
December	2.04	2.04	2.04	.49	2.18	.99
1980						
January	1.43	1.23	1.33	.44	1.32	.95
February	1.16	1.47	1.31	.56	.95	1.22
March	4.02	4.53	4.28	.98	4.05	3.57
April	2.05	2.57	2.31	1.56	2.05	1.50
TOTAL			34.83	12.22	38.44	11.09

[1] Locations of precipitation gages are shown in figure 2.3-1.

3.0 Surface Water
    3.3 Storm Runoff

STORM RUNOFF AND PEAK DISCHARGES DECREASE WITH INCREASING AREA OF SURFACE MINING

Storm-runoff volumes and peak discharges were reduced as a result of surface mining. Equations were developed to predict runoff volumes and peak discharges from surface-mined basins.

A typical storm rainfall-runoff hydrograph is shown in figure 3.3-1. It shows that flow in Turkey Creek, which drains an unmined basin, had a higher and sharper peak than flow in West Branch Big Creek, which drains a mined basin. Also, storm-runoff volumes are considerably less from mined basins than from unmined basins. Selected storm characteristics are listed in table 3.3-1; asterisks (*) indicate peak discharges that correspond to a 2-year flood based on an equation by Curtis (1977).

Multiple-regression techniques were used to develop relations for volume and peak discharge. Stepwise regression was used and the level of significance to enter each variable was 0.15. The following equations were developed:

$$VOL = 3.02 \; PTOT^{1.35} \; QINIT^{0.353} \; X^{-0.641}$$

$$QPEAK = 58.6 \; AREA^{-0.402} \; PTOT^{0.982} \; QINIT^{0.221} \; X^{-0.682}$$

where

  VOL   = volume of storm runoff, in inches;

  QPEAK = peak discharge, in cubic feet per second;

  AREA = drainage area of the basin, in square miles;

  PTOT = average total depth of precipitation over the drainage area during the storm, in inches;

  QINIT = initial discharge, in cubic feet per second, before precipitation began;

  X   = indicator variable having a value of 0 for a mined basin and a value of 1 for an unmined basin.

For both equations, sample size equaled 52. The following independent variables: mined area in the basin, drainage density, age of the mines, antecedent precipitation index, storm duration, air temperature, channel slope, and area of lakes in the basin, did not pass the test to enter regression analysis. Most of the parameters in the equations are significant at the 95 percent confidence level, especially X, the indicator variable.

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The estimating equations developed have high standard errors of estimate (greater than 90 percent for both equations) and should be used with caution. However, it is important to note that the designation of a basin as mined or unmined is significant as evidenced by the negative coefficient of X in both equations and its level of significance. The equations could probably be further improved if other characteristics were known such as the type of mine spoil material or the storage capacity of lakes in the basin.
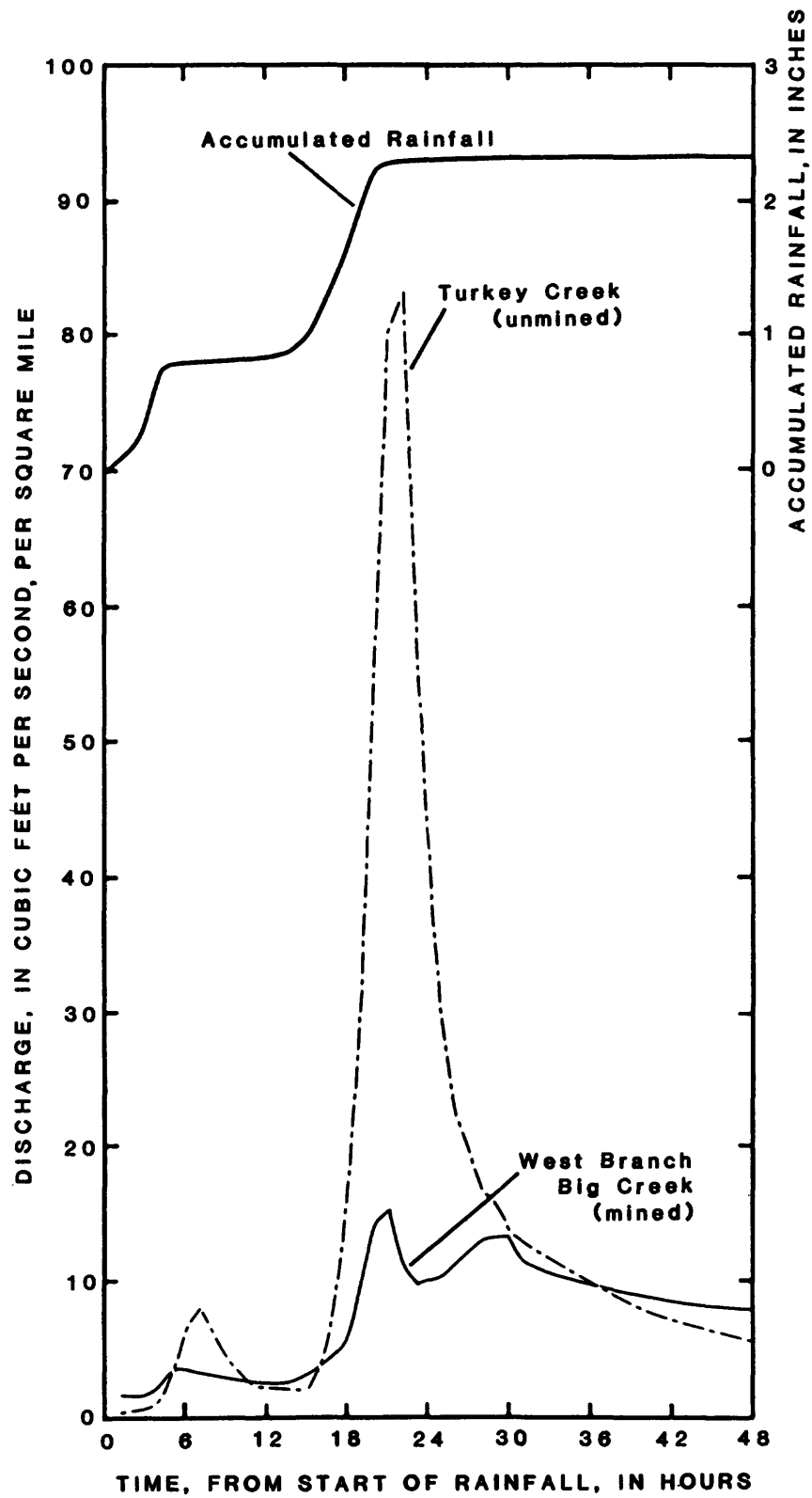
Figure 3.3-1.--Storm hydrographs of April 12, 1979, for Turkey Creek and West Branch Big Creek.

Table 3.3-1   Storm characteristics for the seven study sites

Station	Date	Rainfall (inches)	Runoff volume (inches)	Peak discharge [(ft³/s)/mi²]	Initial discharge [(ft³/s)/mi²]
Little Cana Creek	03-22-78	1.61	1.10	199	0.6
	04-11-79	1.31	.97	*393	1.2
	04-23-79	2.08	1.49	199	.2
	05-03-79	.93	.31	43.0	.3
	08-11-79	2.54	.45	195	.0
	11-08-79	.73	.10	23.4	.1
	11-25-79	1.15	.28	33.1	.6
	03-16-80	1.48	.66	190	.5
Bankston Fork	12-07-78	1.08	.09	3.6	.8
	03-22-79	1.20	.03	6.8	2.2
	04-11-79	1.31	.10	13.1	3.8
	04-23-79	2.08	.09	10.0	3.7
	05-03-79	.93	.02	5.4	3.8
	11-08-79	.72	.06	7.5	.7
	11-25-79	1.15	.04	5.8	4.5
	03-16-80	.90	.13	15.8	.5
Turkey Creek	04-10-78	1.41	.67	26.5	2.7
	05-07-78	1.84	.31	10.4	1.0
	05-12-78	2.10	1.00	38.7	2.3
	07-01-78	1.98	.24	17.2	.3
	03-19-79	.83	.30	18.4	5.6
	03-29-79	1.35	.43	29.2	1.6
	04-11-79	2.24	.85	*80.4	.7
	07-24-79	3.15	.22	27.4	.1
West Branch Big Creek	04-10-78	1.41	.41	16.0	3.1
	05-07-78	1.32	.14	6.8	2.2
	05-12-78	2.10	.52	13.9	4.2
	07-01-78	1.98	.02	9.7	.3
	03-19-79	.83	.13	10.6	2.8
	03-29-79	1.35	.14	5.4	2.6
	04-11-79	2.24	.45	16.2	1.9
	07-24-79	3.17	.04	5.7	.01
Slug Run	04-10-78	1.54	.37	17.7	3.3
	05-07-78	1.82	.19	5.6	1.5
	05-12-78	1.36	.18	15.0	3.3
	07-01-78	1.54	.14	12.3	.4
	03-19-79	.83	.19	12.3	2.2
	03-29-79	1.35	.05	5.3	1.5
	04-11-79	2.24	.49	36.8	1.4
	07-24-79	3.17	.06	3.8	.2
South Branch Doza Creek	11-25-78	1.86	.10	4.9	.1
	03-20-79	1.49	.26	29.3	.4
	03-22-79	1.65	.83	31.1	.7
	04-11-79	3.09	2.68	*77.0	.3
	07-28-79	4.33	1.21	52.4	.1
	03-30-80	1.03	.42	23.1	.1
Doza Creek	11-25-78	1.53	.10	2.6	.4
	03-20-79	1.60	.24	9.8	1.2
	03-22-79	1.72	.63	17.1	2.7
	04-11-79	3.31	2.07	63.9	3.0
	07-28-79	4.10	1.09	34.0	.1
	03-30-80	.95	.18	7.2	1.1

3.0 Surface Water
3.4 *Flow Duration and Variability*

STREAMS DRAINING MINED BASINS HAVE
LOWER STREAMFLOW VARIABILITY

*Streams draining mined basins have lower streamflow variability
than those draining unmined basins. The percentage reduction
in variability index is related to the percentage of drainage
area that has been surface mined.*

Distribution of daily mean flows of a stream can be shown by a flow-duration curve. Figure 3.4-1 presents flow-duration curves for Little Cana Creek (unmined) and Bankston Fork (mined). For comparison, flows of each stream were converted to cubic feet per second per square mile. Steep slopes and fewer reverse slopes are characteristic of curves for Little Cana Creek and other streams in unmined basins and indicate large flow variability and low base flows. The curve for Bankston Fork shows that the mined basin produces a higher sustained low flow than that of the unmined basin. At a duration of 50 percent, daily flow per square mile from the mined basin is approximately 10 times greater than from the unmined basin. Little Cana Creek shows higher flood discharges than Bankston Fork. At durations of less than 2 percent, discharges at Little Cana Creek are approximately three times as great as those of Bankston Fork.

Lane and Lei (1950) developed a variability index for characterizing flow of a stream. They compute the index as follows: (1) from the duration curve, select values of discharge at 10 percent intervals from 5 percent to 95 percent, (2) compute the logarithms of these values, and (3) compute the standard deviation of these logarithms (index of variability). The method was modified, for streams in which there is zero flow more than 5 percent of the time, to be based on the period which flow exists. An example of the calculation of the variability index for Bankston Fork is shown in table 3.4-1.

The variability indexes for the seven sites were computed using the above method and are given in table 3.4-2. The variability indexes were compared to values from Mitchell's (1957) (section 3.5, fig. 3.5-1) statewide map and with the percent of area mined. The unmined basins agree with Mitchell's values (table 3.4-2). The percentage reduction in variability index is related, for each area, to the percent of area mined (fig. 3.4-2). However, note that this is a tentative relationship based on limited data. Also, the variability index and the flow-duration curves are based on only 2 years of record and are subject to rather large time-sampling errors.

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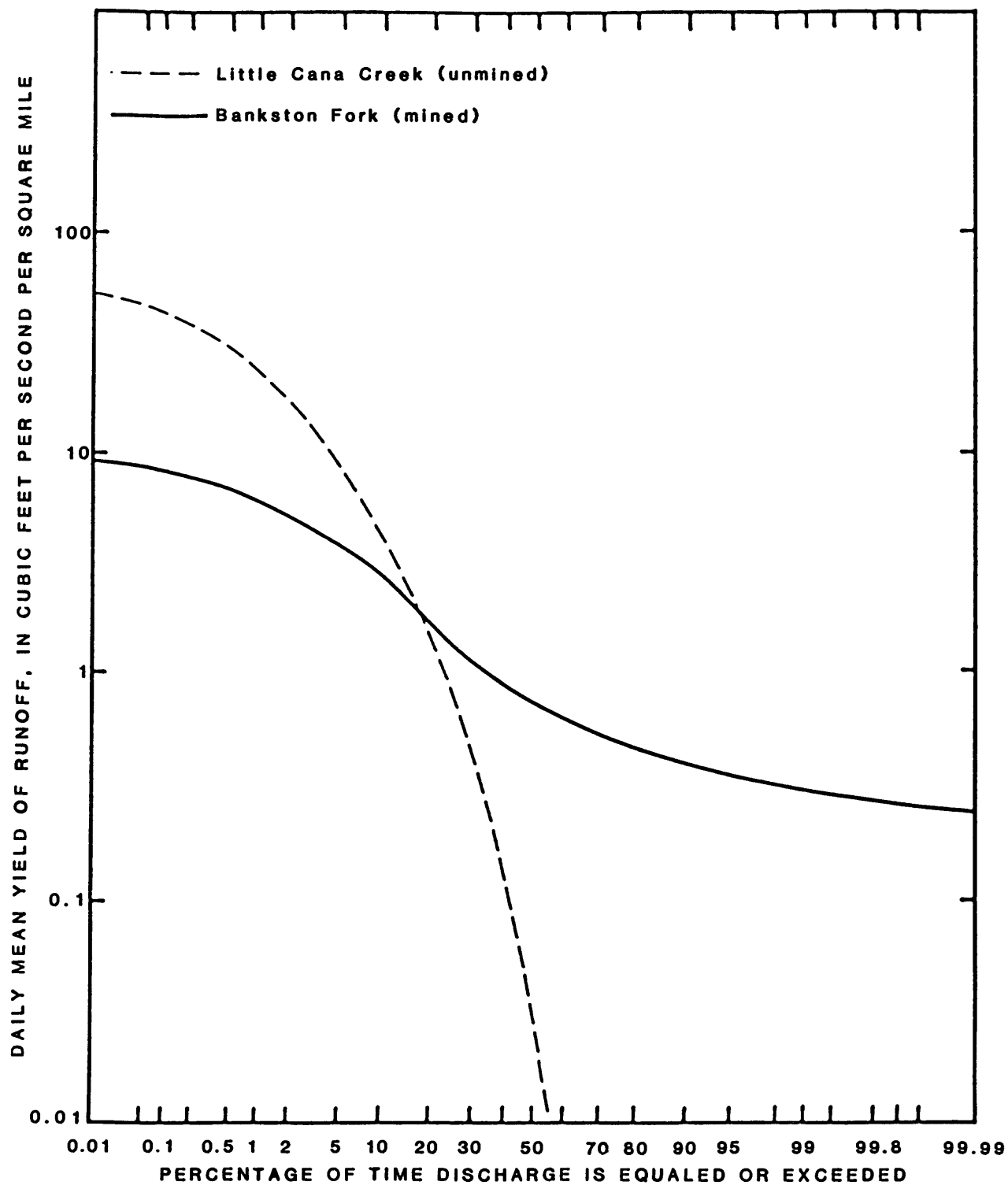
Figure 3.4-1.—Flow-duration curves for Little Cana Creek
and Bankston Fork.
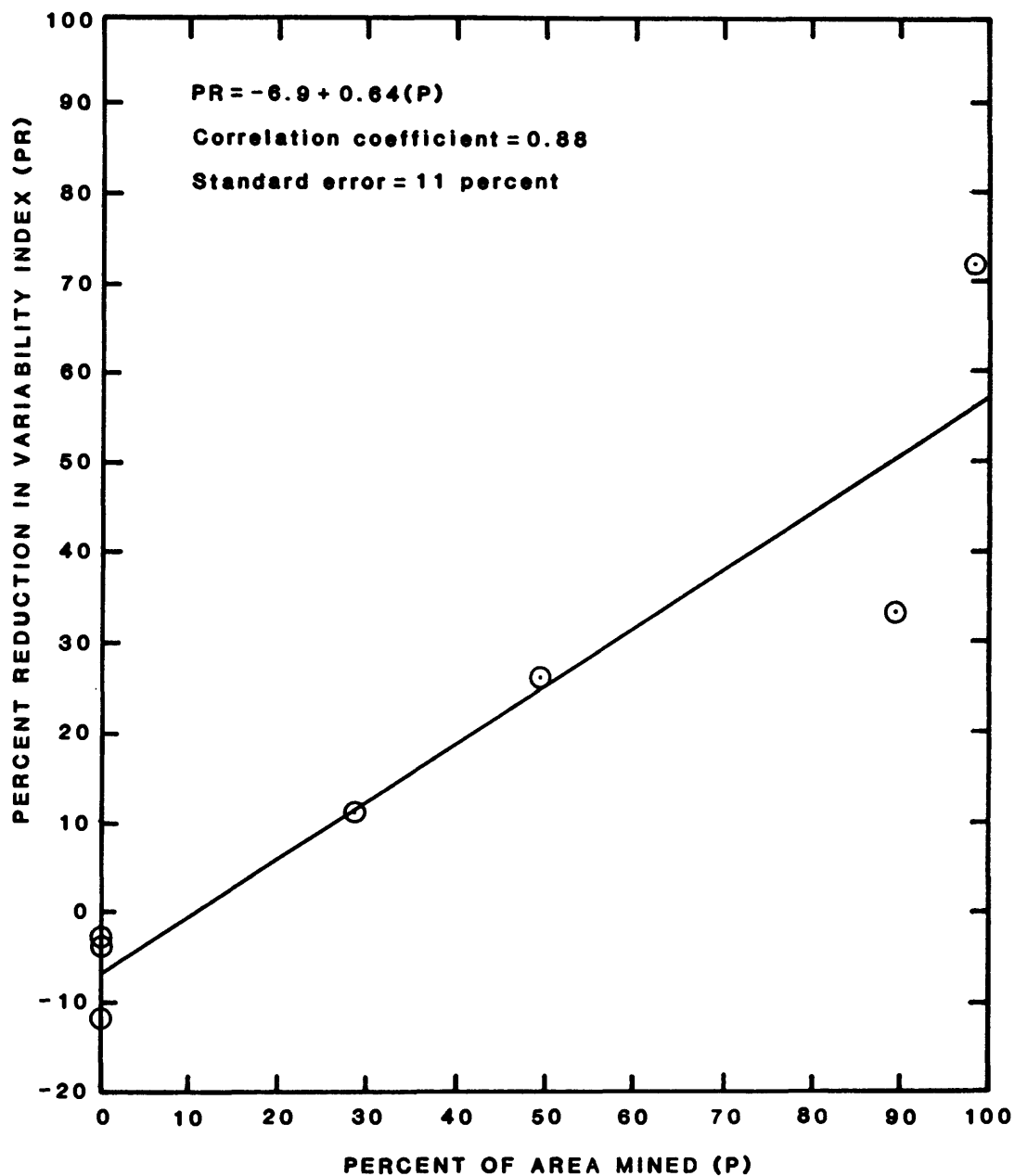
Figure 3.4-2.--Variability index comparison, Lane and Lei (1950) to Mitchell (1957) index, with percent area mined.

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Table 3.4-1   Computations of variability index for
Bankston Fork

Percent time	Cubic feet per square mile	log.	Departure from mean	Square of departure
5	4.1	0.61	0.70	0.49
15	2.3	.36	.45	.20
25	1.1	.05	.14	.02
35	.88	-.06	-.03	.001
45	.75	-.12	-.03	.001
55	.62	-.21	-.11	.012
65	.53	-.27	-.18	.032
75	.44	-.35	-.26	.068
85	.40	-.40	-.31	.096
95	.35	-.45	-.36	.130
SUMS		-.90		1.05
Mean of values in log column		-.09		

$$\text{Variability index}^{1} = \sqrt{\frac{1.05}{9}} = 0.34$$

[1] Lane and Lei, 1950

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Table 3.4-2 Variability index for the seven study sites

Station	Percent mined	Variability index	Index from Mitchell's map	Reduction in variability
SOUTHERN ILLINOIS				
Little Cana Creek	0	1.29	1.20	-12
Bankston Fork	99	.34	1.20	72
WESTERN ILLINOIS				
Turkey Creek	0	.78	.75	-4
West Branch Big Creek	29	.67	.75	11
Slug Run	90	.50	.75	33
SOUTHWESTERN ILLINOIS				
South Branch Doza Creek	0	.98	.95	-3
Doza Creek	50	.70	.95	26

SYNTHETIC FLOW-DURATION CURVES CAN BE
DEVELOPED FOR SURFACE-MINED AREAS

*Synthetic flow-duration curves were developed for a basin
that will be surface mined in the future.*

Mitchell (1957) described a technique for developing flow-duration curves
for ungaged streams. His technique is presented here, with some modifications,
for the purpose of developing flow-duration curves applicable to streams in
mined basins. Steps 2, 4, and 5 are modifications to his method.

(1)   Find the variability index of the stream from Mitchell's map, repro-
    duced here as figure 3.5-1.

(2)   Determine the percentage reduction in the variability index caused by
    surface mining with the equation developed in the previous section
    (fig. 3.4-2).

(3)   Compute the adjusted variability index (V).

(4)   Determine the average discharge (Q_A), in cubic feet per second
    (ft^3/s), by equations developed by Zuehls and others (1981a, 1981b)
    and Fitzgerald, Peters, and Zuehls (1983):

$$\text{Southern Illinois} \quad - \quad Q_A = A^{0.97}$$

$$\text{Southwestern Illinois} \quad - \quad Q_A = 0.81\ A$$

$$\text{Western Illinois} \quad - \quad Q_A = 0.72\ A^{0.98}$$

where A is the drainage area, in square miles.

(5)   Divide the average discharge (Q_A) by the drainage area to obtain
    average runoff (Q_a) in cubic feet per second per square mile
    $[(ft^3/s)/mi^2]$.

(6)   Determine the discharge equaled or exceeded 1 percent of the time by
    the equation (Mitchell, 1957, p. 168):

$$Q_{1.0} = 12.06\ V^{0.58}\ Q_a^{0.99}$$

    where $Q_{1.0}$ is the discharge equaled or exceeded 1 percent of the
    time, in cubic feet per second per square mile.

(7)   Determine the discharge equaled or exceeded 99 percent of the time by
    the equation:

$$Q_{99} = 0.002\ V^{-4.88}\ Q_a^{0.566}$$

where Q_{99} = the discharge equaled or exceeded 99 percent of the time, in cubic feet per second per square mile.

The equation in step 7 is a modification of Mitchell's (1957, p. 168) equation. Mitchell related Q_{99} to the variability index only. However, by relating Q_{99} to both the variability index and average runoff, the accuracy of estimating Q_{99} was improved (lower standard error of estimate).

(8) Determine the percentage of time the average discharge is equaled or exceeded by use of the equation (Mitchell, 1957, p. 175).

$$t_a = 36.6 - 16.6 \ V$$

where t_a = percentage of time the average discharge is equaled or exceeded.

Plotting instructions (fig. 3.5-2):

(1) Plot antilogarithm of adjusted variability index at an abscissa of 15.87 percent (probability scale). Identify it as point A.

(2) Plot 1.0 $(ft^3/s)/mi^2$ as ordinate at abscissa of 50.0 percent. Identify it as point B.

(3) Plot $Q_{1.0}$ at abscissa of 1.0 percent. Identify it as point C.

(4) Multiply the value of $Q_{1.0}$ by 2 and plot the product at abscissa of 0.1 percent. Identify it as point D.

(5) Plot Q_{99} at abscissa of 99.0 percent. Identify it as point E.

(6) Plot average runoff as ordinate at t_a as abscissa. Identify it as point F.

(7) Through point F; draw a straight line parallel to a line through points A and B; extend this line from near 5 percent abscissa to near 95 percent abscissa.

(8) Through point C and through or near to point D, draw a curve to merge with the straight line through point F.

(9) Through point E draw another curve to merge with the straight line through point F.

Figure 3.5-2 shows synthetic flow-duration curves developed for Brushy Creek near Harco (southern Illinois). Surface mining has just begun in this basin, and the intent is to mine the entire watershed (13.3 mi^2). Flow-duration curves are shown for conditions of no mining and for different percentages of mining. An example computation is given for 100 percent of the basin mined. The number to the left refers to the step explained above.

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1. From Mitchell's map (fig. 3.5-1), variability index = 1.25.

2. From the equation (fig. 3.4-2), percent reduction = -6.9 + .64(100) = 57 percent.

3. Adjusted variability index = 0.43(1.25) = 0.54.

4. From the equation for southern Illinois, $Q_A = A^{0.97}$, average discharge = 12.3 ft^3/s.

5. Q_a = 12.3/13.3 = 0.92 $(ft^3/s)/mi^2$.

6. $Q_{1.0}$ = 12.06$(0.54^{0.58})(0.92^{0.99})$ = 7.8 $(ft^3/s)/mi^2$.

7. Q_{99} = 0.002$(0.54^{-4.88})(0.92^{0.566})$ = 0.04 $(ft^3/s)/mi^2$.

8. t_a = 36.6 - 16.6(0.54) = 27.6 percent.

Plotting points

1. Point A = antilogarithm (0.55) = 3.5 at 15.87 percent.

2. Point B = 1.0 $(ft^3/s)/mi^2$ at 50.0 percent.

3. Point C = $Q_{1.0}$ = 7.8 $(ft^3/s)/mi^2$ at 1.0 percent.

4. Point D = 2$(Q_{1.0})$ = 15.8 $(ft^3/s)/mi^2$ at 0.1 percent.

5. Point E = Q_{99} = 0.04 $(ft^3/s)/mi^2$ at 99 percent.

6. Point F = Q_a at t_a = 0.92 $(ft^3/s)/mi^2$ at 27.6 percent.

The error in developing a synthetic duration curve by the above method can be large. This is due to the use of a tentative relationship (fig. 3.4-2) based on limited data and the errors in estimating the variability index, average discharge, Q_1, and Q_{99}.
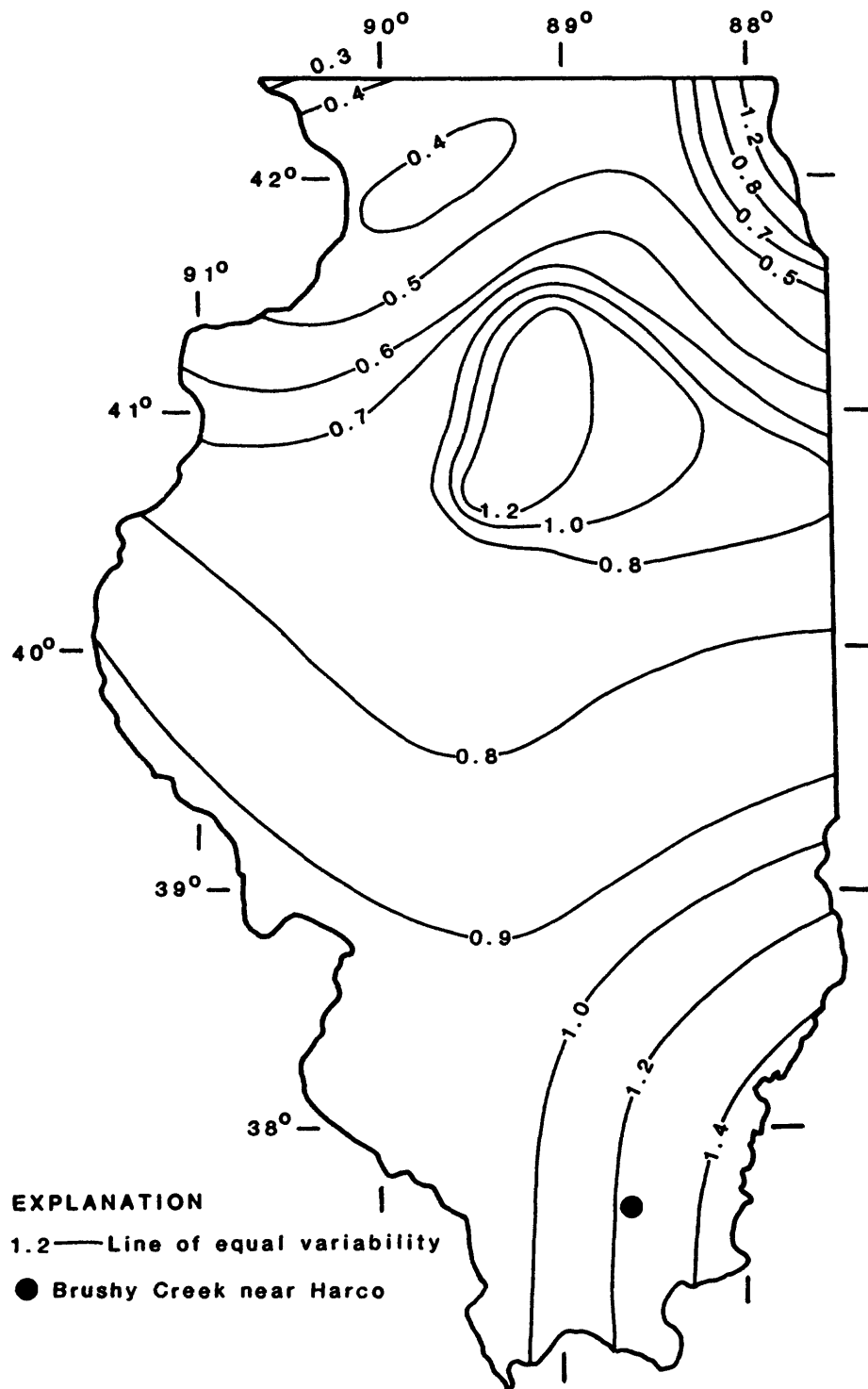
Figure 3.5-1.—Variability index values adapted
from Mitchell, 1957, p. 165.
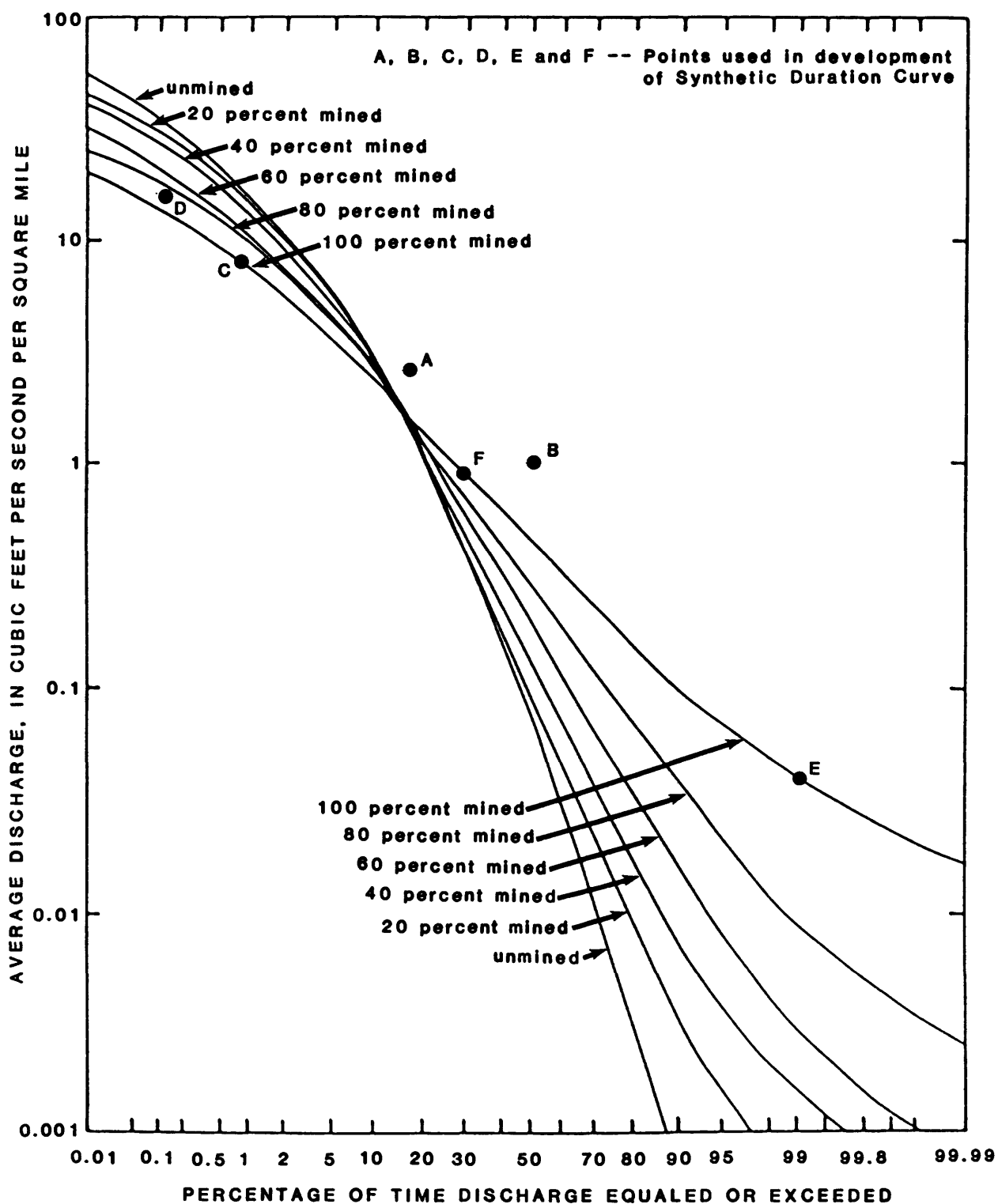
Figure 3.5-2.—Synthetic duration curves for Brushy Creek near Harco for different stages of mining.

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3.0 Surface Water
  3.6 Conclusions

   Several conclusions may be drawn from the analyses of surface-water data collected at the seven study sites.

   (1) Precipitation is fairly uniform among the basins. Unmined basins, which are primarily farmland, have higher runoff during the spring high-flow periods and lower runoff during the summer and fall low-flow periods than mined basins.

   (2) Streams draining areas that have undergone surface mining have lower variability indexes. The percentage reduction in the variability index is related to the percentage of the drainage basin mined.

   (3) Synthetic flow-duration curves may be prepared for ungaged streams by using Mitchell's (1957) technique. Mitchell's variability index can be adjusted on the basis of percent mined land in order to predict flow-duration curves for ungaged streams in basins intended for surface mining.

   (4) For a given storm, increased storage resulting from surface mining reduces storm runoff and peak discharges. Equations were developed that relate storm-runoff volume and peak discharges to climatologic data and basin characteristics.

4.0 Quality of Surface Water
  4.1 Water-Quality Characteristics

SURFACE MINING INCREASES CHEMICAL AND PHYSICAL WEATHERING

*Chemical and physical weathering are increased as a result of
surface mining. Streams draining mined areas have higher
concentrations of dissolved constituents than streams
draining unmined areas.*

Dissolved constituents in runoff are derived from precipitation and
chemical weathering. In the weathering process, air-water-mineral reactions
contribute solutes to runoff and to ground-water recharge.

The geologic logs in figures 2.1-1, 2.2-1, 2.3-1 show that the Harrisburg-
Springfield (No. 5) or Herrin (No. 6) coal member is overlain by a black shale,
locally known as the Anna Shale Member. This shale ranges from 1 to 4 feet in
thickness and has an average thickness of less than 2 feet. The shale contains
significant quantities of the iron sulfide minerals, pyrite and marcasite.
Although both minerals have the same ratio of sulfur to iron, the structural
properties cause marcasite to be less stable and more easily decomposed than
pyrite.

During surface mining, pyrite and marcasite are brought to the surface and
subjected to weathering. A large amount of acid, in the form of sulfuric acid
(H_2SO_4), can be caused by weathering. However, because limestone overlies the
Anna Shale, mine drainage may be neutralized before it is discharged to streams.
Calcium, magnesium, sulfate, and bicarbonate go into solution when limestone or
dolomite reacts with sulfuric acid in the mine drainage. As a result waters
draining surface-mined basins tend to have high concentrations of sulfate,
calcium, magnesium, and bicarbonate.

A common way to classify water is by its predominant cations and anions.
Concentrations in milligrams per liter are converted into milliequivalents per
liter, thus making unit concentrations of all ions chemically equivalent. This
was done for selected chemical analyses of water from six sites (fig. 4.1-1).

Two analyses were selected for each site, one representing a high discharge
and one representing a low discharge. The analyses are presented as bar graphs,
the lengths of the bars being proportional to the sum of milliequivalents of
anions or cations. Each bar is split to represent cations and anions and
divided into segments showing the concentrations of individual ions.

The bar graphs illustrate that the mined areas have higher concentrations
of dissolved constituents. The dissolved constituents are diluted at high
flows; however, the dilution seems less in the mined areas than in the unmined
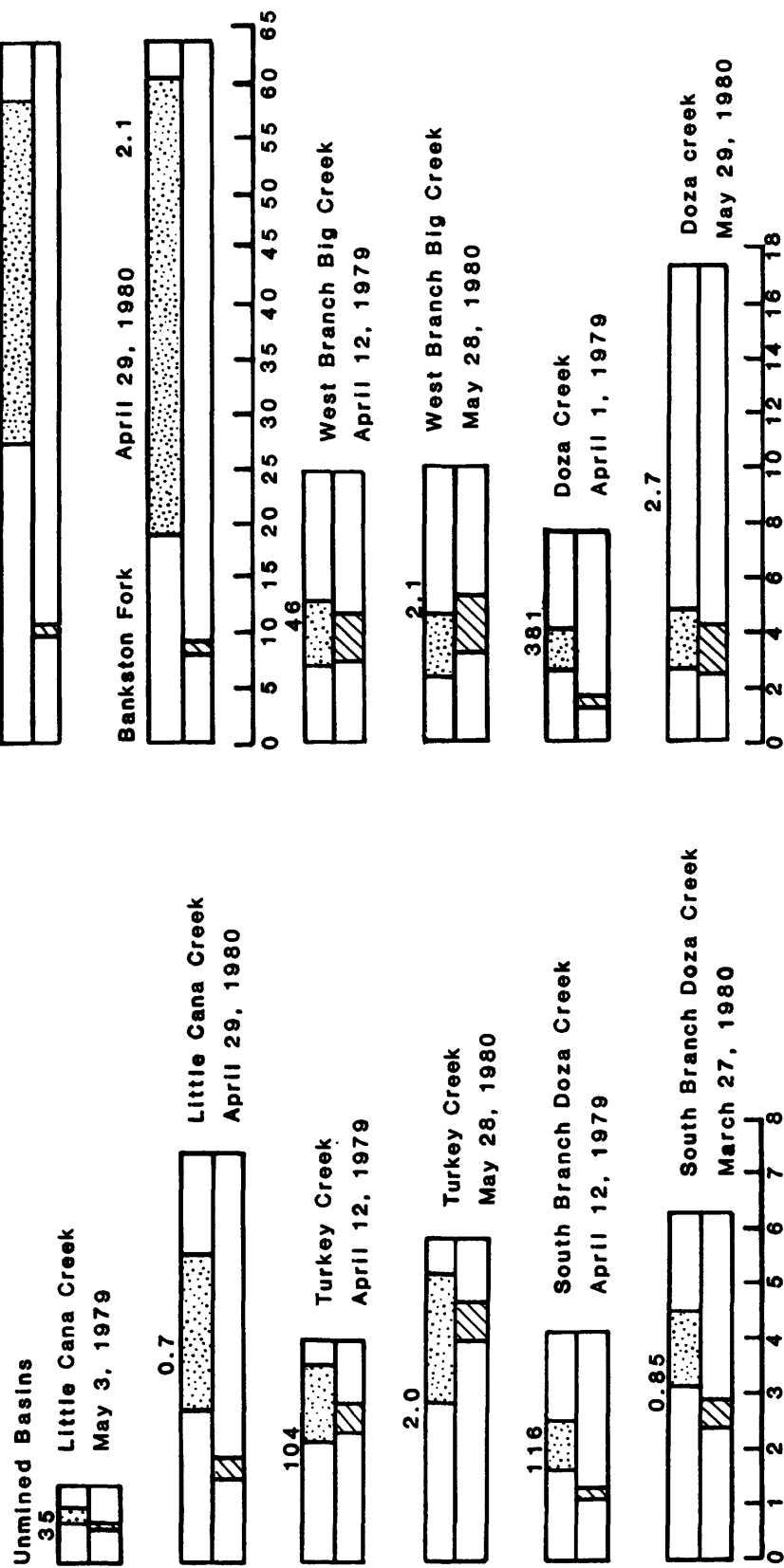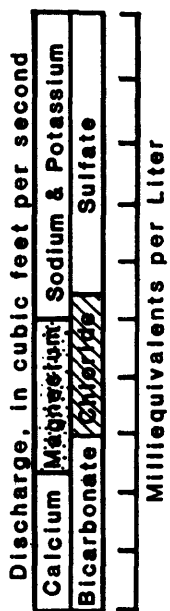areas.

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Figure 4.1-1.--Variation in concentration of chemical constituents in mined and unmined basins at relatively high and low levels of stream discharge.

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4.0 Quality of Surface Water
    4.2 *Specific Conductance as Indicator of Dissolved Solids*

DISSOLVED-SOLIDS CONCENTRATIONS HIGHER IN MINED AREAS

*Annual dissolved-solids loads were determined from measurements of
specific conductance and discharge and by relating dissolved solids
to discharge. Mined areas had higher yields than unmined areas
and regional relations showed the high dissolved-solids
loads in the Saline and Big Muddy River basins.*

Specific conductance, an indirect measure of dissolved solids, was
recorded at six sites for 2 years, beginning in 1978, and at Slug Run since
July 1975. Figure 4.2-1 shows the relation between dissolved-solids concen-
trations and specific conductances for Doza Creek. The two characteristics
are highly correlated at this site and also at the other six sites.

The relation between dissolved solids and specific conductance for each
station was developed from periodic samples taken at various discharges.
From these relations and records of daily specific conductance and daily
discharge, daily dissolved-solids loads for each station were determined.

Two years of daily loads in tons for each of the six sites were used to
compute mean annual dissolved-solids yields in tons per square mile. Four
years of data for the Slug Run basin were used to compute its mean yield.
Mean dissolved-solids yields for 1978-79 water years are:

Southern Illinois basins	Little Cana Creek (unmined)	=	190 tons/mi^2
	Bankston Fork (99 percent mined)	=	4,400 tons/mi^2
Western Illinois basins	Turkey Creek (unmined)	=	160 tons/mi^2
	West Branch Big Creek (29 percent mined)	=	390 tons/mi^2
	Slug Run (90 percent mined)	=	800 tons/mi^2
Southwestern Illinois basins	South Branch Doza Creek (unmined)	=	94 tons/mi^2
	Doza Creek (50 percent mined)	=	270 tons/mi^2

Dissolved-solids yields were also calculated for two sites where data were
scant, Big Muddy River at Murphysboro and South Fork Saline River near Carrier
Mills. Neither of these sites has continuous records of specific conductance,
but both have continuous discharge records. The annual dissolved-solids yields
were computed by the duration-curve technique (Searcy, 1959). This technique

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depends on the correlation of the dissolved-solids concentration with stream discharge and the availability of flow-duration curves. An example of this technique is shown in Toler (1982, p. 10-13). The mean annual dissolved-solids yields for these two stations were:

South Fork Saline River (6.7 percent mined) = 414 tons/mi^2

Big Muddy River (2.4 percent mined) = 172 tons/mi^2

Dissolved-solids yields were plotted against the percentage of drainage area disturbed by surface mining. Two graphs, one for basins in the western part of Illinois (fig. 4.2-2) and one for basins in the southern part of Illinois (fig. 4.2-3), indicate correlation between yields and percentage of area mined. Dissolved-solids yields from the basins in the southern part of Illinois were higher than yields from the basins in the western part.

A method to estimate mean annual dissolved-solids loads for streams in the western and southern parts of Illinois is as follows:

(1) From figure 4.2-2 or 4.2-3, determine the mean annual dissolved-solids yield, in tons per square mile, using the percentage of drainage area surface mined.

(2) Compute the mean annual dissolved-solids loads, in tons, by multiplying the mean annual dissolved-solids yields by the drainage area.
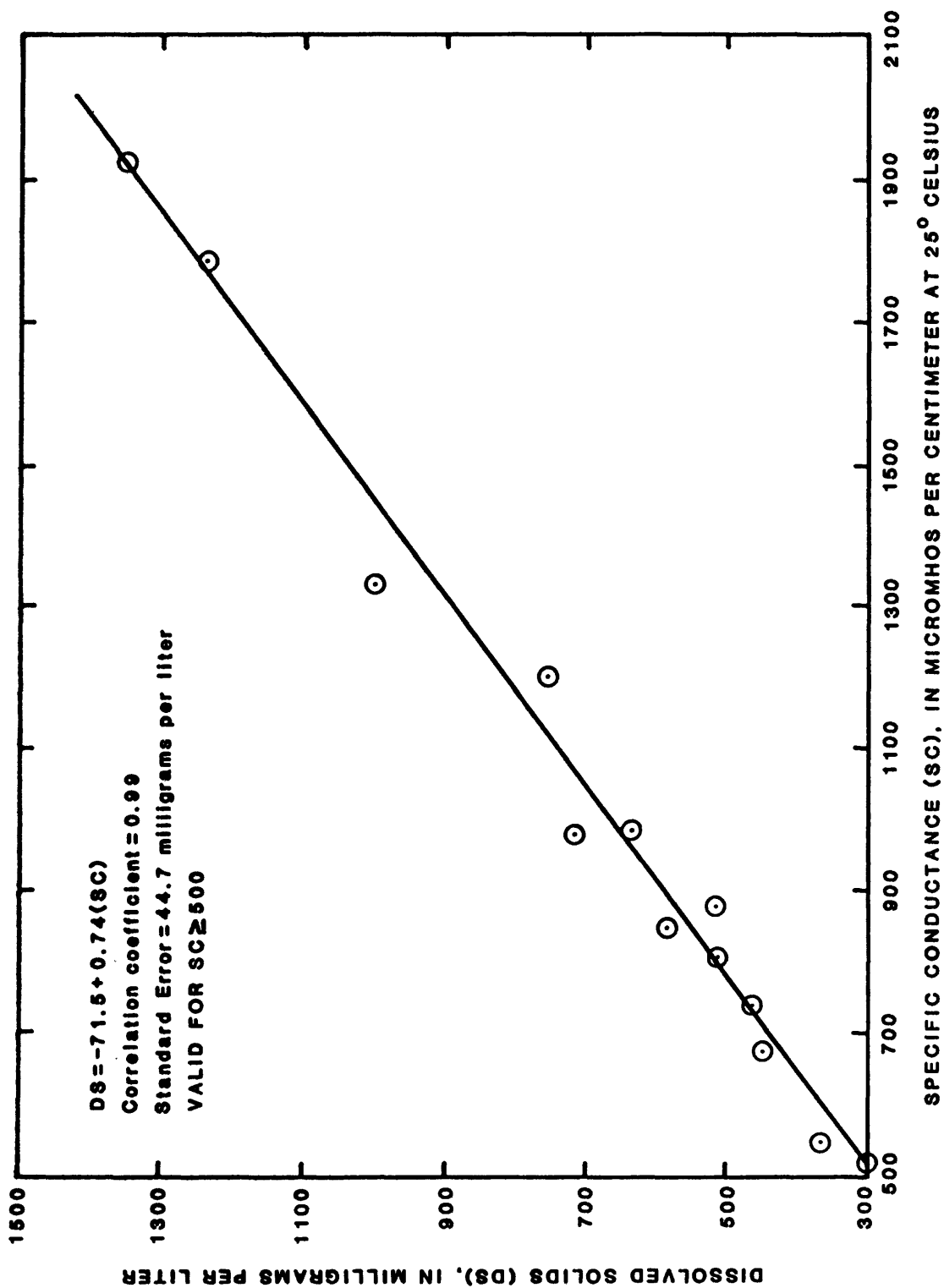
Figure 4.2-1.--Relation between dissolved-solids concentration and specific conductance for Doza Creek.

DS = -71.5 + 0.74(SC)
Correlation coefficient = 0.99
Standard Error = 44.7 milligrams per liter
VALID FOR SC ≥ 500

SPECIFIC CONDUCTANCE (SC), IN MICROMHOS PER CENTIMETER AT 25° CELSIUS

DISSOLVED SOLIDS (DS), IN MILLIGRAMS PER LITER

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MEAN ANNUAL DISSOLVED SOLIDS YIELD (Y), IN TONS PER SQUARE MILE

$Y = 170 + 7.0(P)$

Correlation coefficient = 0.99

Standard Error = 19.0 tons per square mile per year

1000

800

600

400

200

0

0   20   40   60   80   100

AREA OF SURFACE MINES (P) AS A PERCENTAGE OF TOTAL DRAINAGE AREA

Figure 4.2-2.--Relation between dissolved-solids yield and
percentage of the area surface mined for
three western Illinois basins.
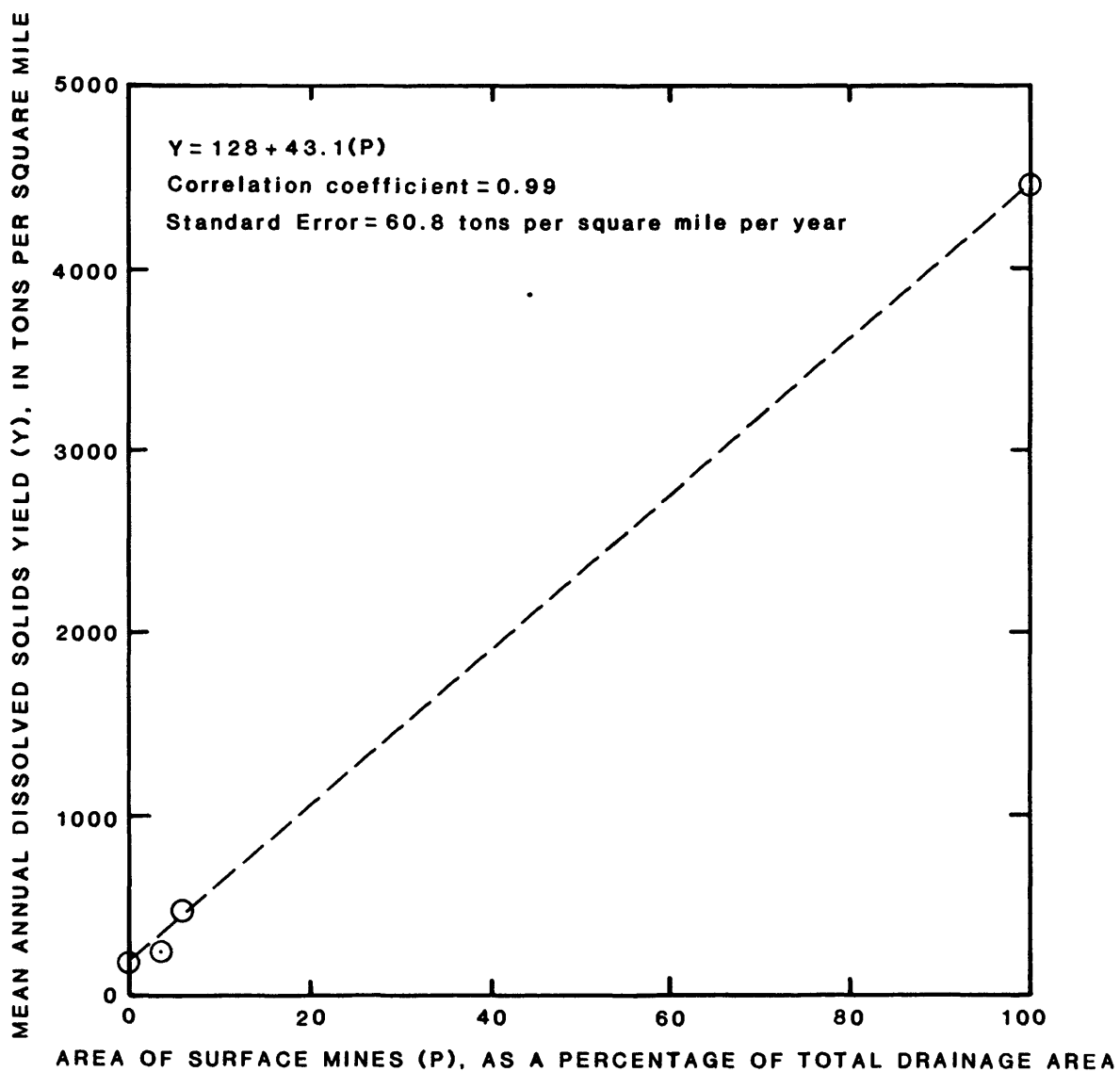
Figure 4.2-3.--Relation between dissolved-solids yield and
percentage of the area surface mined for
four southern Illinois basins.

SURFACE MINING INCREASES SULFATE YIELDS

*Annual sulfate yields were determined by relating sulfate
concentrations to dissolved-solids concentrations.
Regional relations show the largest sulfate yields
are in the Saline-Big Muddy River basins.*

Sulfate is a major solute produced in the formation of acid mine water.
Although other constituents may subsequently be dissolved or precipitated as a
result of neutralization by acidic waters, the sulfate introduced through mine
drainage remains in solution and can be used as an indicator of mine drainage.

For all seven sites, a high degree of correlation exists between sulfate
and dissolved-solids concentrations, as shown in figure 4.3-1 for South Branch
Doza Creek. Annual sulfate loads were calculated by using the equation
relating sulfate and dissolved solids and the equations developed in section
4.2. The annual sulfate yields for the seven sites are:

Southern
Illinois —
basins

    Little Cana Creek (unmined)   =   109 tons/mi^2

    Bankston Fork (99 percent mined) = 2,650 tons/mi^2

Western
Illinois —
basins

    Turkey Creek (unmined)   =   19 tons/mi^2

    West Branch Big Creek
      (29 percent mined)   =   160 tons/mi^2

    Slug Run (90 percent mined)   =   448 tons/mi^2

Southwestern
Illinois —
basins

    South Branch Doza Creek (unmined) =   47 tons/mi^2

    Doza Creek (50 percent mined)   =   140 tons/mi^2

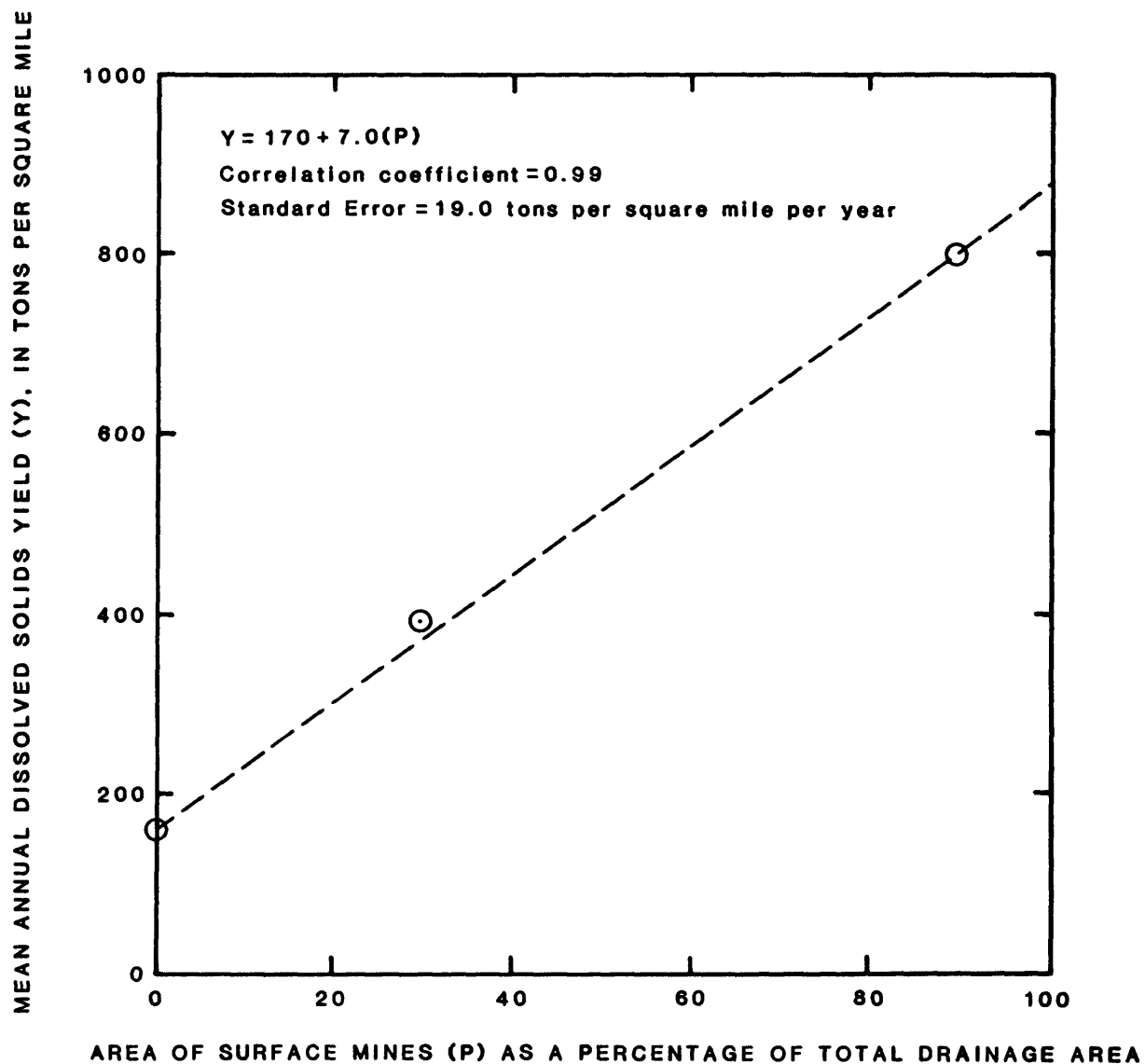Sulfate yields were plotted as a function of the percentage of drainage
area that has been surface mined. Separate relations were developed for the
sites in western and southern parts of Illinois (figs. 4.3-2 and 4.3-3).
Toler (1982) had previously established such a relation for sites in the
southern part of Illinois. Data for Bankston Fork (99 percent mined, fig.
4.3-3) were used to extend Toler's relation.

A comparison of figures 4.3-2 and 4.3-3 shows that more sulfate is pro-
duced in the basins studied in the southern part of Illinois than in basins
studied in other parts of Illinois. The least amount of sulfate was produced
in basins studied in the southwestern part of Illinois (Kaskaskia River
basin).
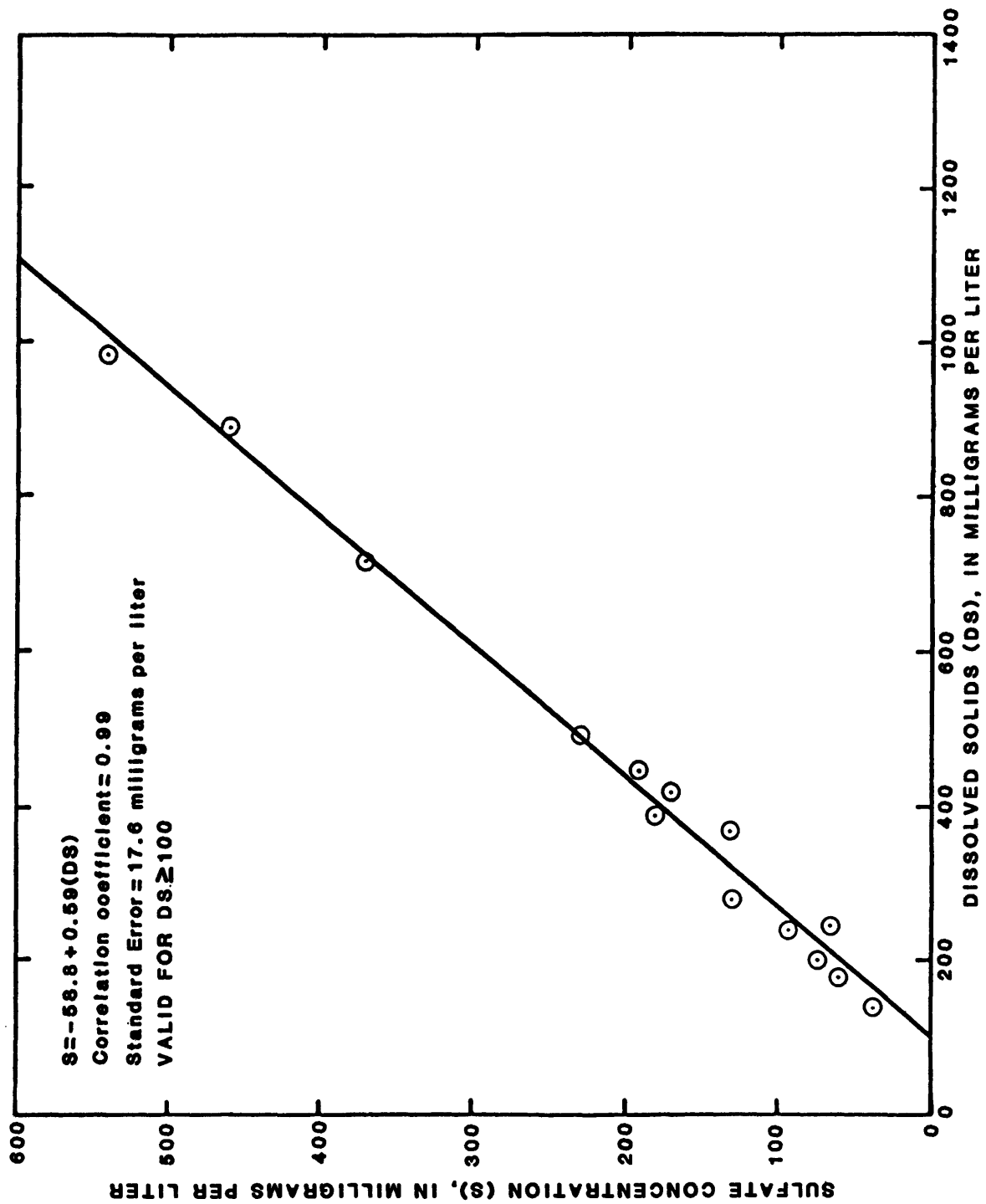
Figure 4.3-1.--Relation between dissolved sulfate and dissolved-solids concentrations for South Branch Doza Creek.

Y = 20 + 4.8(P)

Correlation coefficient = 0.99

ANNUAL SULFATE YIELD (Y), IN TONS PER SQUARE MILE

AREA OF SURFACE MINES (P), AS A PERCENTAGE OF TOTAL DRAINAGE AREA

Figure 4.3-2.--Relation between dissolved sulfate yield and
percent area surface mined for three
western Illinois basins.

Figure 4.3-3.—Relation between dissolved sulfate yield
and percent area surface mined for
13 southern Illinois basins.

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4.0 Quality of Surface Water
   4.4 Calcium

SURFACE-MINED BASINS HAVE HIGH CALCIUM YIELDS

*Annual calcium yields were determined by relating calcium to
dissolved solids. Regional relations show the highest
calcium yields in the Saline-Big Muddy River basins.*

Limestone (calcium carbonate), in contact with acid mine drainage, will
neutralize the acid produced by the oxidation of pyrite. If limestone is
present in sufficient quantities, calcium can become a major constituent in
waters draining surface-mined areas.

Calcium concentrations are plotted as a function of dissolved-solids con-
centrations for South Branch Doza Creek (fig. 4.4-1). Annual calcium yields
for the seven sites were computed to be:

Southern
   Illinois ——— ⌈ Little Cana Creek (unmined)   =   23 tons/mi^2
   basins   ⌊ Bankston Fork (99 percent mined) =   700 tons/mi^2

Western   ⌈ Turkey Creek (unmined)   =   38 tons/mi^2
   Illinois ———   West Branch Big Creek
   basins   (29 percent mined)   =   52 tons/mi^2
                 ⌊ Slug Run (90 percent mined)   =   64 tons/mi^2

Southwestern   ⌈ South Branch Doza Creek (unmined) =   7 tons/mi^2
   Illinois ———
   basins   ⌊ Doza Creek (50 percent mined)   =   11 tons/mi^2

Annual calcium yields were also calculated for Big Muddy River at
Murphysboro and South Fork Saline River near Carrier Mills and are:

   Big Muddy River (2.4 percent mined) = 24 tons/mi^2;

   South Fork Saline River (6.7 percent mined) = 55 tons/mi^2.

Annual calcium yields were plotted as a function of percentage of surface-
mined area for sites in western and southern parts of Illinois. Figures 4.4-2
and 4.4-3 show that more calcium is produced as a result of surface mining at
sites in the southern part of the State than at sites in the western part.

Comparing the calcium yields from Doza Creek and South Branch Doza Creek
to values in figures 4.4-2 and 4.4-3 indicates that sites in the southwestern
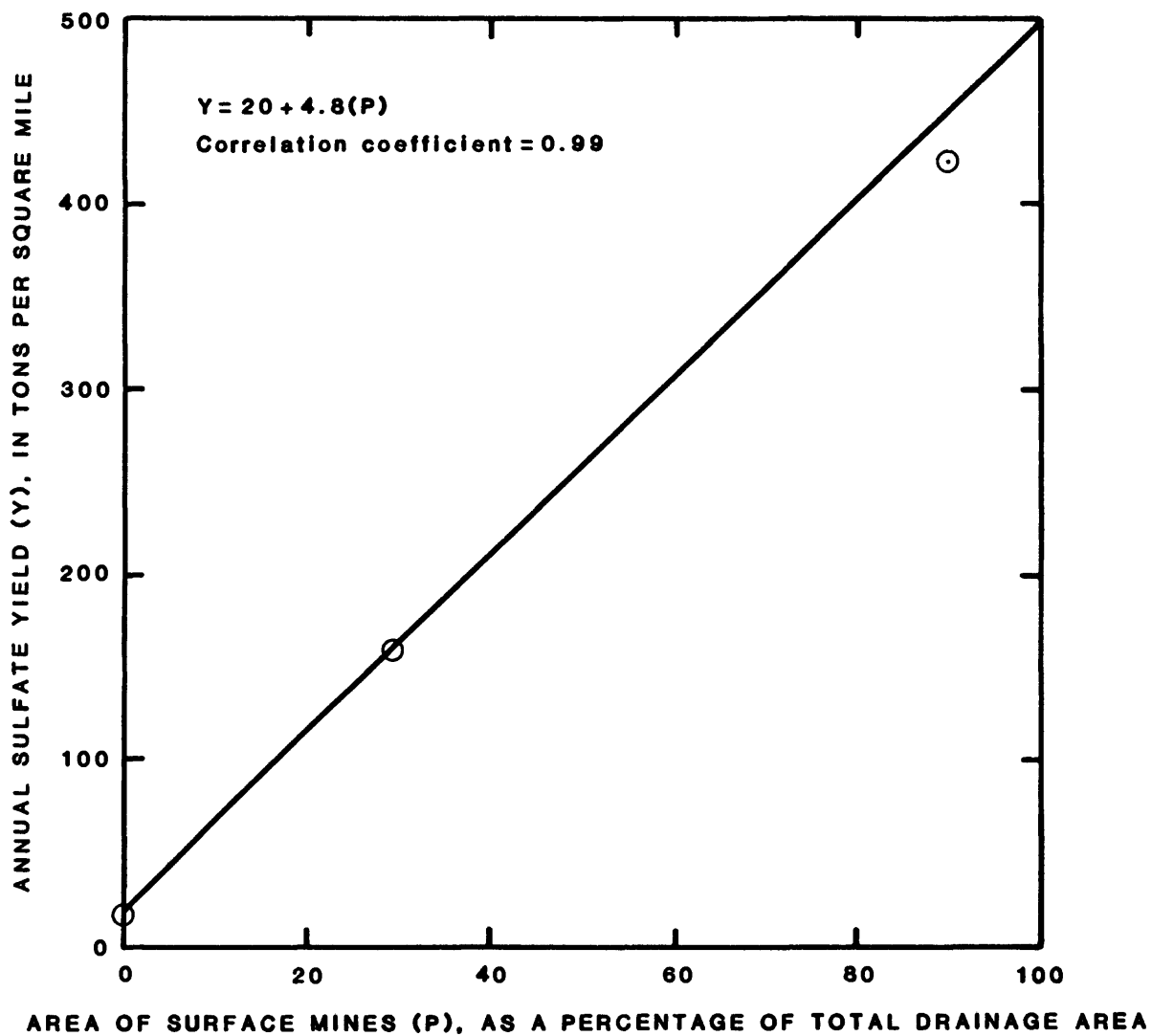part of Illinois produce the lowest calcium yields of the sites studied.
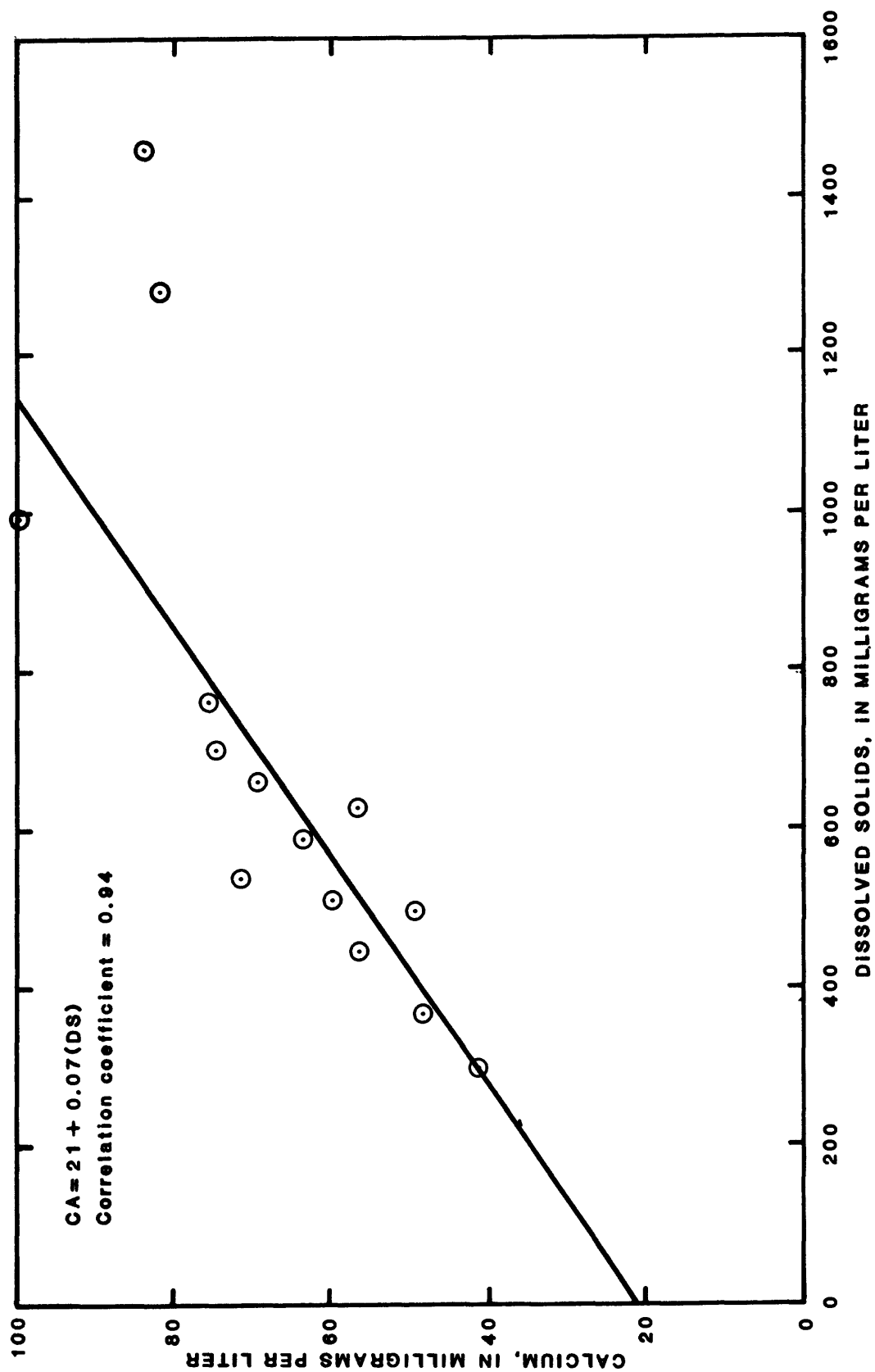
Figure 4.4-1.--Relation between dissolved calcium and dissolved solids
for South Branch Doza Creek.

CA = 21 + 0.07(DS)
Correlation coefficient = 0.94

DISSOLVED SOLIDS, IN MILLIGRAMS PER LITER

CALCIUM, IN MILLIGRAMS PER LITER
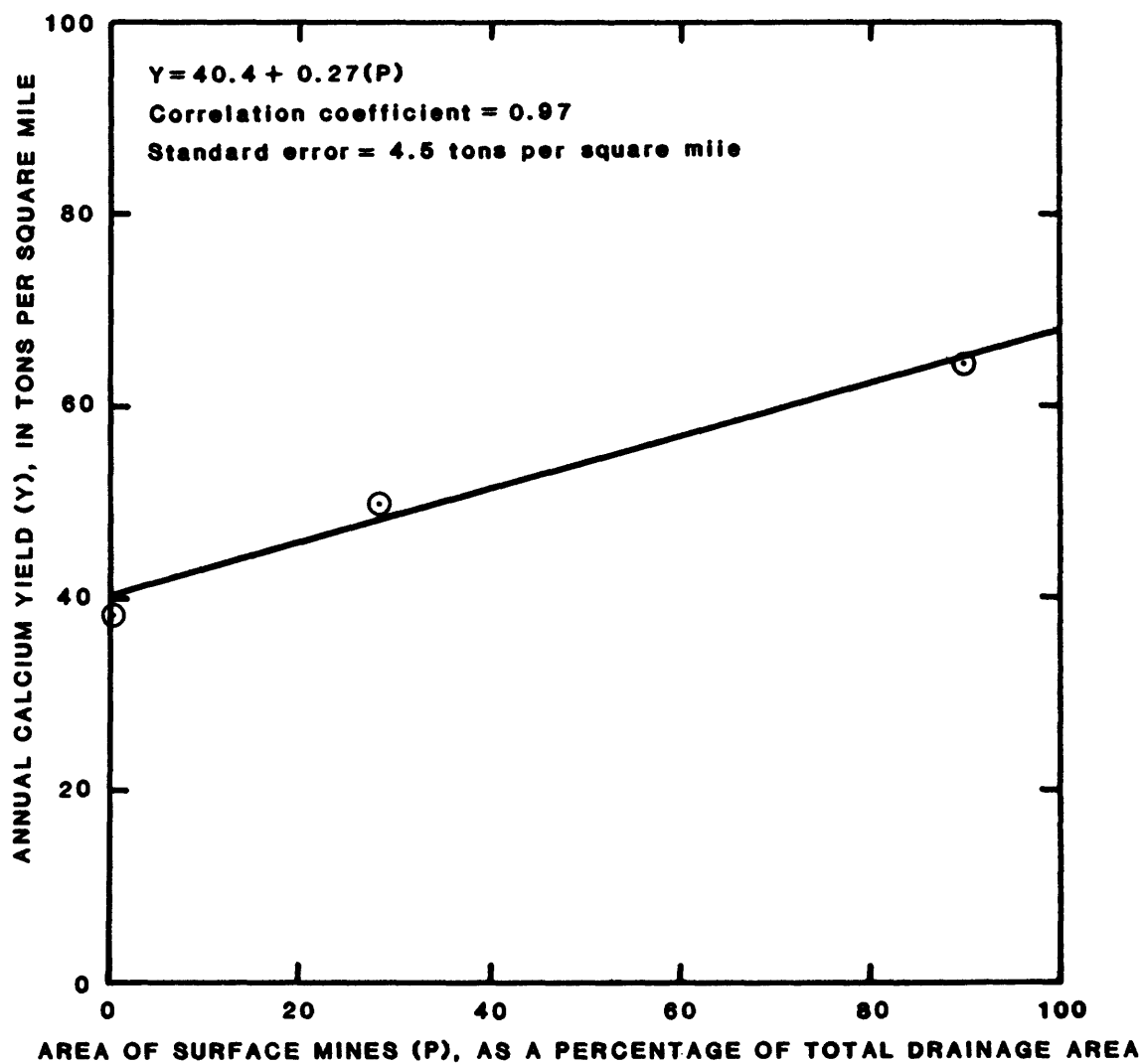
Figure 4.4-2.—Relation between dissolved calcium yield
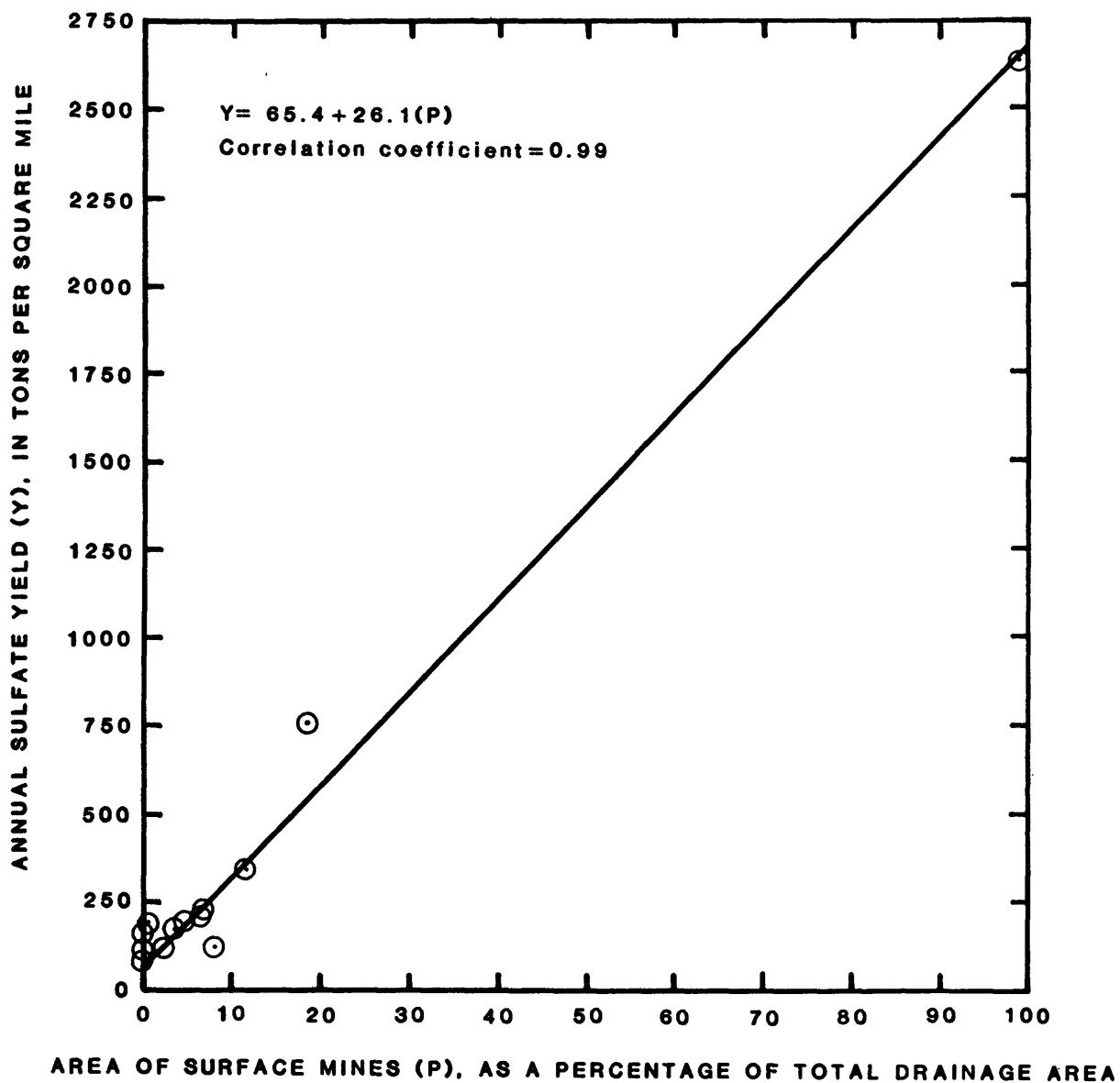and percent area surface mined for
western Illinois basins.

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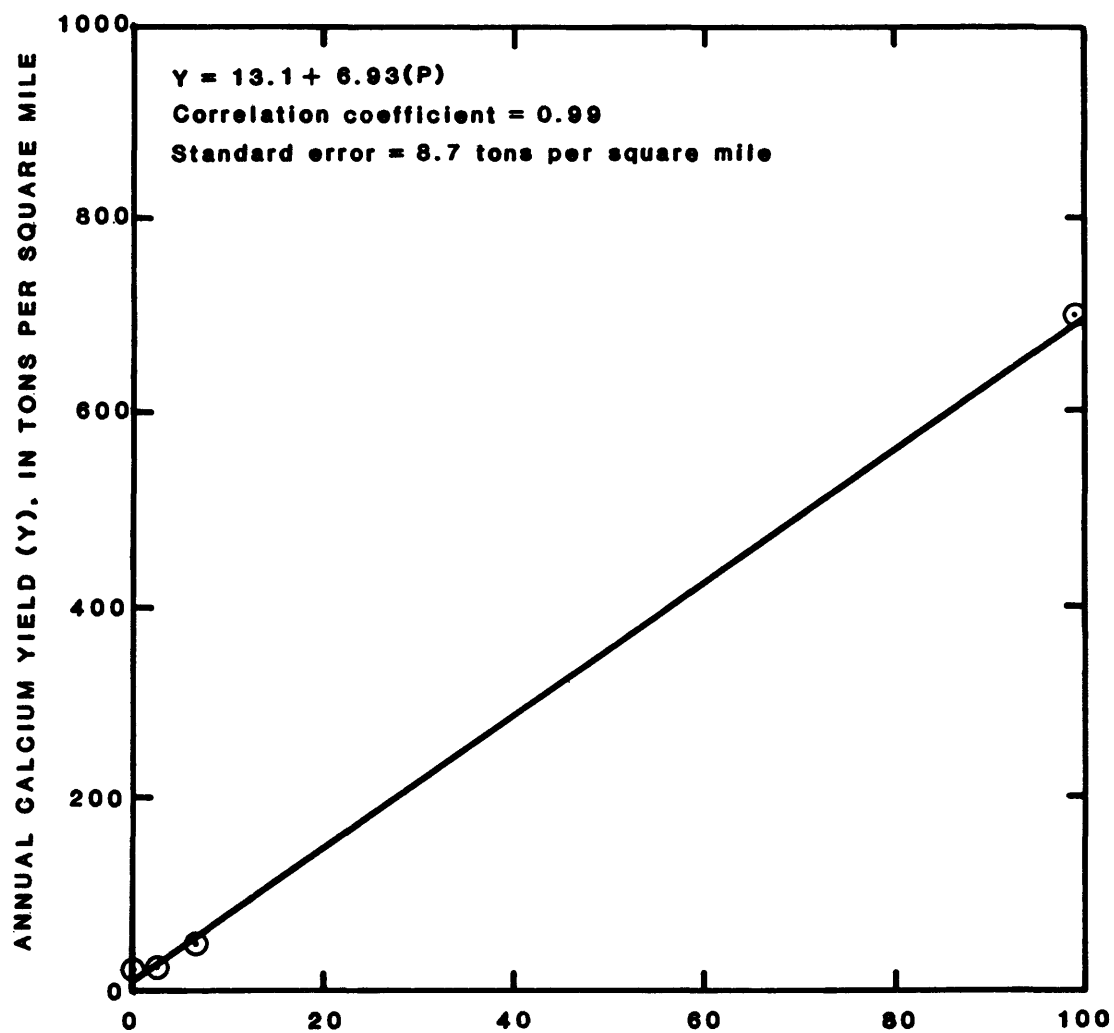
Figure 4.4-3.—Relation between dissolved calcium yield and percent area surface mined for southern Illinois basins.

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4.0 Quality of Surface Water
     4.5 Water Temperature

SURFACE MINING AFFECTS WATER TEMPERATURE

*Harmonic analysis of data from seven stations indicates higher
mean temperatures and lower amplitudes of the temperature
curve for streams draining surface-mined basins than
unmined basins. However, these differences are
not apparent in streams draining large basins.*

The annual variation of stream temperature has been shown (Ward, 1963;
Collings, 1969; Steele and Gilroy, 1972) to be approximated by a simple har-
monic function of the form:

$$T = M + A [\sin(0.0172x + C)]$$

where T = stream temperature, in degrees Celsius, on day x, as x varies from
           1 to 366 (October 1 as day 1);

       M = mean annual stream temperature, in degrees Celsius;

       A = amplitude of the annual stream-temperature curve, in degrees Celsius;

       C = phase coefficient of the annual cycle, in radians.

A generalized harmonic curve illustrating these relations is shown in figure
4.5-1.

The generalized harmonic curve was fitted to the daily stream-temperature
data from each site. Water temperature data from Zogorski and Kiesler (1976)
plotted in figure 4.5-1, show the harmonic character of the seasonal tempera-
ture changes. Harmonic coefficients M, A, and C were calculated for each site
and are shown in table 4.5-1. In addition to the harmonic coefficients, the
standard error of estimate of a daily temperature value and the percentage of
the variation in daily temperature values that is accounted for by the har-
monic function also are presented.

Results of the harmonic analyses of data from the seven sites show that
the harmonic mean is higher for mined basins than for unmined basins and that
amplitude A is lower for mined basins. However, these relationships were
noted only in streams that have relatively small drainage areas; for streams
draining large watersheds, no differences were apparent. Table 4.5-2 shows
the results of harmonic analyses of records from long-term gaging stations.

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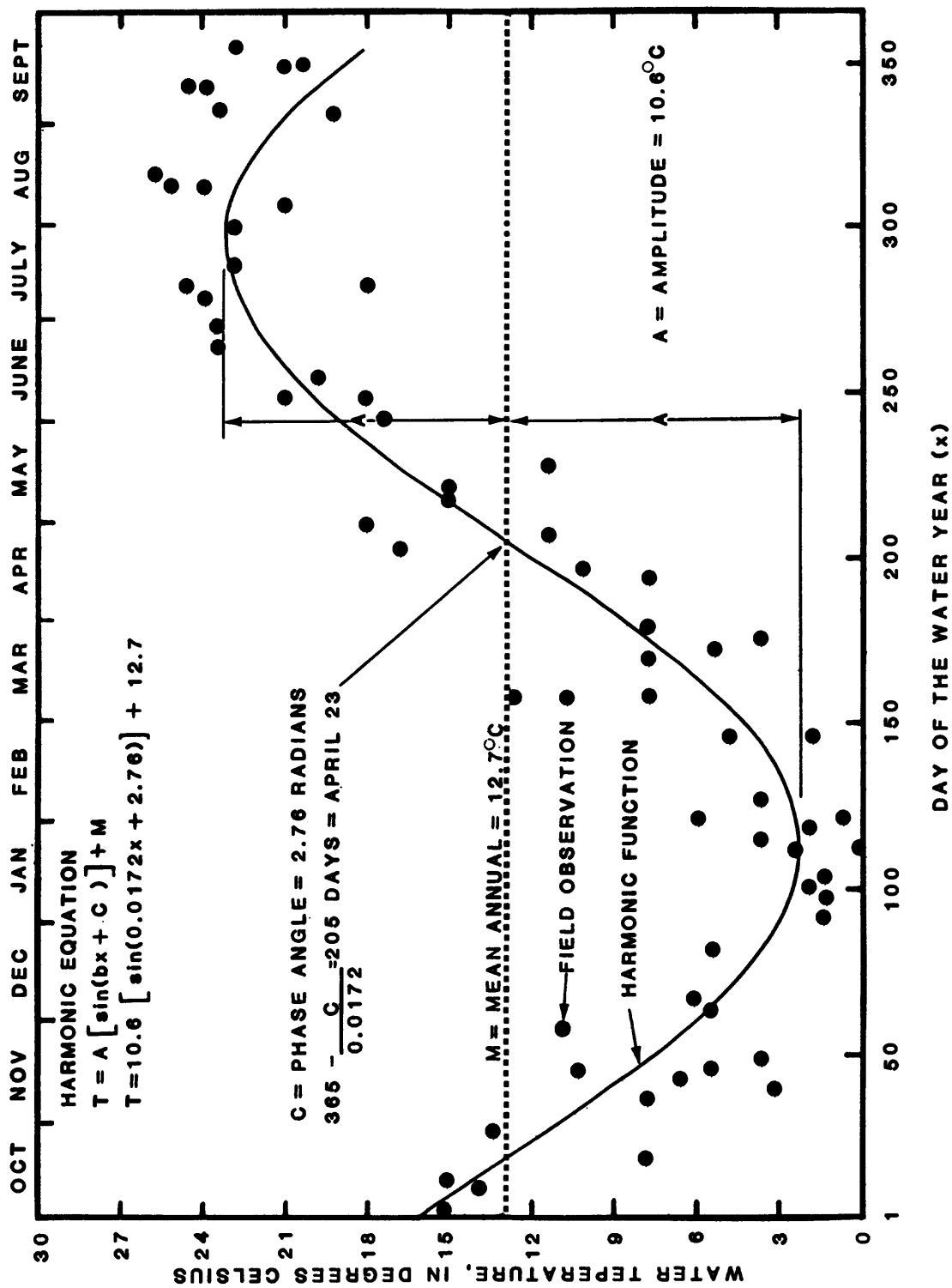
Figure 4.5-1.--Generalized harmonic curve for Triplett Creek at Morehead, Kentucky.

Table 4.5-1 Harmonic coefficients for the seven study sites

	Sample size (days)	Harmonic mean M (deg. C)	Amplitude A (deg. C)	Phase angle C (radians)	Variation explained (percent)	Standard error of estimate (deg. C)
Little Cana Creek	183	13.49	12.43	2.79	88	2.56
Bankston Fork	365	14.93	9.71	2.80	94	1.75
Turkey Creek	292	11.85	14.66	2.75	91	2.97
West Branch Big Creek	345	12.72	13.53	2.81	96	1.87
Slug Run	715	12.39	12.68	2.80	93	2.51
Doza Creek	254	14.53	13.90	2.84	96	1.96
South Branch Doza Creek	221	13.18	13.89	2.84	93	2.66

Table 4.5-2 Harmonic coefficients for long-term gaging stations

Geographic location of basin	Station	Drainage area (mi²)	Sample size N	Harmonic mean M (deg. C)	Amplitude A (deg. C)	Phase angle C (radians)
Western Illinois	Indian Creek near Wyoming	62.7	121	12.58	12.61	2.79
	Spoon River at London Mills	1,062	83	12.20	12.97	2.79
	Spoon River at Seville	1,636	103	12.73	12.41	2.70
	Drowning Fork at Bushnell	26.3	81	11.77	11.52	2.71
	La Moine River at Colmar	655	160	12.58	13.33	2.81
	La Moine River at Ripley	1,293	160	12.98	12.93	2.83
	Mud Creek near Marissa	72.4	58	12.70	11.44	2.84
	Little Crooked Creek near New Minden	84.3	60	12.15	12.33	2.95
Southwestern Illinois	Sugar Creek at Albers	124	89	13.70	12.88	2.84
	Richland Creek near Hecker	129	95	14.90	12.57	2.84
	Silver Creek near Troy	154	103	13.20	12.05	2.91
	Kaskaskia River near Venedy Station	4,393	83	13.70	13.08	2.75
	Eagle Creek near Equality	8.51	57	12.50	10.93	2.79
	Brushy Creek near Harco	13.3	60	12.20	12.88	2.87
Southern Illinois	Crab Orchard Creek near Marion	31.7	89	13.40	12.13	2.85
	Lusk Creek near Eddyville	42.9	89	12.99	11.31	2.80
	South Fork Saline River near Carrier Mills	147	78	15.00	13.47	2.84

4.0 Quality of Surface Water
  4.6 *Suspended Sediment*

SURFACE-MINED BASINS MAY YIELD LESS SUSPENDED
SEDIMENT THAN UNMINED BASINS

Suspended-sediment loads from mined basins were lower than
yields from unmined basins. However, the unmined basins
are primarily farmland, and the mined basins have had no
active surface mining for at least 5 years.

Suspended-sediment samples were collected monthly and during high runoff at six study sites. In addition, daily suspended-sediment samples have been collected at Slug Run since 1975.

For this study, the suspended-sediment samplers used could not sample within 0.3 foot of the stream bottom. Therefore, the sediment below this level, which constitutes the bedload, was not measured. Only suspended-sediment data are given in this report, and no attempt was made to estimate bedload transport.

Sediment yields at the six study sites were determined by the transport-duration technique. This technique makes use of (1) sediment-transport curves that define relations between instantaneous water and sediment discharges, and (2) streamflow-duration curves that define the percentage of time that any flow value was equaled or exceeded. The sample calculation for Little Cana Creek, shown in table 4.6-1, is based on figures 4.6-1 and 4.6-2.

The above procedure was used to calculate annual sediment yields for the six study sites. These and the 5-year average yield for Slug Run are:

Southern Illinois basins	Little Cana Creek (unmined)	=	125 tons/mi^2
	Bankston Fork (99 percent mined)	=	83 tons/mi^2
Western Illinois basins	Turkey Creek (unmined)	=	233 tons/mi^2
	West Branch Big Creek (29 percent mined)	=	57 tons/mi^2
	Slug Run (90 percent mined)	=	125 tons/mi^2
Southwestern Illinois basins	South Branch Doza Creek (unmined)	=	425 tons/mi^2
	Doza Creek (50 percent mined)	=	151 tons/mi^2

Probable reasons why mined basins produced lower sediment yields than unmined basins are (1) the higher infiltration capacity of mine spoil, (2) the effects of reestablished continual vegetative cover in mined areas that reduces overland flow and sediment loads, and (3) the fact that much of the unmined area was farmland, which when tilled can produce very high sediment yields.
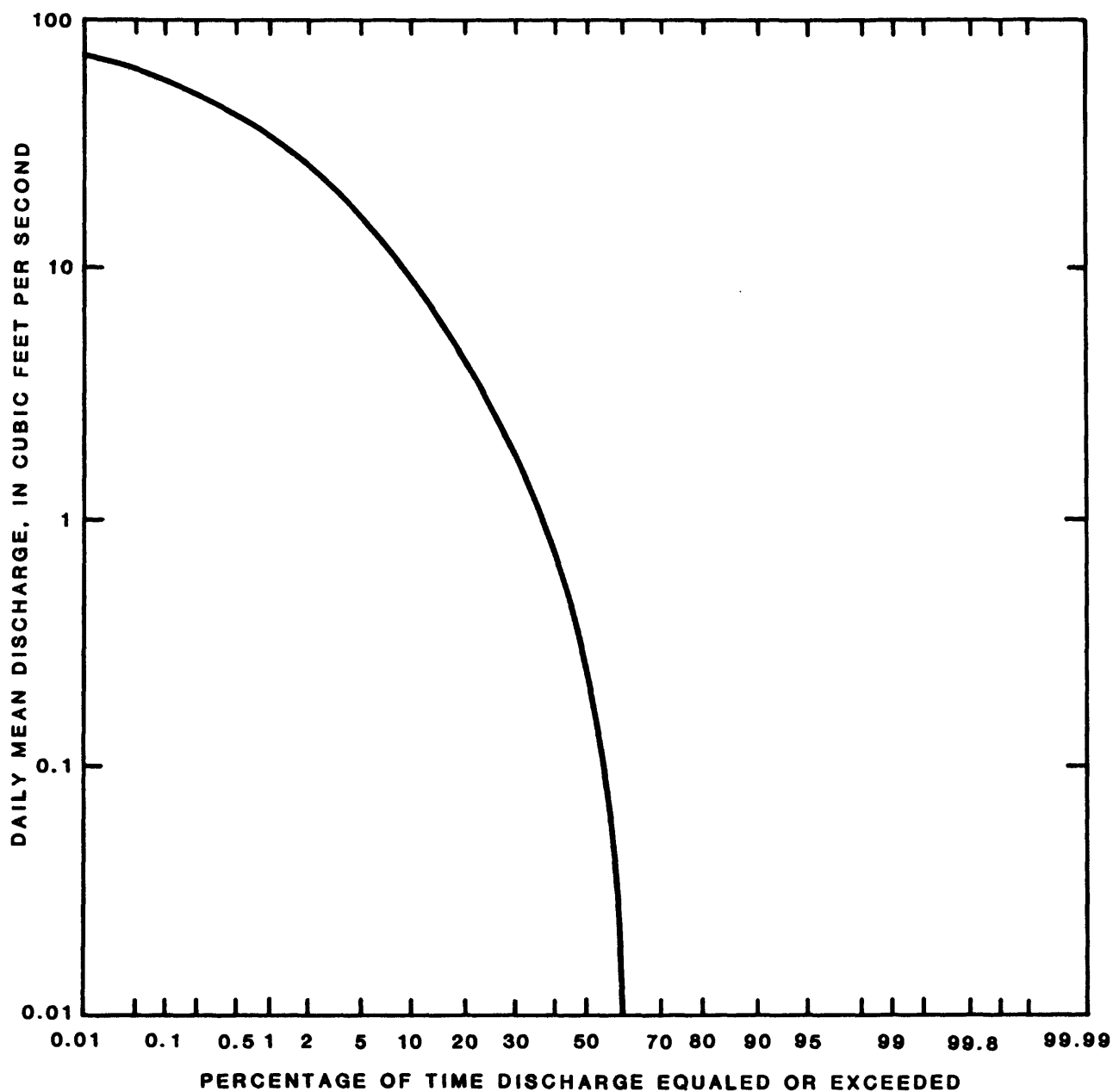
Figure 4.6-1.--Duration curve of daily mean discharge of
Little Cana Creek.
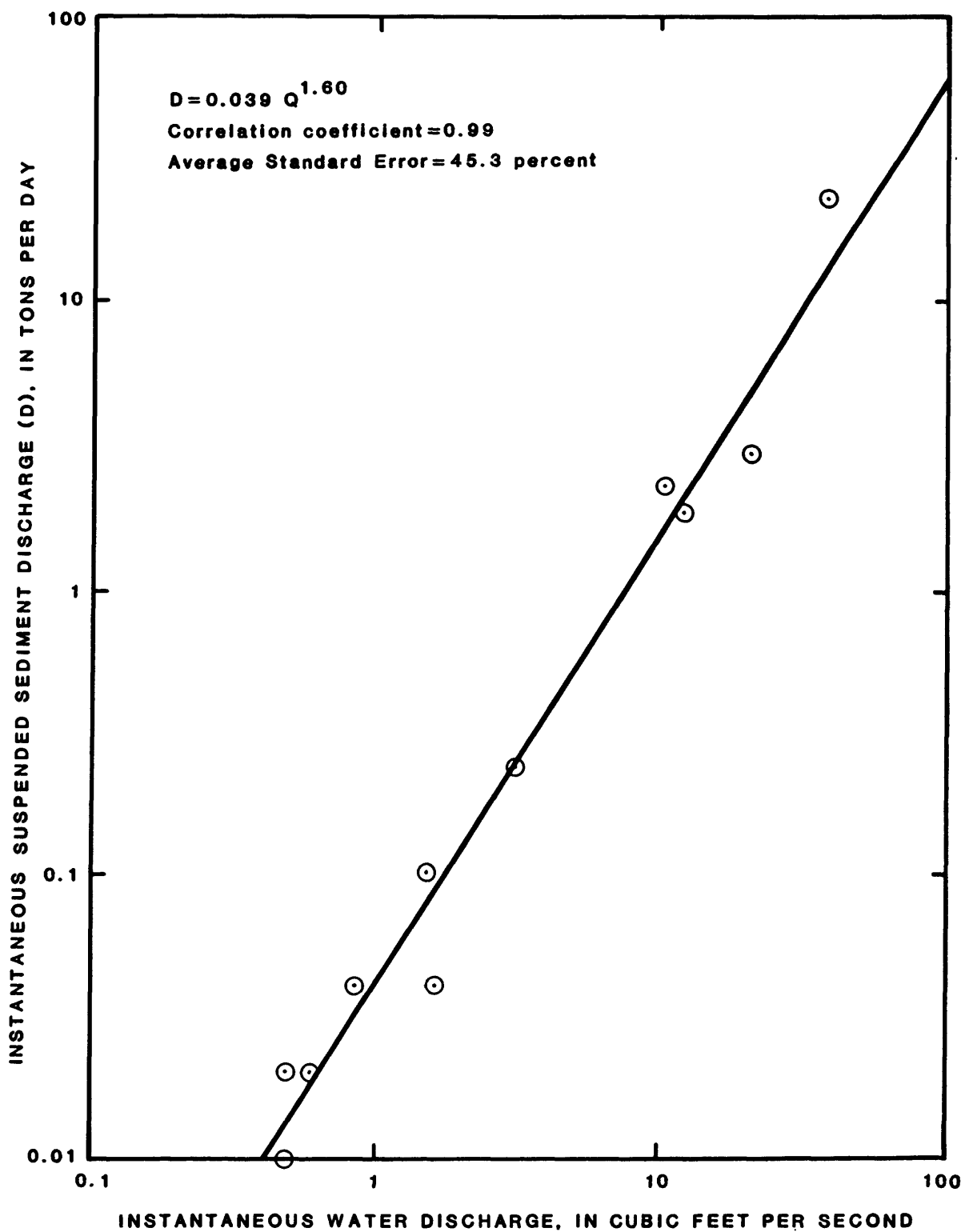
Figure 4.6-2.--Sediment transport curve for
Little Cana Creek.

Table 4.6-1 Computations of mean annual suspended-sediment yield of
Little Cana Creek near Creal Springs

Percentage of time	Water discharge equaled or exceeded (cubic feet per second)	Suspended-sediment discharge (tons per day)	Interval between succeeding percentages of time	Average suspended-sediment discharge for time interval (tons per day)	Sediment discharge multiplied by time interval x 0.01
0	80	65			
.1	60	29	0.1	47	0.047
.3	50	21	.2	25	.050
.9	35	13	.6	17	.102
2	24	6.8	1.1	10	.110
4	15	3.1	2	5	.100
6	8	1.2	2	2	.040
9	3.4	.29	3	.75	.022
15	1.8	.12	6	.20	.012
20	1.3	.07	5	.10	.005
30	.7	.025	10	.05	.005
40	.4	.01	10	.02	.002

Total (tons per day) .495

Mean annual suspended-sediment load = 365 x 0.495 = 181 tons

Drainage area = 1.46 mi^2

Mean annual sediment yield = 181 ÷ 1.46 = 124 tons/mi^2

4.0 Quality of Surface Water
   4.7 *Aluminum*

ALUMINUM IS PRESENT PREDOMINANTLY IN SUSPENDED PHASE

There is a direct relationship between concentrations of suspended
aluminum and suspended sediment. Unmined areas contribute more
aluminum than mined areas where in-place neutralization of
mine-produced acid occurs.

Aluminum rarely is present in natural water in concentrations greater than
a few tenths of a milligram per liter. Hem (1970) notes that, where the con-
centration of aluminum is high, the water generally has a low pH. Hem also
reported that where aluminum concentration is 1 mg/L or more in pH-neutral
water and complexing ions are present, the aluminum probably takes the form of
aluminum hydroxide or an aluminosilicate. Clays are the most common of all
the aluminum-bearing minerals in sediment.

In six study areas, aluminum concentrations in the dissolved phase were
low; no data were available for Slug Run. Suspended-aluminum concentrations
were high during high flow and seemingly are associated with suspended sedi-
ment.

Figure 4.7-1 shows the relation between the suspended-aluminum concentra-
tions and suspended-sediment concentrations for Little Cana Creek. These
constituents are also highly correlated at the other five study sites. The
respective equations and correlation coefficients (cc) for each station are:

> Little Cana Creek (unmined)
>
> $SA = 16.3 + 19.8 (SS)$ $cc = 0.99$

> Bankston Fork (99 percent mined)
>
> $SA = 4.9 + 0.47 (SS)$ $cc = 0.80$

> Turkey Creek (unmined)
>
> $SA = -436 + 9.2 (SS)$ $cc = 0.99$
> $SS > 48$

> West Branch Big Creek (29 percent mined)
>
> $SA = 129 + 7.8 (SS)$ $cc = 0.71$

> South Branch Doza Creek (unmined)
>
> $SA = -444 + 16.9 (SS)$ $cc = 0.97$
> $SS > 27$

> Doza Creek (50 percent mined)
>
> $SA = -348 + 19.0 (SS)$ $cc = 0.90$
> $SS > 18$

where SA = concentration of suspended aluminum, in micrograms per liter ($\mu g/L$);

SS = suspended-sediment concentration, in milligrams per liter (mg/L);

cc = correlation coefficient.

Slopes from the regression equations give the micrograms of aluminum associated with each milligram of suspended sediment. Using the annual load of suspended sediment (from section 4.6) and the above relations, the annual yield of aluminum for the six sites can be estimated. The estimated annual yields are:

Little Cana Creek (unmined) = 2.5 tons/mi^2

Bankston Fork (99 percent mined) = 0.04 tons/mi^2

Turkey Creek (unmined) = 2.1 tons/mi^2

West Branch Big Creek (29 percent mined) = 0.44 tons/mi^2

South Branch Doza Creek (unmined) = 7.2 tons/mi^2

Doza Creek (50 percent mined) = 2.9 tons/mi^2

These results indicate that more aluminum is transported from the unmined basins than the mined basins. However, the three mined basins have near-neutral pH ranges (see table 4.11-1), and, thus, little aluminum is in solution. An example of the potential abundance of aluminum at low pH is provided by the South Fork Saline River. During the 1979 water year, pH ranged from 2.9 to 6.2 and dissolved aluminum values ranged from <100 to 34,500 $\mu g/L$. A relation was developed between dissolved aluminum and dissolved solids (fig. 4.7-2). Based on this relation, the annual yield of aluminum transported from this basin was 87 tons/mi^2, which is considerably higher than yields from the six study basins.
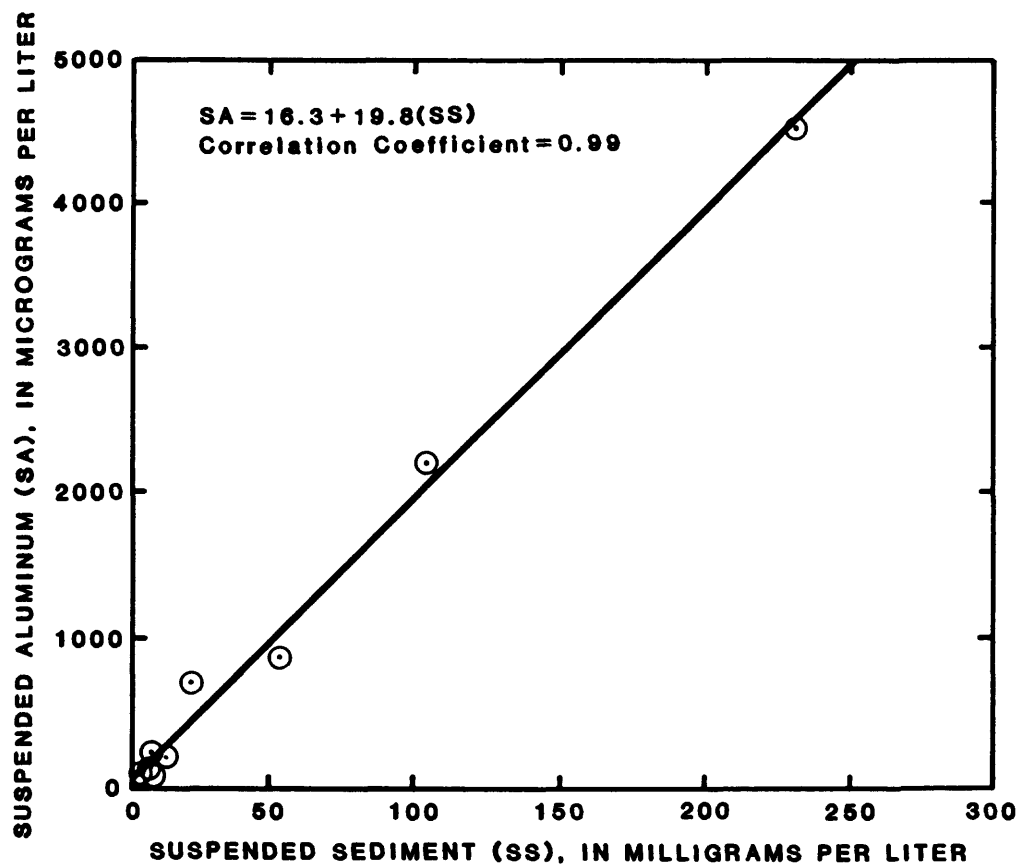
Figure 4.7-1.--Relation between suspended aluminum and suspended sediment for Little Cana Creek.
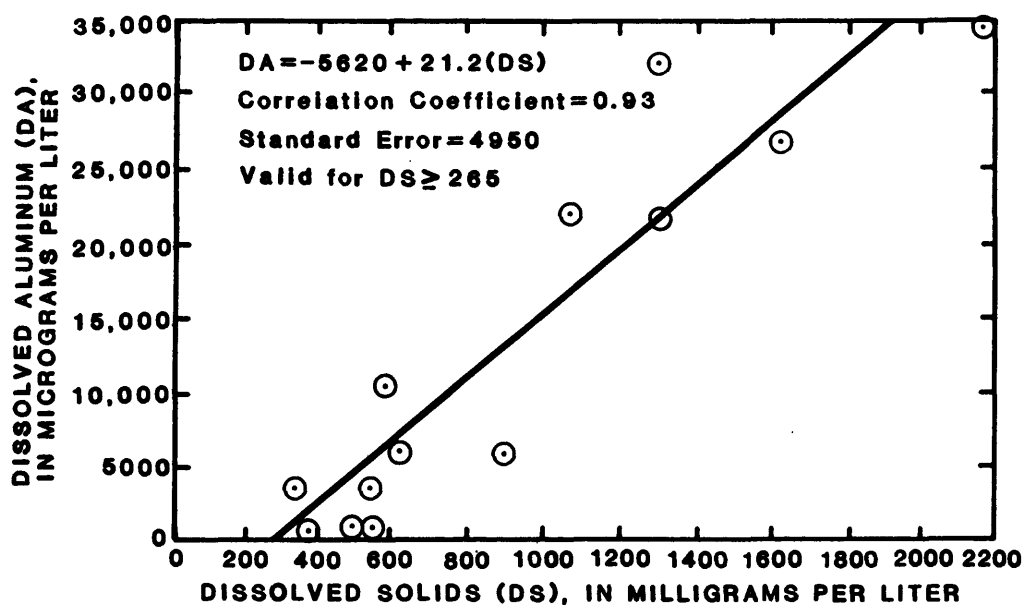
Figure 4.7-2.--Relation between dissolved aluminum and dissolved solids for South Fork Saline River.

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4.0 Quality of Surface Water
   4.8 Iron

IRON IS PRESENT PREDOMINANTLY IN SUSPENDED PHASE

*There is a relation between concentrations of suspended iron
and suspended sediment. Unmined areas yield more iron
than mined areas where in-place neutralization of
mine-produced acid occurs.*

Iron is an abundant and widespread constituent of rocks and soils. It is most common in sediments in the ferrous form as polysulfides (pyrite or marcasite), siderite, and magnetite. Hem (1970, p. 114) has stated that at near-neutral pH, water will not contain significant concentrations of dissolved iron. If the concentration of iron is high, it probably is present as particles of ferric hydroxide.

For six watersheds, near-neutral pH ranges and low dissolved-iron concentrations were observed; no dissolved-iron data were available for Slug Run. However, suspended-iron concentrations were high during high flows. Because high suspended-sediment concentrations were also observed during high flows, the iron is probably present as particles of iron minerals or sorbed on grains of suspended sediment.

Figure 4.8-1 shows the relationship between suspended iron and suspended sediment for Little Cana Creek. The relation is similar for the five other sites. Regression equations and correlation coefficients (cc) for the other five sites are:

Bankston Fork (99 percent mined)
$$Fe = 105 + 20.7 \ (SS) \qquad cc = 0.98$$

Turkey Creek (unmined)
$$Fe = -116 + 9.3 \ (SS) \qquad cc = 0.86$$
$$SS > 13$$

West Branch Big Creek (29 percent mined)
$$Fe = 620 + 121 \ (SS) \qquad cc = 0.84$$

South Branch Doza Creek (unmined)
$$Fe = -73 + 18.1 \ (SS) \qquad cc = 0.98$$
$$SS > 4.1$$

Doza Creek (50 percent mined)
$$Fe = -78 + 24.1 \ (SS) \qquad cc = 0.94$$
$$SS > 3.3$$

where   Fe = concentration of suspended iron, in micrograms per liter (µg/L);

SS = concentration of suspended sediment, in milligrams per liter (mg/L);

cc = correlation coefficient.

As was the case with aluminum (section 4.7), the slope of the regression line (coefficient for SS) gives the micrograms of iron associated with each milligram of suspended sediment. With knowledge of the annual sediment loads for the six sites and the above relation, the annual yield of iron can be estimated. The estimated annual yields are:

Little Cana Creek (unmined) = 2.8 tons/mi^2

Bankston Fork (99 percent mined) = 1.7 tons/mi^2

Turkey Creek (unmined) = 2.1 tons/mi^2

West Branch Big Creek (29 percent mined) = 1.2 tons/mi^2

South Branch Doza Creek (unmined) = 7.6 tons/mi^2

Doza Creek (50 percent mined) = 3.6 tons/mi^2

The calculated yields of suspended iron are higher from the unmined basins than from the mined basins. As with aluminum, most of the iron occurs in the suspended phase.

Figure 4.8-1.--Relation between suspended iron and suspended sediment for Little Cana Creek.

SI = 128 + 22.8(SS)
Correlation coefficient = 0.98
Standard error = 363

SUSPENDED SEDIMENT (SS), IN MILLIGRAMS PER LITER

SUSPENDED IRON (SI), IN MICROGRAMS PER LITER

MANGANESE AND ZINC CONCENTRATIONS ARE GENERALLY LOW

*Manganese and zinc concentrations were similar in three study
areas. However, concentrations of these metals
are high in acid mine water.*

Mean manganese concentrations ranged from 33 to 1,100 µg/L, and mean zinc concentrations ranged from 24.5 to 37.6 µg/L at the six study sites. Hem (1970, p. 130, 203) has noted that, commonly, at near-neutral pH levels, manganese concentrations will range from 100 to 1,000 µg/L and that zinc concentrations will remain less than 500 µg/L. Thus, for all study areas, the concentrations of these two elements were within commonly observed ranges.

Under acidic conditions, metals such as manganese and zinc are more soluble. Figures 4.9-1 and 4.9-2 show the relation between concentrations of dissolved zinc, dissolved manganese, and dissolved solids for the acidic conditions in the South Fork Saline River. Concentrations are high, and the average annual yields are 1.9 tons/mi^2 of zinc and 34 tons/mi^2 of manganese.

$$Z = -17.7 + 0.52(DS)$$

Correlation coefficient = 0.90
Standard error = 149 micrograms per liter
Valid for DS $\geq$ 34 milligrams per liter
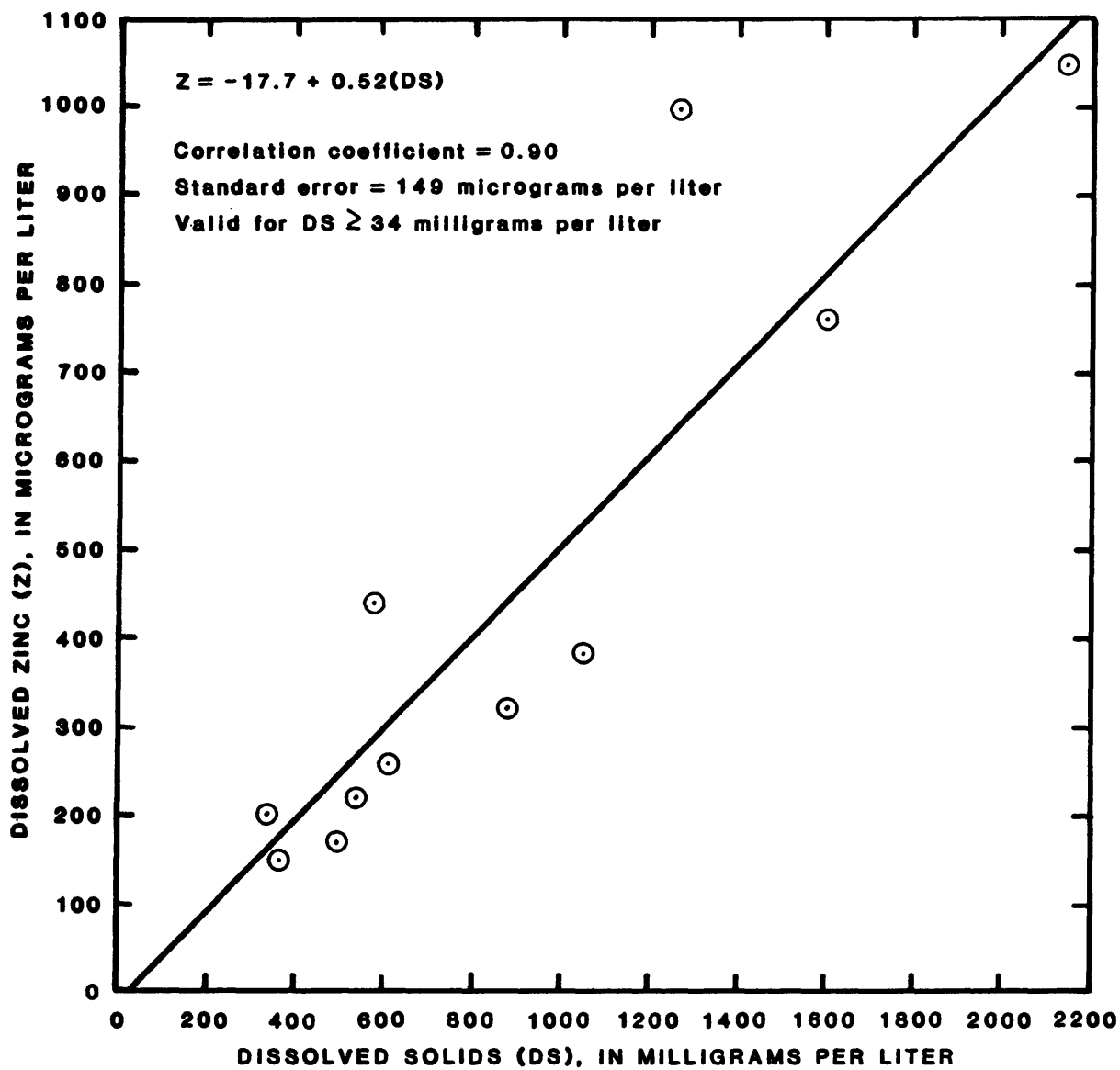
Figure 4.9-1.--Relation between dissolved zinc and dissolved solids for South Fork Saline River.
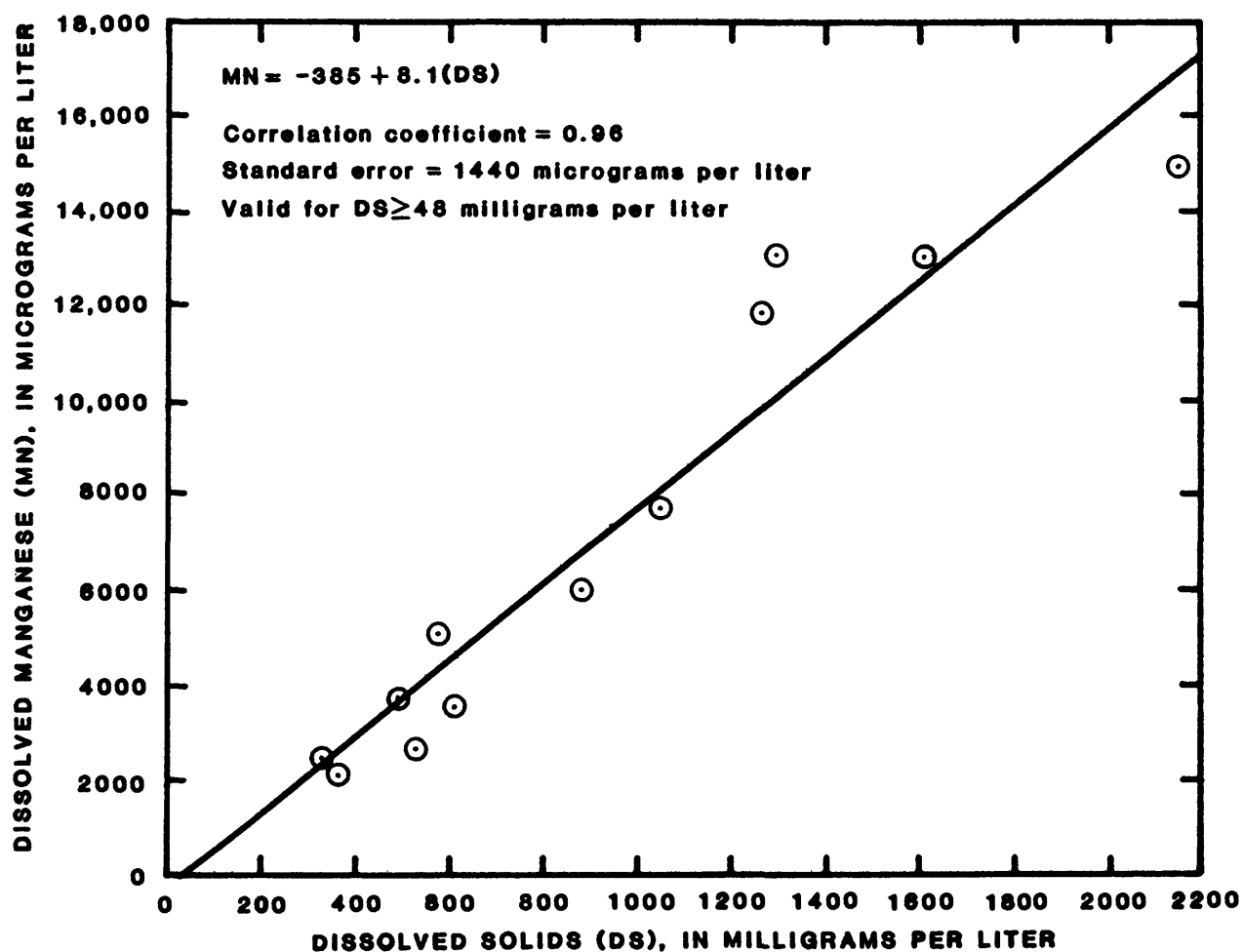
Figure 4.9-2.—Relation between dissolved manganese and dissolved solids for South Fork Saline River.

TRACE METAL CONCENTRATIONS ARE SIMILAR IN MINED
AND UNMINED BASINS

*An analysis of nine trace metals showed no major differences
in concentration between unmined and mined basins,
where waters are in near-neutral pH range.*

Tables 4.10-1 to 4.10-3 show the results of analyses for trace elements in samples collected at six of the study sites. For each metal the number of samples, range, mean, and standard deviation are given.

Concentrations of most trace elements are correspondingly similar in mined and unmined areas. Boron concentrations, however, seem to be slightly higher in the mined basins.

Linear regression techniques were used for data from six of the watersheds to check for any relations among the trace metals, dissolved solids, suspended sediment, or discharge. As noted in sections 4.6, 4.7, and 4.8, high levels of correlation existed between suspended sediment and discharge, suspended aluminum and suspended sediment, and suspended iron and suspended sediment. In sections 4.7, 4.8, and 4.9, it was shown that, under acidic conditions, dissolved aluminum, iron, manganese, and zinc correlate well with dissolved solids. The remaining metals showed little correlation with dissolved solids, discharge, and suspended sediment.

Table 4.10-1 Trace metal concentrations for Little Cana Creek and Bankston Fork

[Concentrations are in micrograms per liter]

Trace metal	Little Cana Creek (0 percent mined)				Bankston Fork (99 percent mined)			
	Number of samples	Range	Mean	Standard deviation	Number of samples	Range	Mean	Standard deviation
Aluminum-dissolved	17	10-150	47	41	23	0-70	23	15.8
Arsenic-dissolved	4	0-1	0.8	0.5	9	0-2	0.7	0.71
Arsenic-suspended	4	0-1	0.25	0.5	9	0-1	0.22	0.44
Boron-dissolved	7	0-140	42.2	47.6	11	30-230	173	61
Boron-suspended	6	0-350	77.7	131	10	0-80	12	24
Cadmium-dissolved	7	0-4	0.71	1.5	11	0-3	1.0	1.2
Cadmium-suspended	7	0-1	0.28	0.49	10	0-2	0.2	0.63
Chromium-dissolved	7	0-10	2.1	3.5	10	0-2	0.8	0.63
Chromium-suspended	7	0-29	12.1	9.4	11	0-30	18	8.2
Copper-dissolved	17	0-10	2.6	2.5	23	0-4	1.8	1.3
Copper-suspended	17	0-12	1.2	2.9	23	0-20	1.3	4.1
Iron-dissolved	17	10-420	82	101	22	20-240	88	55
Lead-dissolved	17	0-10	1.6	2.5	23	0-5	1.3	1.7
Lead-suspended	17	0-5	2.3	2.0	23	0-5	1.0	1.3
Mercury-dissolved	4	0	0	0	9	0	0	0
Mercury-suspended	4	0	0	0	9	0	0	0
Nickel-dissolved	17	3-10	6.2	1.9	23	3-24	11.0	5.7
Nickel-suspended	17	0-26	5.6	7.0	23	0-87	11.1	19.2
Selenium-dissolved	5	0	0	0	9	0-1	0.22	0.44
Selenium-suspended	5	0	0	0	9	0	0	0

Table 4.10-2 Trace metal concentrations for Turkey Creek and West Branch Big Creek
[Concentrations are in micrograms per liter]

Trace metal	Turkey Creek (0 percent mined)				West Branch Big Creek (29 percent mined)			
	Number of samples	Range	Mean	Standard deviation	Number of samples	Range	Mean	Standard deviation
Aluminum-dissolved	22	0-200	34	46.2	21	0-80	22.8	21
Arsenic-dissolved	10	1-3	1.3	0.67	10	0-2	1.0	0.47
Arsenic-suspended	10	0-1	0.2	0.42	10	0-1	0.2	0.42
Boron-dissolved	11	30-410	121	131	11	30-500	355	122
Boron-suspended	11	0-30	6.4	10.2	10	0-600	93	200
Cadmium-dissolved	11	0-5	0.91	1.5	12	0-7	1.4	2.5
Cadmium-suspended	10	0-1	0.2	0.42	11	0	0	0
Chromium-dissolved	11	0-10	1.2	3.0	13	0-20	1.8	5.5
Chromium-suspended	10	0-30	10.8	7.4	11	8-20	10.7	3.1
Copper-dissolved	22	0-8	2.5	1.8	21	0-5	1.95	1.2
Copper-suspended	22	0-31	3.3	7.0	21	0-4	1.7	1.6
Iron-dissolved	22	0-240	43	57.7	21	0-60	15.2	15.3
Lead-dissolved	21	0-7	1.8	1.9	20	0-6	1.6	2.0
Lead-suspended	21	0-23	1.95	2.2	21	0-7	2.0	2.3
Mercury-dissolved	10	0	0	0	9	0	0	0
Mercury-suspended	10	0	0	0	9	0	0	0
Nickel-dissolved	22	0-18	2.4	3.8	21	0-9	1.7	2.4
Nickel-suspended	22	0-30	7.9	7.4	21	0-22	8.0	5.9
Selenium-dissolved	10	0-1	0.4	0.51	10	0-1	0.7	0.48
Selenium-suspended	10	0-1	0.1	0.32	10	0-1	0.1	0.32

Table 4.10-3 Trace metal concentrations for South Branch Doza Creek and Doza Creek
[Concentrations are in micrograms per liter]

Trace metal	South Branch Doza Creek (0 percent mined)				Doza Creek (50 percent mined)			
	Number of samples	Range	Mean	Standard deviation	Number of samples	Range	Mean	Standard deviation
Aluminum-dissolved	17	0-310	85	94.2	16	10-270	49.3	62
Arsenic-dissolved	4	1-4	2.2	1.7	6	1	1	0
Arsenic-suspended	4	0-1	0.25	0.5	6	0	0	0
Boron-dissolved	7	7-340	148	120	8	40-193	193	81
Boron-suspended	7	0-60	14.5	22	8	0-50	13.8	18.4
Cadmium-dissolved	7	0-2	0.57	0.78	8	0-2	0.5	0.76
Cadmium-suspended	7	0-1	0.28	0.48	8	0-1	0.12	0.35
Chromium-dissolved	7	0-10	2.4	3.4	8	0-10	1.6	3.5
Chromium-suspended	7	0-28	13.2	9.2	8	0-70	15.8	22.1
Copper-dissolved	17	2-16	4.9	3.4	16	1-9	3.5	2.1
Copper-suspended	17	0-10	2.5	3.6	16	0-5	1.7	1.8
Iron-dissolved	17	20-270	103	70	16	0-180	32	44.8
Lead-dissolved	17	0-16	1.2	2.0	16	0-4	.94	1.2
Lead-suspended	17	0-20	4.7	6.0	16	0-18	4.2	4.4
Mercury-dissolved	4	0	0	0	6	0	0	0
Mercury-suspended	4	0	0	0	6	0	0	0
Nickel-dissolved	17	0-9	3.3	3.3	16	1-13	5.4	3.3
Nickel-suspended	17	0-30	9.5	9.4	16	0-50	11.7	14.4
Selenium-dissolved	4	0-1	0.25	0.50	6	0-2	1	0.63
Selenium-suspended	4	0	0	0	6	0-1	0.17	0.40

CONCENTRATIONS OF MANY COMMON CHEMICAL CONSTITUENTS AND PROPERTIES ARE SIMILAR IN MINED AND UNMINED BASINS

*An analysis of common chemical constituents and properties shows
concentrations to be similar in mined and unmined basins.
These concentrations seem to vary more according to
location than to mining conditions.*

Tables 4.11-1, 4.11-2, and 4.11-3 show that many chemical elements have similar concentrations for both mined and unmined basins. Included in this category are dissolved organic carbon, total organic carbon, nitrogen, dissolved oxygen, phosphorus, and silica. Properties such as pH and sodium adsorption ratio were also similar for both mined and unmined basins.

Sodium concentrations were consistently higher in streams draining the surface-mined basins. However, little correlation was found between this element and the percentage of the drainage basin that was surface mined.

Noncarbonate hardness is that portion of hardness in excess of that equivalent to carbonate plus bicarbonate. This type of hardness was greater in streams draining surface-mined basins.

The concentrations of other common constituents or properties vary more as a result of location of the study basin than as a result of mining. In the Saline River basin, alkalinity, bicarbonate, and total hardness are higher in streams draining mined basins. In the lower Kaskaskia River basin, water from South Branch Doza Creek (unmined site) has higher alkalinity and bicarbonate values than Doza Creek (mined site). However, Doza Creek has higher total hardness values. In western Illinois, Turkey Creek (unmined) has higher alkalinity, bicarbonate, and total hardness values than West Branch Big Creek (mined). Slug Run (90 percent mined) has higher total hardness values than Turkey Creek but similar values for alkalinity and bicarbonate. Chloride values were higher for the study basins in western and southwestern Illinois for streams draining mined areas but lower for streams draining surface-mined areas in the Saline River basin. Potassium values were higher in southern and western Illinois basins but lower in southwestern Illinois for streams draining mined basins. Magnesium values were higher in the mined basin in southern Illinois basins (Bankston Fork) but about the same for mined and unmined basins in southwestern and western Illinois.

Table 4.11-1 Water-quality data for Little Cana Creek and Bankston Fork
[Concentrations are in milligrams per liter]

Chemical element	Little Cana Creek (0 percent mined)				Bankston Fork (99 percent mined)			
	Number of samples	Range	Mean	Standard deviation	Number of samples	Range	Mean	Standard deviation
pH (units)	17	6.8-8.2	7.3	0.36	23	7.2-8.0	7.6	0.22
Alkalinity	17	25-110	53.4	25.4	23	280-480	358	63.3
Bicarbonate	16	31-130	65.2	31.4	23	320-584	437	77.2
Hardness-noncarbonate	17	23-250	153	73.0	23	1500-2800	2180	407
Hardness-total	17	52-330	207	88.0	23	2000-3000	2530	384
Dissolved organic carbon	4	2-11	5.9	4.2	9	1.7-11	5.6	3.0
Total organic carbon	7	3.6-20	7.9	5.6	11	1.8-14	5.5	3.8
Chloride	17	2.8-14	9.8	3.4	23	6.2-9.7	7.5	0.82
Magnesium-dissolved	17	4.8-42	24.8	11.0	23	240-420	362	54
Nitrogen-dissolved NH_4 + org-N	17	0.09-2.4	0.56	0.60	22	0-0.53	0.22	0.14
Nitrogen-suspended NH_4 + org-N	17	0-0.5	0.08	0.12	22	0-0.34	0.07	0.09
Nitrogen-NO_2 + NO_3 total	17	0-1.0	0.31	0.31	23	0-1.6	0.16	0.34
Nitrogen-N-total	15	0.14-2.8	0.95	0.81	23	0.03-0.55	0.30	0.15
Nitrogen-NO_3-total	15	0.62-11.0	3.6	2.8	23	0.1-2.4	1.3	0.64
Oxygen-dissolved	17	6.5-16.8	11.8	2.5	23	7.0-12.0	9.7	1.7
Phosphorus	17	0.01-0.24	0.09	0.16	23	0-0.13	0.02	0.03
Potassium-dissolved	17	1.8-6.7	3.1	1.2	23	4.0-6.8	5.4	0.68
Sodium adsorbtion ratio	17	0.3-1.0	0.72	0.21	23	0.5-0.8	0.67	0.08
Silica	17	5.8-13	10.1	2.4	23	7.3-12	10.1	1.5
Sodium	17	5.1-41	24.8	10.7	23	65-95	76.9	9.4

Table 4.11-2 Water-quality data for Turkey Creek and West Branch Big Creek
[Concentrations are in milligrams per liter]

Chemical element	Turkey Creek (0 percent mined)				West Branch Big Creek (29 percent mined)			
	Number of samples	Range	Mean	Standard deviation	Number of samples	Range	Mean	Standard deviation
pH (units)	22	7.1-8.5	8.0	0.33	22	7.7-9.0	8.3	0.30
Alkalinity	20	110-380	250	72	22	100-170	144	19
Bicarbonate	22	130-420	298	76	22	124-200	172	20
Hardness-noncarbonate	22	0-110	67	38	22	64-290	106	44
Hardness-total	22	180-440	310	62	22	200-400	250	39
Dissolved organic carbon	9	1.7-9.3	5.9	2.5	8	2.6-11	6.7	2.8
Total organic carbon	10	2.3-12.0	7.0	3.1	10	3.5-14	7.2	4.0
Chloride	22	6-26	14	5.8	22	51-67	58	4.6
Magnesium-dissolved	22	16-40	31	5.7	22	23-32	28	2.9
Nitrogen-dissolved NH$_4$ + org-N	22	0-2.4	0.67	0.62	21	0.13-0.80	0.44	0.19
Nitrogen-suspended NH$_4$ + org-N	22	0-2.1	0.30	0.50	21	0-23	1.3	5.0
Nitrogen-NO$_2$ + NO$_3$ total	21	0-8.4	2.3	3.0	20	0.04-2.9	1.3	0.7
Nitrogen-N-total	22	0.22-9.4	3.2	3.2	21	0.35-25	2.9	5.1
Nitrogen-NO$_3$-total	21	0.34-43	14.3	14.7	20	1.7-110	13.5	23
Oxygen-dissolved	21	8.3-16.4	11.6	2.3	20	7.3-14.2	11.0	2.1
Phosphorus	22	0.01-0.77	0.15	0.18	21	0.01-0.10	0.05	0.03
Potassium-dissolved	22	1.1-6.0	2.9	1.3	22	1.4-6.0	5.1	0.89
Sodium adsorbtion ratio	22	0.1-0.4	0.21	0.06	22	0.3-3.3	2.7	0.6
Silica	22	2.2-10	7.8	2.4	22	1.6-11.0	3.4	1.9
Sodium	22	4.1-12	9.3	2.3	22	85-120	94	20

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Table 4.11-3 Water-quality data for South Branch Doza Creek and Doza Creek
[Concentrations are in milligrams per liter]

Chemical element	South Branch Doza Creek (0 percent mined)				Doza Creek (50 percent mined)			
	Number of samples	Range	Mean	Standard deviation	Number of samples	Range	Mean	Standard deviation
pH (units)	17	7-8.6	7.7	0.40	16	7.0-9.1	8.0	0.6
Alkalinity	17	37-190	102	45	16	58-150	92	30
Bicarbonate	17	80-228	125	54	16	71-182	112	37
Hardness-noncarbonate	17	27-430	135	109	16	85-360	192	75
Hardness-total	17	80-610	238	148	16	190-480	283	90
Dissolved organic carbon	3	4-17	10.0	6.6	6	3.2-16	10.3	4.9
Total organic carbon	7	5.2-24	10.8	6.2	8	4.6-21	11.8	5.9
Chloride	17	4.5-48	15.5	10.0	16	13-64	28	15
Magnesium-dissolved	17	4.1-64	21	17	16	14-50	27	10
Nitrogen-dissolved NH_4 + org-N	17	0.07-2.5	0.95	0.68	16	0.15-1.1	0.58	0.28
Nitrogen-suspended NH_4 + org-N	16	0-1.1	0.35	0.34	15	0-0.93	0.30	0.24
Nitrogen-NO_2 + NO_3 total	16	0-2.1	0.84	0.90	15	0-3.9	0.87	0.95
Nitrogen-N-total	16	0-3.5	1.8	1.2	15	0.07-2.6	1.45	0.74
Nitrogen-NO_3-total	16	0.68-16	8.2	5.4	15	0.81-12	6.5	3.4
Oxygen-dissolved	16	6.5-13.5	10.5	2.2	16	8.4-14.5	10.8	1.8
Phosphorus	17	0.03-0.60	0.31	0.17	16	0.05-0.31	0.14	0.07
Potassium-dissolved	17	3.6-9.6	5.4	1.3	16	3.3-5.5	4.8	0.50
Sodium adsorbtion ratio	17	0.5-6.0	2.0	1.6	16	1.0-6.3	4.5	5.4
Silica	17	0.79-9.5	5.9	3.1	16	1.0-5.6	2.8	1.7
Sodium	17	8.6-340	85	88	16	29-330	126	94

4.0 Quality of Surface Water
    4.12 Conclusions   .

    Surface mining in Illinois has exposed unweathered rocks, chemical weather-
ing of which has resulted in increased concentrations and loads of dissolved
chemical constituents in runoff.

    Relations between dissolved solids, sulfate, and calcium were developed
for the Saline-Big Muddy River basins in southern Illinois and the Spoon River
basin in western Illinois. If the percentage of a basin that is surface mined
is known, annual yields for these constituents in runoff can be estimated.
Yields of dissolved solids, sulfate, and calcium associated with mining were
greater in the Saline-Big Muddy River basins than in basins studied in western
Illinois. Increases in concentrations of dissolved constituents related to
mining were least in the southwestern part of Illinois (the lower Kaskaskia
River basin).

    Harmonic analyses of daily water temperatures indicate that streams drain-
ing mined areas have higher harmonic means and lower amplitudes than streams
draining unmined areas.

    Suspended-sediment yields from each study area show that unmined areas
have higher sediment yields than mined areas; however, the mined basins no
longer have active surface mines and have been revegetated. Much of the
unmined area is farmland.

    Several trace metals were analyzed for possible correlations with
suspended sediment and dissolved solids. Associations between iron, aluminum,
and suspended sediment indicate that streams draining unmined basins have
greater yields of aluminum and iron than the mined basins, possibly resulting
from higher sediment yield from the unmined basins. However, this relation-
ship does not hold for surface-mined basins with acidic (low pH) conditions
such as the South Fork Saline River near Carrier Mills.

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