HYDROLOGIC RESPONSES OF STREAMS TO MINING OF THE MULBERRY COAL RESERVES IN EASTERN KANSAS

By Hugh E. Bevans

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CONVERSION FACTORS

Inch-pound units of measurement used in this report may be converted to the International System of Units (SI) using the following factors:

Multiply inch-pound unit	By	To obtain SI unit
inch	25.4	millimeter
foot	0.3048	meter
mile	1.609	kilometer
square mile	2.590	square kilometer
cubic foot per second	0.02832	cubic meter per second
ton, short (2,000 pounds)	0.9072	megagram
ton per day, short	0.9072	megagram per day
micromho per centimeter at 25° Celsius	1.000	microsiemens per centimeter at 25° Celsius
degree Fahrenheit	1/	degree Celsius

1 Degree Celsius = (degree Fahrenheit -32)/1.8

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ABSTRACT

The U.S. Geological Survey investigated the hydrologic responses of streams with respect to past and current (1982) coal-mining activities in the Mulberry coal reserves of Miami, Linn, and Bourbon Counties, eastern Kansas. A low-flow water-quality reconnaissance determined that streams draining basins where most of the past coal mining has occurred, North Sugar Creek and Indian Creek, have relatively large concentrations of dissolved solids and sulfate. Streams draining basins that have been mined to a lesser degree have larger concentrations of sulfate than those where no mining has occurred. The two major streams draining the study area, the Marais des Cygnes and Little Osage Rivers, have been relatively unaffected.

A comparison of streamflow characteristics for a stream draining an actively mined basin to a stream draining an unmined control basin, showed that sediment ponds in the actively mined basin decrease high flow and increase low flow.

Water-quality characteristics affected significantly by active strip mining were specific conductance and instream concentrations and loads of dissolved solids, sulfate, and suspended sediment. Loads of dissolved solids, sulfate, and suspended sediment were respectively, 41 percent, 244 percent, and 25 percent greater in a stream draining an actively mined basin than in a stream draining an unmined control basin. The increased loads of dissolved solids and sulfate were contributed by effluent pumped from the active strip mine. The increased load of suspended sediment was caused by exposure and disturbance of soil during clearing and excavation.

INTRODUCTION

Purpose and Scope

The Mulberry coal is one of the largest remaining reserves of strip-pable coal in eastern Kansas. Information concerning the hydrologic environment of these reserves and its response to coal-mining activities is necessary to preserve and protect area water resources.

The U.S. Geological Survey began a two-phase investigation during 1979 to:

Phase 1.--describe the physical and hydrologic environments of the Mulberry coal reserves; and

Phase 2.--determine hydrologic responses to mining of the Mulberry coal reserves.

The results of phase 1 of the investigation have been presented by Kenny and others (1982).

Phase 2 of the investigation was designed to provide additional data and interpretation needed to:

(1) evaluate area stream-water quality with respect to coal-mining activities;

(2) determine the effects of active strip mining on streamflow characteristics of small streams; and

(3) determine the effects of active strip mining on water-quality characteristics of small streams draining the Mulberry coal reserves.

The purpose of this report is to present the results of phase 2 of the investigation.

The scope of this phase of the investigation was based on the results of phase 1 (Kenny and others, 1982). Streamflow and water-quality stations were established to provide data necessary to determine the effects of past and current (1982) coal mining on area streams. The data were collected from July 1980 through August 1982.

Study Area

The study area includes approximately 300 square miles in southeastern Miami, eastern Linn, and northeastern Bourbon Counties, Kansas (fig. 1). The boundary to the north, south, and west is determined by the extent of the strippable reserves of Mulberry coal. The eastern boundary is the Kansas-Missouri State line. The strippable reserves include coal measures that are at least 12-inches thick and have a stripping ratio (thickness of overburden to coal) of 30 to 1 or less (Brady and others, 1976).

Areal descriptions of physiography, soils, vegetation, land use, geology, climate, and hydrology are available in the phase-1 report (Kenny and others, 1982). The following descriptions are condensed from that report.

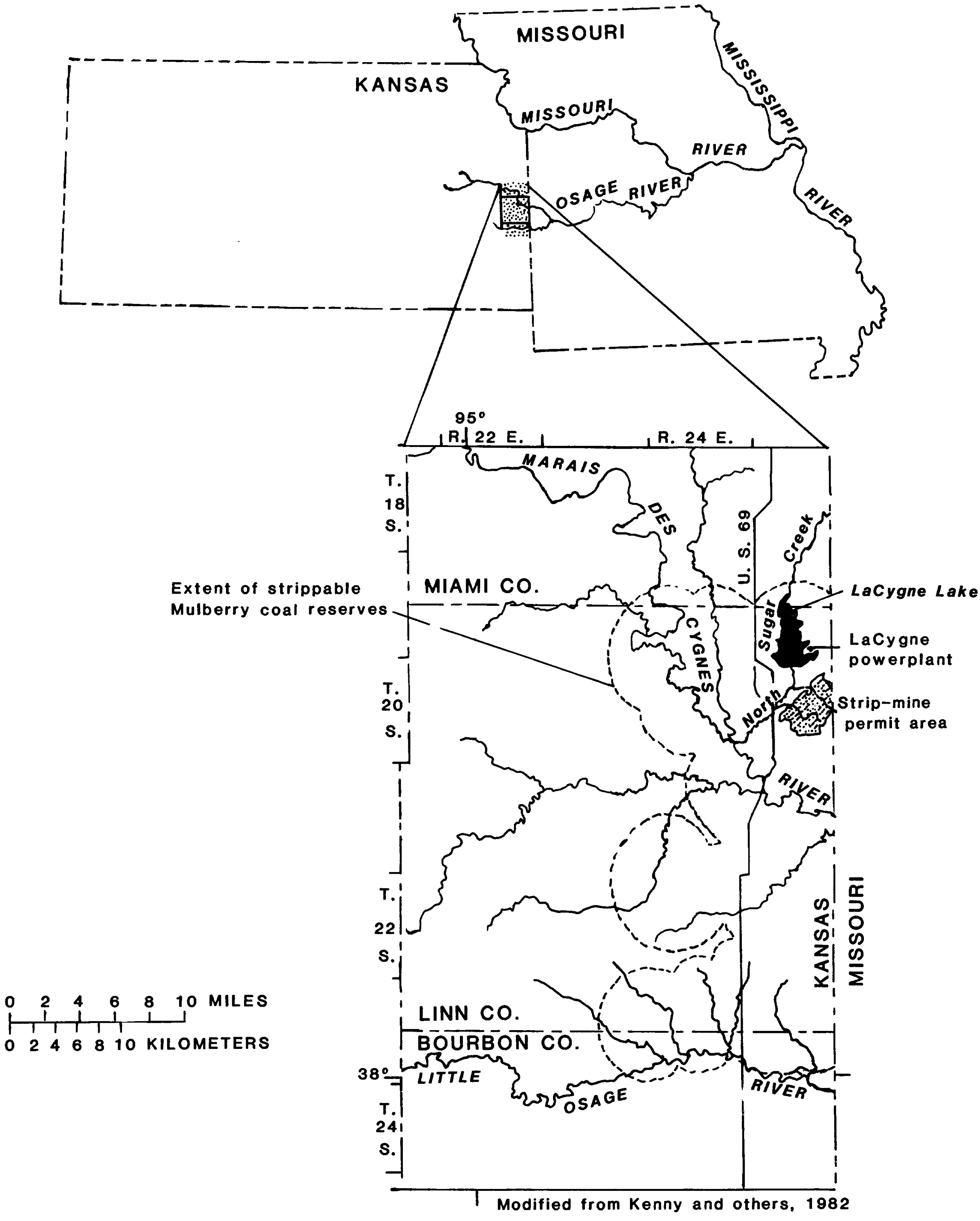

Figure 1.--Location of study area.

The study area is included in the Osage Cuestas of the Osage Plains physiographic province (Frye and Schoewe, 1953, p. 248), which is characterized by broad, level flood plains and gently rolling to hilly uplands. Soils are primarily silt and clay loams with moderate to slight permeabilities (Penner, 1981; Bell and Fortner, 1981). Agriculture is the predominant land use.

Surface geology consists of rocks of Pennsylvanian age and alluvial deposits of Quaternary age. Pennsylvanian rocks that crop out are, in order of most common occurrence; shale, limestone, sandstone, and small quantities of coal (including the Mulberry coal) and underclay. The Mulberry coal bed of the Bandera Shale crops out in southeastern Linn and northeastern Bourbon Counties, although outcrops are scarce because of erosion and mining. Unconsolidated alluvial deposits (chert, limestone gravel, and clay) of Quaternary age are found in the major stream valleys and adjacent terraces (Seevers, 1969).

The climate is humid continental with average annual precipitation of about 40 inches and a growing season (May through October) averaging 181 days. Most of the precipitation occurs as rain during the growing season when intense local thunderstorms or longer storms of great areal extent can produce large volumes of runoff. Drought conditions can occur anytime during the year.

The area is drained by the Marais des Cygnes and Little Osage Rivers and their tributaries. Streamflow is extremely variable in unregulated streams. Storm runoff provides most of the streamflow because there are few shallow aquifers capable of sustaining base flow. Consequently, extreme streamflow deficiencies occur during droughts. The chemical type of water in major streams is predominantly calcium bicarbonate throughout the range of streamflow, pH is about 7, and concentrations of dissolved solids seldom exceed 500 milligrams per liter.

Mulberry coal has been mined in the study area since 1858. Shaft mining was the predominant method of mining until 1939, when strip mining became more practical. Since 1964, strip mining has been the only method used in this area. Approximately 11 million short tons of Mulberry coal have been mined in the study area through 1975. A strip mine began operating in the North Sugar Creek drainage basin during January 1981. The permit area for this mine is shown in figure 1.

Data Collection and Analysis

Data-collection activities for phase 2 began during July 1980 and continued through August 1982. Stations at 21 stream sites and 5 sediment-pond sites, described in table 1, were established for the collection of streamflow and water-quality information (fig. 2). Three types of stations were established on streams. Reference stations are those located upstream from coal-mined areas and on streams draining unmined basins to obtain data unaffected by coal mining. Trend stations are those located downstream from coal-mined areas to detect hydrologic responses resulting from coal mining. Synoptic stations are those situated throughout the study area to evaluate area stream-water quality with respect to coal mining.

Table 1.--Descriptions of data-collection stations

Station index number (figure 2)	Station name	Land-line location (township-range-section)	Drainage area (square miles)	Station type
1	Marais des Cygnes River near Fontana	18S. 24E. 30	2,600	Reference
2	Middle Creek near Fontana	19S. 23E. 10	63.3	Synoptic
3	Middle Creek 4 miles west of LaCygne Lake	19S. 24E. 35	58.5	Synoptic
4	North Sugar Creek below LaCygne Lake	20S. 25E. 04	57.6	Synoptic
5	North Sugar Creek tributary 1 below LaCygne Lake	20S. 25E. 09	2.06	Trend
6	North Sugar Creek tributary 2 below LaCygne Lake	20S. 25E. 16	1.91	Trend
7	North Sugar Creek tributary 3 below LaCygne Lake	20S. 25E. 18	1.96	Reference
8	North Sugar Creek near Trading Post	20S. 24E. 25	73.0	Synoptic
9	Big Sugar Creek 4 miles east of Farlinville	21S. 24E. 05	306	Synoptic
10	Little Sugar Creek 5 miles east of Farlinville	21S. 24E. 09	73.6	Synoptic
11	Marais des Cygnes River tributary 2 miles northeast of Trading Post	21S. 25E. 03	2.11	Synoptic
12	Marais des Cygnes River tributary 4 miles east of Trading Post	21S. 25E. 11	6.04	Synoptic
13	Marais des Cygnes River near Kansas-Missouri State Line	21S. 25E. 16	3,250	Trend
14	Mine Creek near Pleasanton	21S. 25E. 27	28.7	Synoptic
15	Little Osage River near Mapleton	23S. 23E. 33	204	Reference
16	Lost Creek near Mapleton	23S. 23E. 23	14.3	Synoptic
17	Elk Creek near Fulton	23S. 24E. 21	20.3	Synoptic
18	West Laberdie Creek near Fulton	23S. 24E. 24	6.96	Synoptic
19	East Laberdie Creek near Fulton	23S. 24E. 24	10.1	Synoptic
20	Little Osage River at Fulton	23S. 24E. 25	295	Trend
21	Indian Creek near Fulton	23S. 25E. 26	21.9	Synoptic
22	Sediment pond 1 upstream from station 6	20S. 25E. 22	---	Sediment pond
23	Sediment pond 2 upstream from station 6	20S. 25E. 22	---	Sediment pond
24	Sediment pond 3 upstream from station 5	20S. 25E. 15	---	Sediment pond
25	Sediment pond 4 upstream from station 5	20S. 25E. 15	---	Sediment pond
26	Sediment pond 4 upstream from station 5	20S. 25E. 10	---	Sediment pond

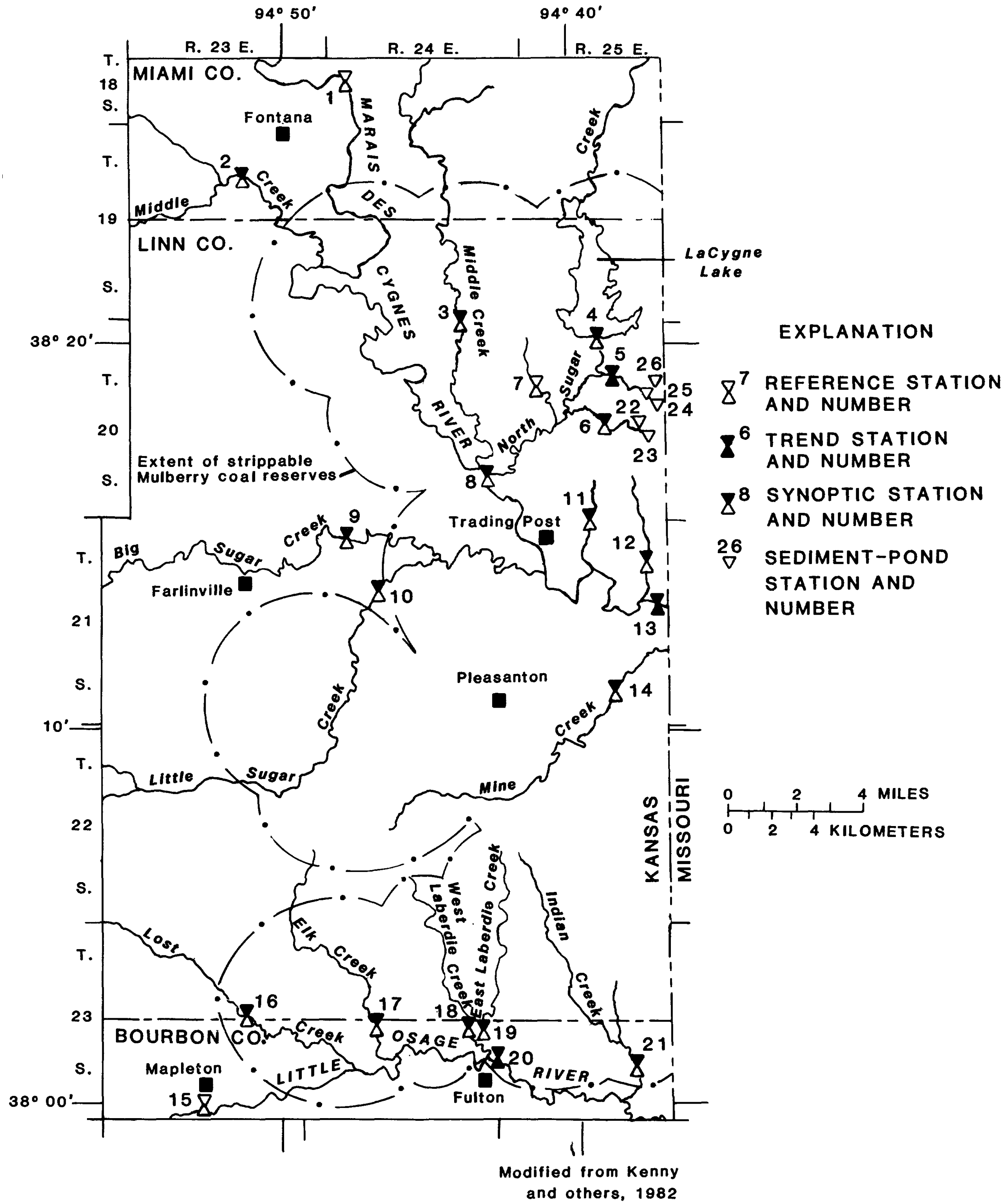

Figure 2.--Location of data-collection stations.

Because of active coal strip mining in the North Sugar Creek drainage basin, data-collection activities at stations in that basin were given priority. North Sugar Creek tributary 1 (station 5) and tributary 2 (station 6), which drain the active strip-mine area, and tributary 3 (station 7) , an unmined control basin, were sampled monthly and during storm runoff.

Data collection was less intensive in the rest of the study area. Reference and trend stations were sampled infrequently for streamflow and water-quality information, usually during low-flow conditions. Synoptic stations were sampled during a low-flow water-quality reconnaissance during November 1981.

Data-collection activities were hampered by a severe drought that persisted from early June 1980 through May 16, 1981. During this drought all streams in the study area, except the Marais des Cygnes River, were dry most of the time.

Streamflow measurements (Buchanan and Somers, 1976) were used to develop stage-discharge relations for calibrating continuously recording stream-stage equipment and to develop relations with concurrent water-quality data.

Measurements of pH, specific conductance, and water temperature and water samples for determination of selected chemical constituents were collected and analyzed according to procedures described by Skougstad and others (1979). Specific-conductance measurements were used to calibrate continuously recording specific-conductance monitors and to develop relations with selected water-quality constituents. Water samples for suspended-sediment determinations were collected according to procedures described by Guy and Norman (1976) and were analyzed by the U.S. Geological Survey laboratory in Lawrence, Kansas, according to procedures described by Guy (1969). Water-quality data collected for this investigation have been published by the U.S. Geological Survey (1980-82).

Methods of Investigation

Results of chemical analyses of water samples collected during a low-flow reconnaissance of area streams were examined, with respect to coal-mining activities, to evaluate the extent and degree of contamination. Streams draining coal-mined areas are affected most during low-flow periods when ground water discharged from the mined areas, containing large concentrations of sulfate and dissolved solids, provides a significant part of the streamflow (Bevans, 1980).

To determine hydrologic responses of small area streams to active coal strip mining, selected streamflow and water-quality characteristics known to be affected by coal mining were compared for streams draining an active coal mine and a stream draining an unmined control basin. Streamflow hydrographs were compared to determine differences in response to storms, and flow-duration curves were compared to determine longer-term differences. Selected water-quality characteristics, including specific conductance and concentrations and loads of dissolved solids, sulfate, and suspended sediment, were compared to determine the effects of strip mining.

AREAL EVALUATION OF STREAMFLOW QUALITY WITH RESPECT TO COAL MINING

The study area contains many abandoned strip and shaft mines (fig. 3). In order to manage the effects of future coal mining on water-quality characteristics of area streams, it was necessary to determine their current (1982) characteristics with respect to coal-mining activities.

Geochemical Reactions in Strip and Shaft Mines

Streams draining strip- and shaft-mined areas usually are contaminated during low-flow periods when ground water from the mined areas, containing large concentrations of sulfate and dissolved solids, discharges into them.

Geochemical reactions in strip and shaft mines that cause large concentrations of sulfate and dissolved solids to be in solution are started when water and oxygen contact the iron sulfide minerals, pyrite and marcasite (FeS_2), which are associated with the coal-bearing strata. The following direct oxidation reaction releases ferrous iron, sulfate, and acidity into solution (Stumm and Morgan, 1981):

$$FeS_2 + 7/2\ O_2 + H_2O \rightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+. \qquad (1)$$

The ferrous iron is oxygenated to ferric iron, which then hydrolyzes to form insoluable ferric oxyhydroxide and releases acidity:

$$Fe^{2+} + 1/4\ O_2 + 5/2\ H_2O \rightarrow Fe\ (OH)_3 + 2H^+. \qquad (2)$$

If acidity generated by reactions 1 and 2 contacts calcite ($CaCO_3$) in limestone rocks and sediments weathered from limestone rocks, calcium and bicarbonate ions are released into solution:

$$CaCO_3 + H^+ \rightarrow Ca^{+2} + HCO_3^-. \qquad (3)$$

Excess acidity that is not used in the weathering of calcite can combine with bicarbonate to produce carbonic acid (H_2CO_3). However, because of the abundance of limestone rocks in the study area, considerable acidity can be released before the pH is decreased noticeably.

Evaluation of a Low-Flow Water-Quality Reconnaissance

A water-quality reconnaissance of area streams was conducted during a period of relative low streamflow during November 1981, to evaluate their conditions with respect to coal mining. The results of this reconnaissance, including determinations of streamflow, pH, specific conductance, and concentrations of sulfate, bicarbonate, and dissolved solids are presented in table 2.

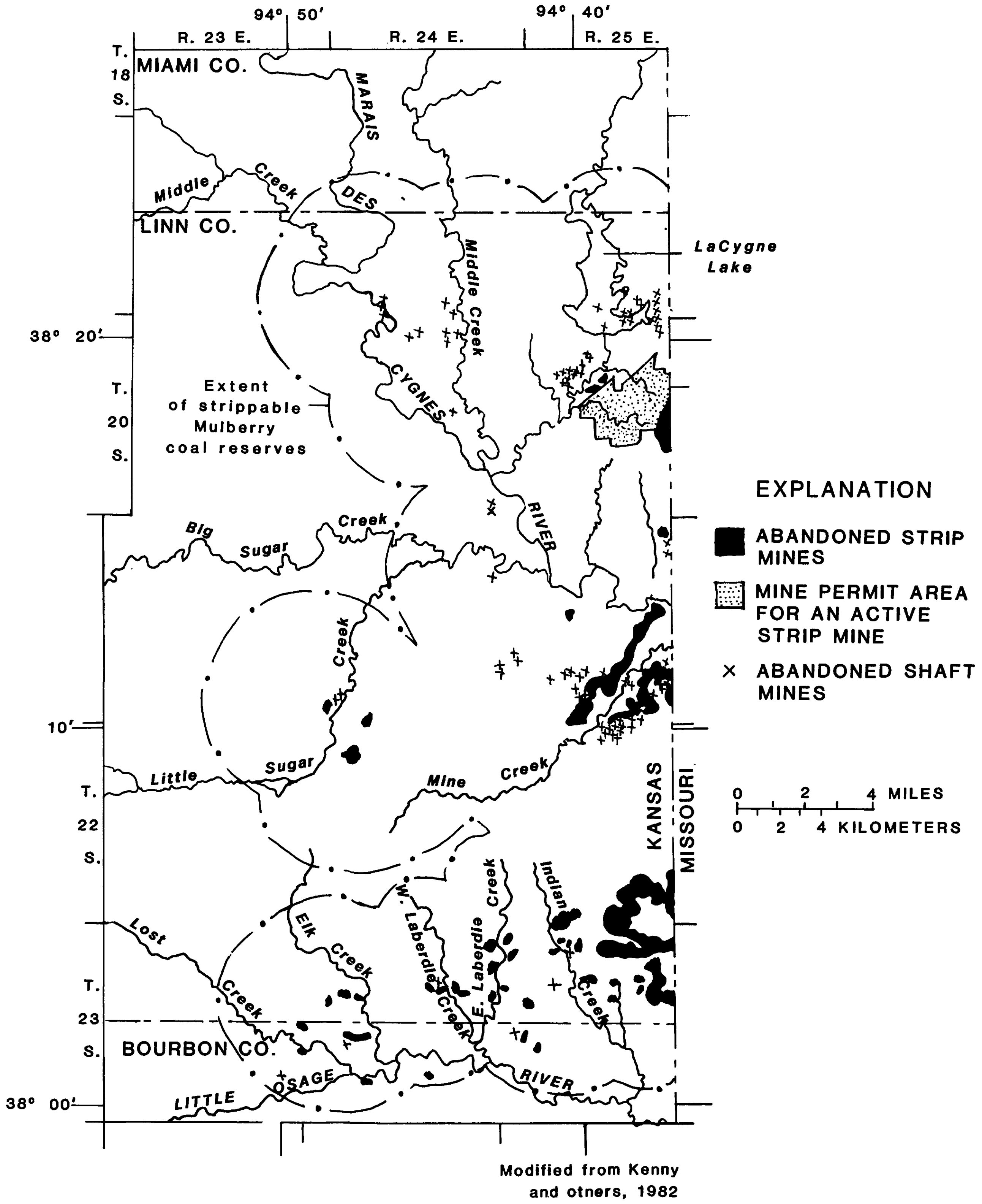

Figure 3.--Location of strip and shaft mines.

Table 2.--Results of a low-flow water-quality reconnaissance, November 1981

Station index number (figure 2)	Streamflow (cubic feet per second)	Specific conductance (micromhos per centimeter at 25° Celsius)	pH (units)	Sulfate (milligrams per liter)	Bicarbonate (milligrams per liter)	Dissolved solids (milligrams per liter)
1	1,030	444	7.3	36	210	253
2	21	553	7.4	47	280	330
3	24	563	7.3	50	290	326
4	0.14	562	8.1	160	130	427
5	.39	529	7.2	100	150	446
6	.12	556	7.7	140	160	345
7	.11	310	7.1	52	120	205
8	19	590	7.4	130	130	372
9	90	569	7.5	46	280	336
10	26	495	7.5	54	290	349
11	.09	370	7.3	75	120	252
12	.51	514	7.1	78	230	313
13	1,460	468	7.6	57	200	279
14	9.1	400	7.4	55	230	287
15	69	536	7.5	45	280	328
16	6.1	490	7.8	51	260	309
17	6.1	510	7.6	54	280	324
18	.82	564	7.4	59	270	324
19	1.5	616	7.3	81	260	368
20	99	565	7.7	50	280	339
21	6.6	966	6.9	360	150	678

Examining the results of the low-flow, water-quality reconnaissance from table 2 with respect to the location of abandoned strip and shaft mines in figure 3 leads to the following conclusions:

(1) pH values ranged from almost neutral to slightly alkaline (6.9-8.1) because acidity released by the oxidation of iron sulfide minerals is used to weather calcite.

(2) Concentrations of sulfate were smallest at stations on streams draining unmined areas (stations 1, 2, 3, 7, 9, 15, and 16). Station 11 is an anomaly because it drains an apparently unmined area but has a relatively large concentration of sulfate. This may result from some undocumented coal mining in that basin. Concentrations of sulfate were largest at stations on streams draining mined areas. These streams are North Sugar Creek (stations 4 and 8), two tributaries of North Sugar Creek that were affected by an active strip mine during the reconnaissance (stations 5 and 6), and Indian Creek (station 21). Stations 10, 13, 14, 17, 18, and 20 are on streams draining mined areas, but most of their flow is provided by unmined areas and sulfate

concentrations were relatively small. Stations 12 and 19 are on streams that have been affected slightly by coal mining and have intermediate concentrations of sulfate.

(3) Concentrations of bicarbonate are largest at stations on streams draining unmined basins or streams that have had only a small proportion of their basin mined (stations 1, 2, 3, 9, 10, 12, 13, 14, 15, 16, 17, 18, 19, and 20). Streams with the smallest concentrations of bicarbonate (stations 4, 5, 6, 8, and 21) drain the most extensively mined areas. Stations 7 and 11 are anomalies. Stations 7 and 11 are on streams' draining basins that contain significant alluvial deposits of silt, clay, sand, and gravel. Water from the alluvial deposits dilutes the base flow discharging from the bedrock and decreases the concentrations of bicarbonate.

(4) Because of the relatively small concentrations of bicarbonate present when concentrations of sulfate are large (and the converse situation), specific conductance and dissolved solids are not good indicators of coal-mine contamination unless their relationships with sulfate are known. The ranges of specific conductance and concentration of dissolved solids were small for area streams, with the exception of Indian Creek near Prescott (station 21), which drains the most extensively coal-mined area.

(5) The two largest streams draining the study area, the Marais des Cygnes and Little Osage Rivers, have a slight change in water quality after draining the study area. The Marais des Cygnes River near Fontana (station 1) had a smaller concentration of sulfate and a larger concentration of bicarbonate than the Marais des Cygnes River near the Kansas-Missouri State line (station 13). The Little Osage River near Mapleton (station 15) had a smaller concentration of sulfate than the Little Osage at Fulton (station 20). It is not certain whether the change in water quality is due to coal mining or a natural response to draining the coal-bearing strata of the study area. However, because there is a change in water quality, it is possible that future coal-mining activities in the study area could result in further changes.

HYDROLOGIC RESPONSES OF SMALL STREAMS TO ACTIVE STRIP MINING OF COAL

Effects on Streamflow Characteristics

The effects of active strip mining on streamflow characteristics of small streams were determined by comparing selected storm hydrographs and flow-duration curves of a stream draining an actively mined basin, North Sugar Creek tributary 1 below LaCygne Lake (station 5), to those of a stream draining an unmined control basin, North Sugar Creek tributary 3 below LaCygne Lake (station 7). Streamflow data collected from another actively mined basin, North Sugar Creek tributary 2 (station 6), were not compared because the stream gage could not record low flow.

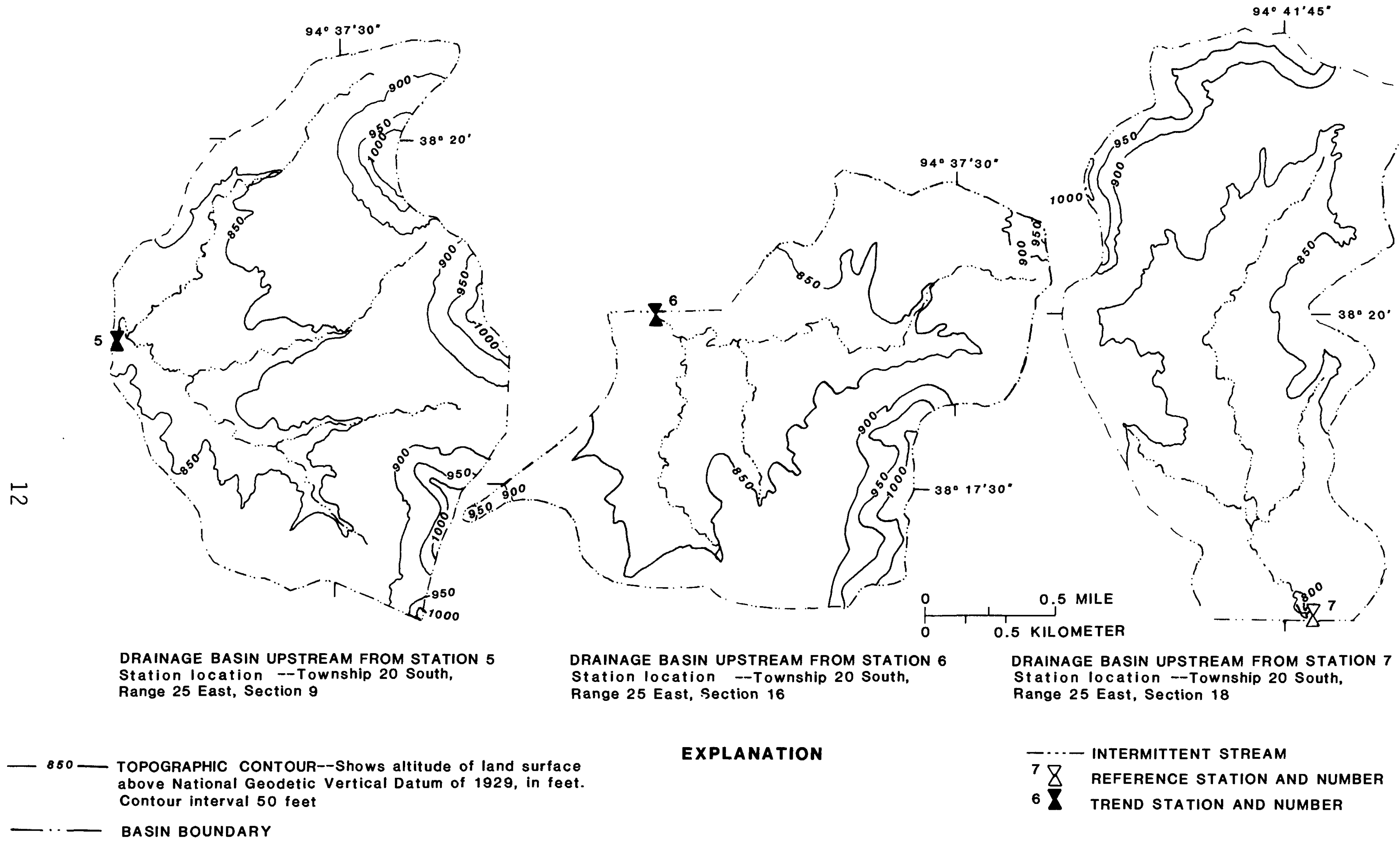

Figure 4.--Topography and drainage patterns of drainage basins upstream from stations 5, 6, and 7 (from U.S. Geological Survey 7 1/2-minute topographic quadrangle; Boicourt, 1973).

Stations 5, 6, and 7 are located on drainage basins that are in close proximity (fig. 2) and have approximately equal drainage areas (table 1). Maps depicting topography and drainage patterns (fig. 4) and geology (fig. 5) are presented for comparison. A coal strip mine began operating in the drainage basins upstream from stations 5 and 6 during January 1981. The extent of the strip mine and associated sediment ponds as of March 30, 1981, are shown in figure 6. Because of an extreme drought, these streams were dry from early June 1980, through May 16, 1981.

Storm Runoff

Storm runoff at station 5, the actively mined basin, was regulated by sediment ponds 24, 25, and 26 (fig. 6). Generally, sediment ponds redistribute storm runoff by decreasing high streamflow and increasing low streamflow. This effect is modified by the operation of the sediment ponds. The effects of different sediment-pond operations on streamflow from storm runoff are illustrated by comparing selected hydrographs from stations 5 and 7.

Prior to the storm that produced the streamflow shown in figure 7, the sediment ponds upstream from station 5 were relatively empty, and their outlets were closed. Consequently, a significant part of the runoff produced early in the storm was trapped, causing streamflow at station 5 to lag behind that of the unmined basin (station 7) and the peak streamflow at station 5 to be less than that at station 7. During the streamflow recession, overflow from the sediment ponds upstream from station 5 maintained the low flow at a higher discharge than at station 7.

The hydrographs in figure 8 represent a storm that occurred during a relatively wet period. The sediment ponds upstream from station 5 were open. This caused the streamflow at stations 5 and 7 to increase similarly to about 45 cubic feet per second. At this point, the outflow from the ponds was limited by the size of the outlets, and the peak streamflow at station 5 was less than that at station 7. During streamflow recession, discharge from the sediment ponds caused streamflow at station 5 to exceed the streamflow at station 7.

The effect of draining sediment ponds during a streamflow recession is illustrated in figure 9. Prior to the storm, the sediment ponds upstream of station 5 were relatively empty, and their outlets were closed. Consequently, streamflow at station 5 lagged behind, and peak streamflow was less than that at station 7. The streamflow at stations 5 and 7 decreased at approximately equal rates for about 1 day following the peaks, indicating that the sediment ponds upstream of station 5 remained closed and were not contributing. Approximately 3 days after the peak, streamflow at station 5 increased rapidly, remained nearly constant for about 2 days, then decreased rapidly. Streamflow at station 7 continued its normal recession through this period. The increased streamflow during the recession at station 5 occurred because a sediment pond was opened and drained.

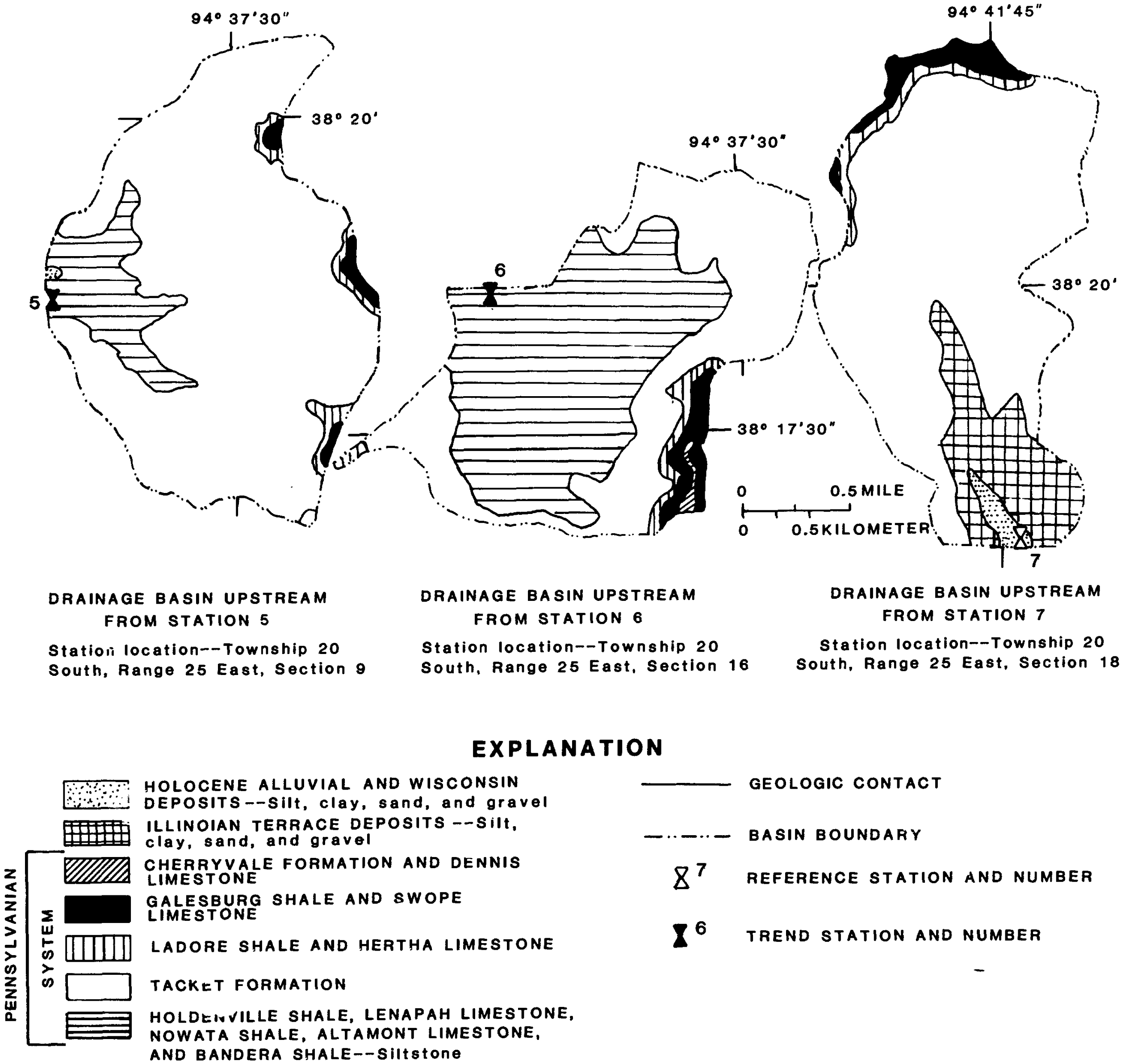

Figure 5.--Surface geology of drainage basins upstream from stations 5, 6, and 7 (geology modified from Seevers, 1969).

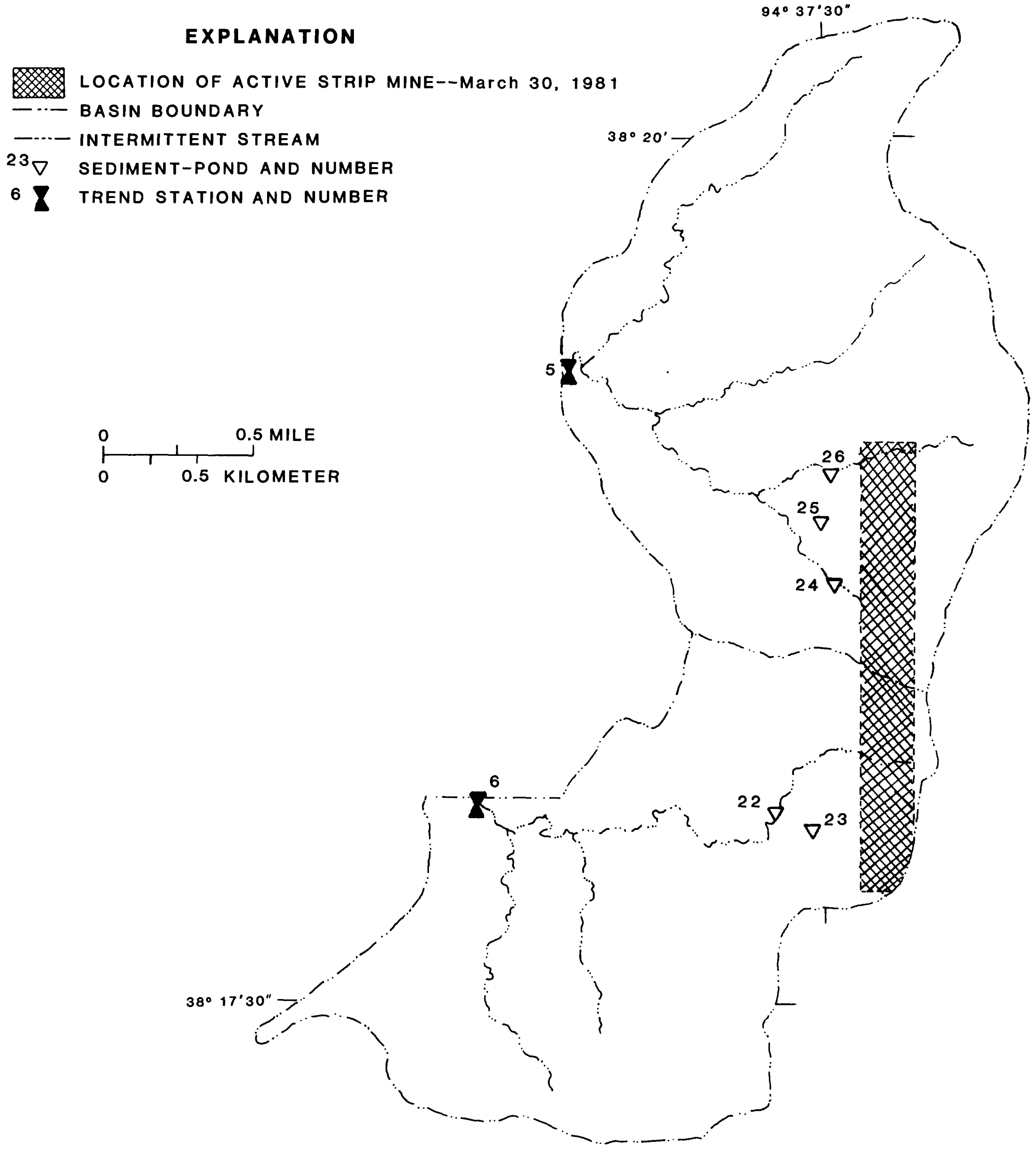

Figure 6.--Location of active strip mine and sediment ponds in drainage basins upstream from stations 5 and 6, March 30, 1981.

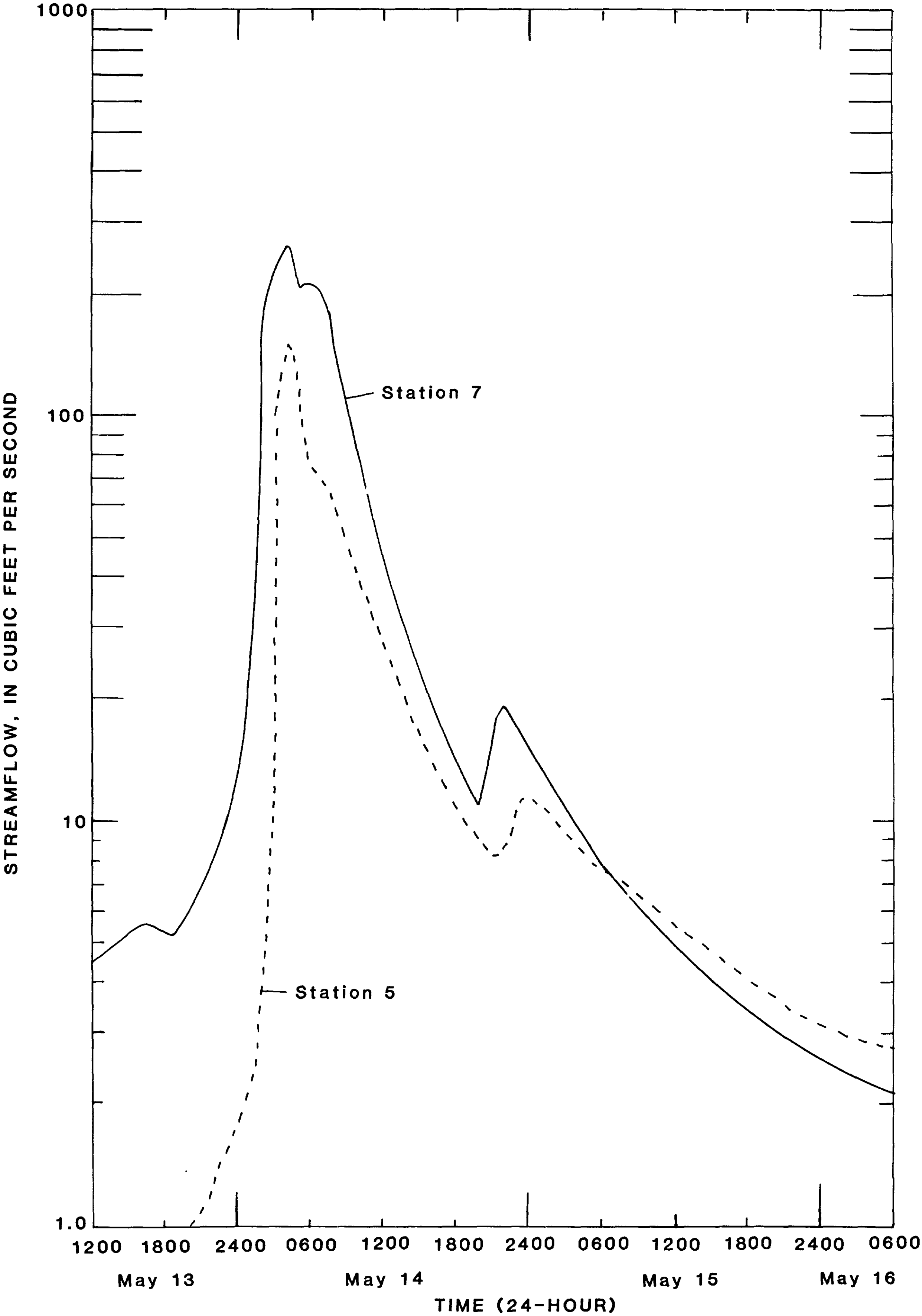

Figure 7.--Comparison of storm hydrographs for stations 5 and 7 when outlets of sediment ponds upstream from station 5 were closed, May 13-16, 1982.

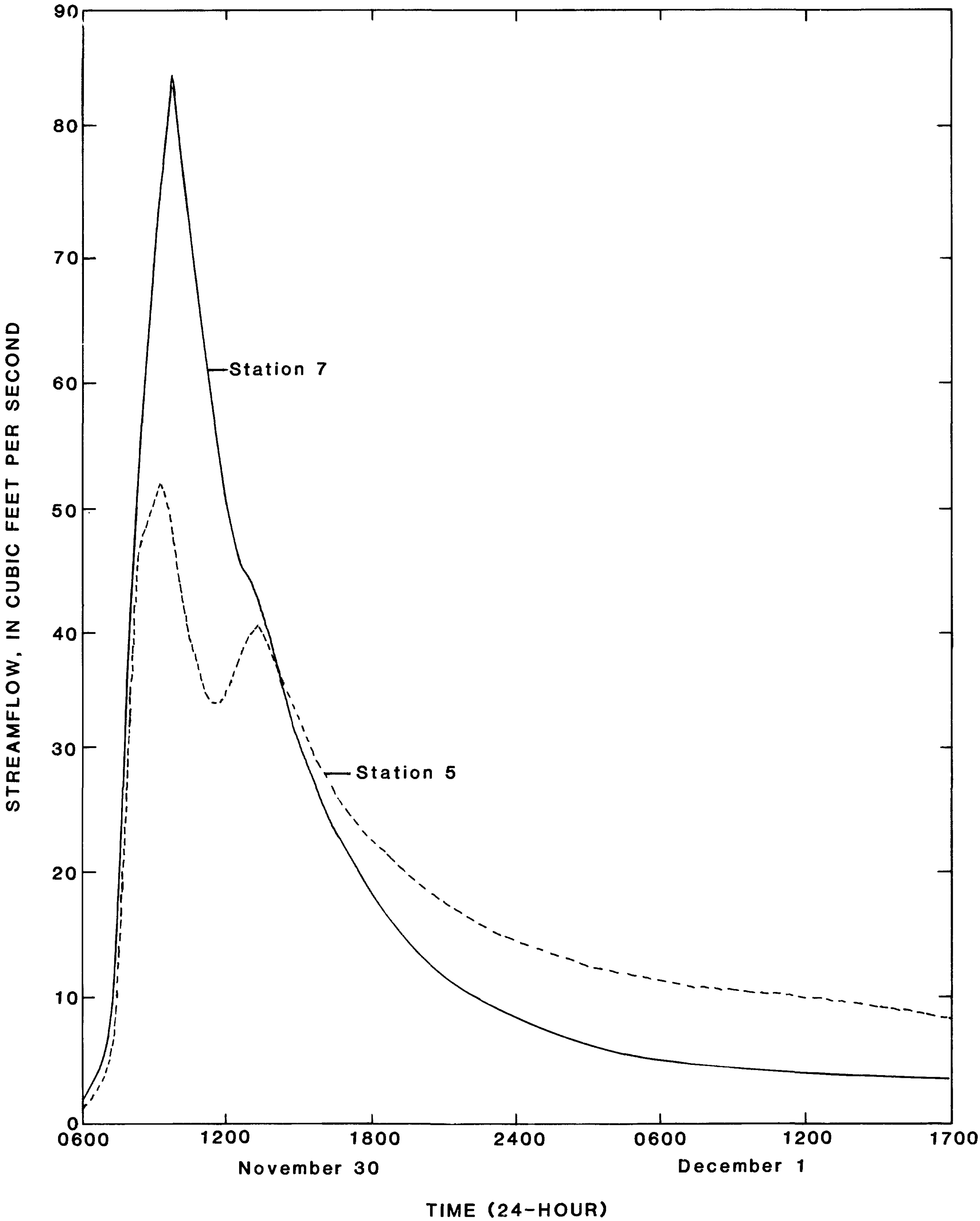

Figure 8.--Comparison of storm hydrographs for stations 5 and 7 when outlets of sediment ponds upstream from station 5 were open, November 30 and December 1, 1981.

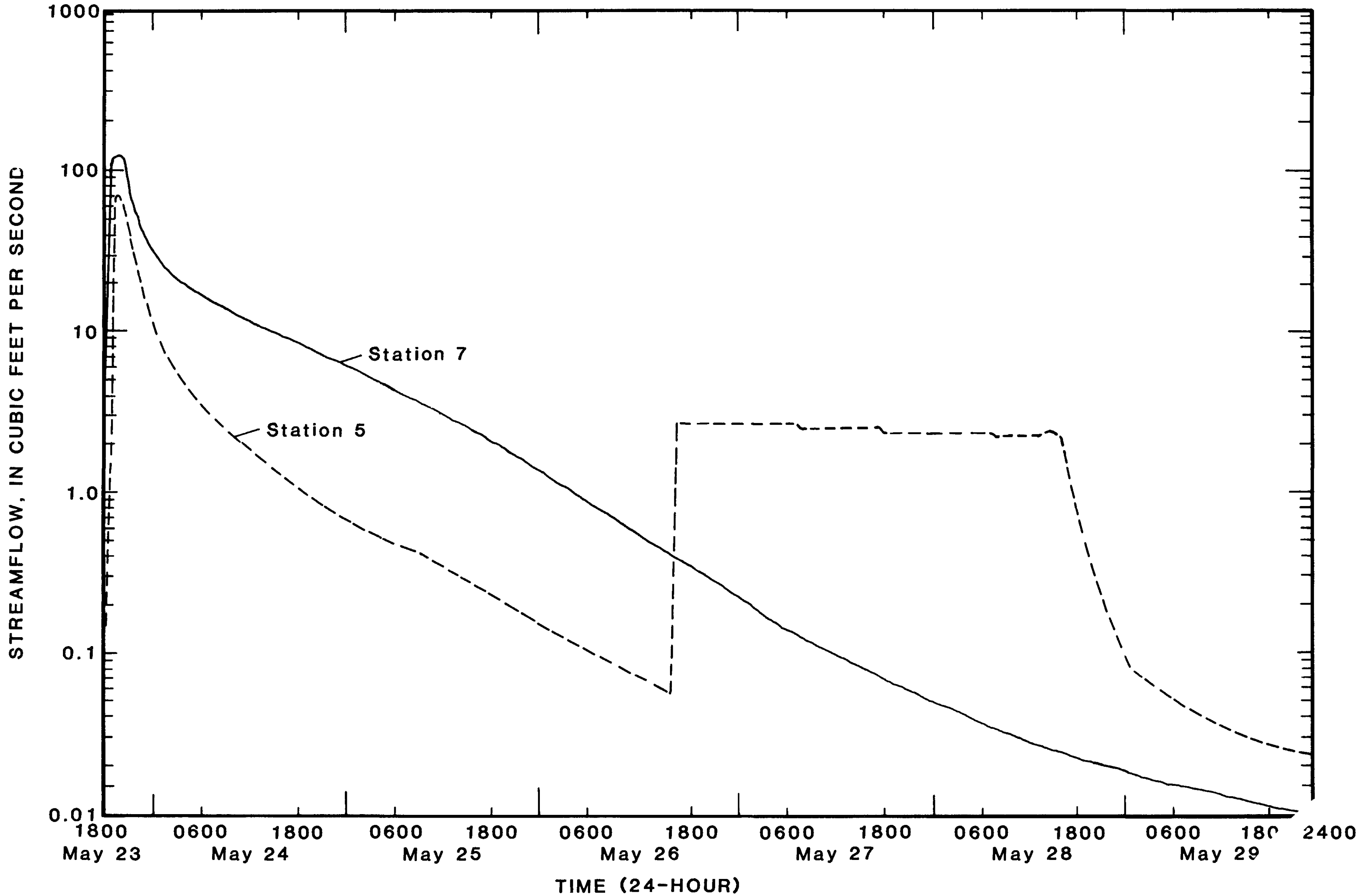

Figure 9.--Comparison of storm hydrographs for stations 5 and 7, showing effect of draining sediment ponds upstream from station 5, May 23-29, 1981.

Flow Duration

The long-term effect of streamflow regulation by the sediment ponds is illustrated by comparing flow duration in the actively mined basin, station 5, to that in the unmined control basin, station 7. The flow-duration curves presented in figure 10 indicate the percentage of time streamflow at each station was equaled or exceeded. These curves represent 247 days of concurrent streamflow data collected between May 17, 1981, and June 25, 1982.

The flow-duration curves show that, for this period of record, streamflow that was equaled or exceeded less than 15 percent of the time (high streamflow) was less in the actively mined basin, station 5. The low streamflow, that which was equaled or exceeded more than 15 percent of the time, was greater in the actively mined basin, station 5. These curves illustrate that the overall regulating effect of the sediment ponds is to redistribute streamflow at station 5 by decreasing high flow and increasing low flow.

Effects on Water-Quality Characteristics

The effects of active coal strip mining on water-quality characteristics of small area streams were determined by comparing selected characteristics of streams draining actively mined basins, stations 5 and 6, to those of a stream draining an unmined control basin, station 7.

Water-quality characteristics that usually are affected by active strip mining include instream specific conductance and concentrations and loads of dissolved solids, sulfate, and suspended sediment. Specific conductance, a physical measurement of the ability of water to conduct an electrical current, is dependent on and related directly to the concentration of dissolved solids in solution. An individual dissolved constituent, such as sulfate, is related directly to specific conductance only if it is present in ionic form and is a significant part of the concentration of dissolved solids. Increased concentrations of dissolved solids in streams draining coal-mined areas result primarily from increased concentrations of sulfate, derived from the oxidation of iron sulfide minerals (pyrite and marcasite) associated with the coal-bearing strata. However, the disturbance of unweathered bedrock and the acidity released by the oxidation of iron sulfide minerals accelerate physical and chemical erosion resulting in increased concentrations of other constituents. Concentrations of suspended sediment are increased by the exposure and disturbance of soil during clearing, excavation, and reclamation activities.

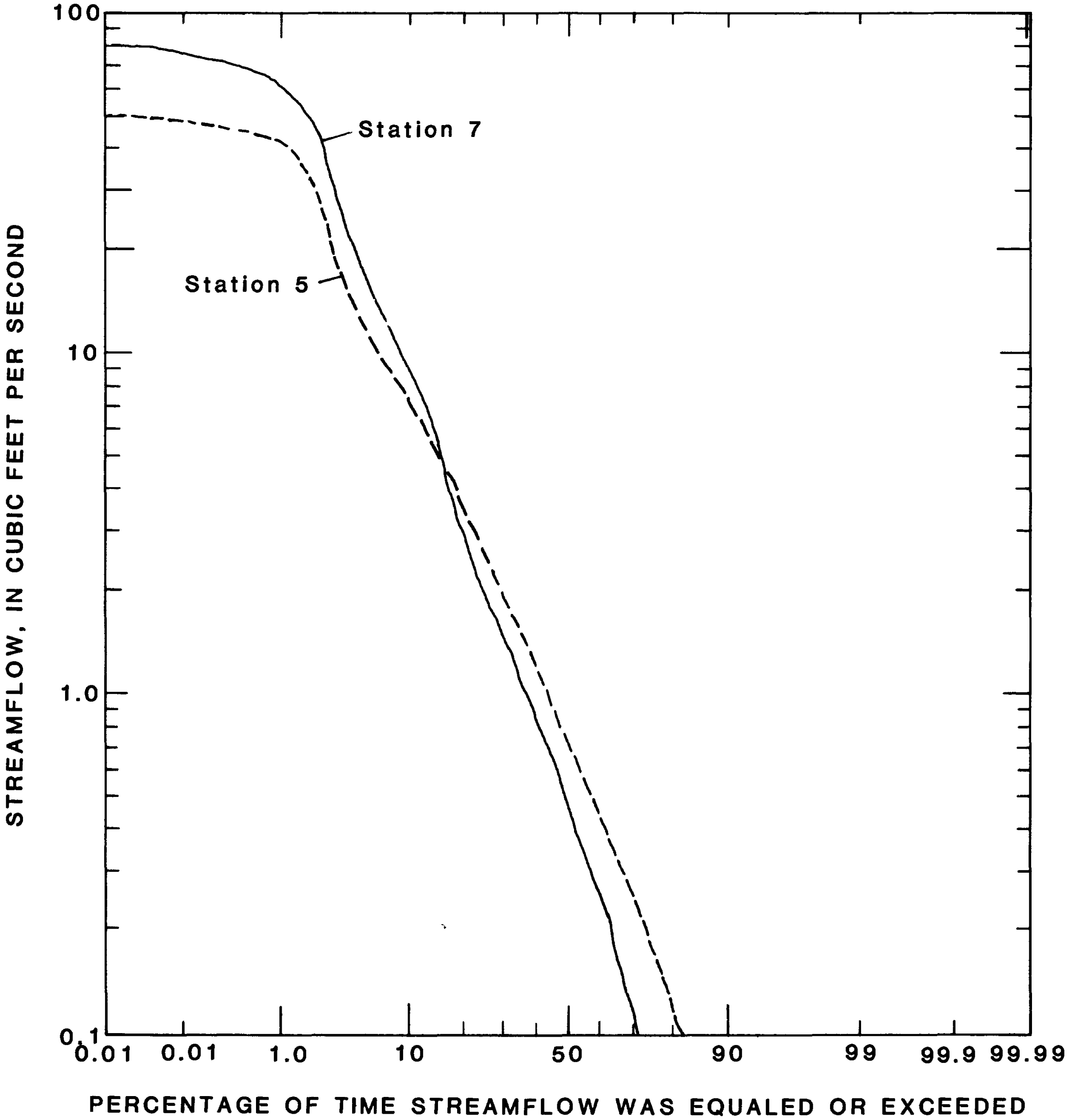

Figure 10.--Comparison of flow-duration curves for stations 5 and 7, computed with concurrent days of record between May 17, 1981, and June 25, 1982.

Specific Conductance, Dissolved Solids, and Sulfate

Results of correlation and regression analyses relating specific conductance to concentrations of dissolved solids and sulfate in streams draining the actively mined basins (stations 5 and 6) and the unmined control basin (station 7) are presented in table 3. The regression equations are of the form:

$$Y = m\,(COND) + b\ , \tag{4}$$

where

Y is the predicted concentration of dissolved solids or sulfate computed by the regression equation, in milligrams per liter;

m is a constant computed by the regression analysis that is the slope of the regression line;

COND is the measured specific conductance, in micromhos per centimeter at 25° Celsius; and

b is a constant computed by the regression analysis that is the Y-intercept value of dissolved solids or sulfate, in milligrams per liter.

The significant positive correlation coefficients and reasonable standard error of the estimates for these relationships indicate that specific conductance is a good indicator of instream concentrations of dissolved solids and sulfate at stations 5, 6, and 7.

Specific-conductance duration curves for stations 5, 6, and 7 were computed for the same period of record represented by the flow-duration curves (fig.10) presented in the flow-duration section and represent concurrently recorded data. The specific-conductance duration curves in figure 11 show that specific conductance generally was larger in streams draining the actively mined basins (stations 5 and 6) than in the stream draining the unmined control basin (station 7). The larger specific-conductance values in streams draining the actively mined basins indicate that concentrations of dissolved solids and sulfate also are larger than those in the stream draining the unmined control basin.

The reason that specific conductance that was exceeded only 10 percent of the time was much larger for the streams draining the actively mined basins relative to the stream draining the unmined control basin (fig. 11) was determined by onsite observation. During an inspection of the stations on July 13, 1981, it was observed that streamflow at stations 6 and 7 had ceased, but streamflow at station 5 was about 0.5 cubic foot per second, and the specific conductance was 1,770 micromhos per centimeter at 25° Celsius. A reconnaissance of conditions in the drainage basin upstream from station 5 revealed that water was being pumped from the active strip mine into a sediment pond and then released into the stream. The specific conductance of 1,770 micromhos per centimeter at 25° Celsius is not reflected on the specific-conductance duration curve because it was an instantaneous value. The specific-conductance monitor was not functioning properly at this time, and the data were not included in the computation of the duration curve.

Table 3.--Results of correlation and regression analyses relating concentrations of dissolved solids and sulfate to specific conductance at stations 5, 6, and 7

[Dissolved solids (DSC) and sulfate (SO_4) are given in milligrams per liter. Specific conductance (COND) is given in micromhos per centimeter at 25° Celsius]

Station index number (figure 2)	Regression equation	Number of samples	Correlation coefficient	Standard error of estimate (milligrams per liter)
5	DSC = 0.620 (COND) + 19.6	22	0.99	16
6	DSC = 0.700 (COND) + 8.02	23	1.0	25
7	DSC = 0.576 (COND) + 31.7	23	.95	19
5	SO_4 = 0.344 (COND) - 51.6	21	.97	21
6	SO_4 = 0.376 (COND) - 53.7	21	.99	25
7	SO_4 = 0.162 (COND) - 13.6	20	.82	12

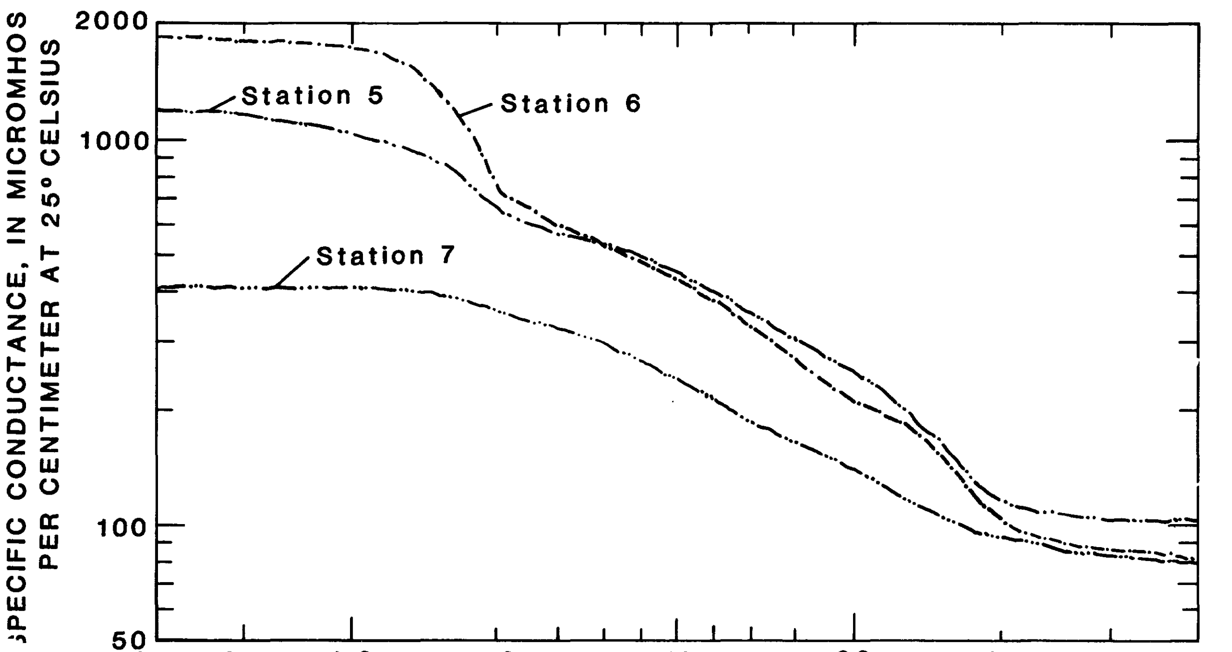

Figure 11.--Comparison of specific-conductance duration curves for stations 5, 6, and 7, computed with concurrent days of record between May 17, 1981, and June 25, 1982.

The 10 percent of the time when specific conductance at station 5 was much larger than at station 7 corresponds to the additional 10 percent of the time that there was streamflow at station 5 after streamflow at station 7 had ceased. Although the flow-duration curves in figure 10 do not show streamflow of less than 0.1 cubic foot per second, the additional 10 percent of the time that streamflow was equal to or greater than 0.1 cubic foot per second at station 5 relative to station 7 indicates that station 5 has flow for an additional 10 percent of the time after flow has ceased at station 7. Therefore, it can be assumed that for approximately 10 percent of the time, represented by the duration curves of both specific conductance and streamflow, flow at station 5 was provided by strip-mine effluent.

The specific-conductance duration curves for stations 5 and 6 gradually converge with the curve for station 7 from 10 percent of the time until about 98 percent of the time. This part of the curve represents periods when stations 5 and 6 are being affected by strip-mine effluent diluted by increasing volumes of surface runoff.

The effect of sediment-pond releases containing strip-mine effluent diluted by surface runoff on specific conductance is illustrated by comparing hydrographs and simultaneously recorded specific-conductance values from stations 5 and 7 for May 23, 1981, at 1900 hours (7:00 p.m.) through May 29, 1981 (fig. 12). Specific-conductance values initially decreased at both stations because the low flow initially was diluted by surface runoff. Specific-conductance values generally increased at both stations as streamflow decreased. At about 1600 hours (4:00 p.m.) on May 26, the streamflow and specific conductance at station 5 increased significantly, while streamflow at station 7 continued its normal recession and specific conductance began to level off. The significant increases in streamflow and specific conductance at station 5 resulted from the release of water from a sediment pond that contained surface runoff and strip-mine effluent.

From about 98 percent to 100 percent of the time, the specific-conductance duration curves for stations 5, 6, and 7 converge and level off at their minimums. This 2 percent of the time, which represents the minimum specific conductance on the duration curves (fig. 11), corresponds to the 2 percent of the time that represented the maximum streamflow on the flow-duration curves in the section on flow duration (fig. 10). During this time, surface runoff provided nearly all of the streamflow, and the strip-mine effluent had little effect on water quality.

Loads of dissolved solids and sulfate, in tons, were computed for stations 5 and 7 for the time period represented by the flow-duration and specific-conductance duration curves. The loads were computed by: (1) Inserting the mean daily specific conductance into the regression equations given in table 3 to compute mean daily concentrations of dissolved solids and sulfate, (2) multiplying mean daily concentrations by mean daily streamflow and 0.0027 to compute daily loads, in tons per day, and (3) summing tons per day for the period of record to compute the loads in tons.

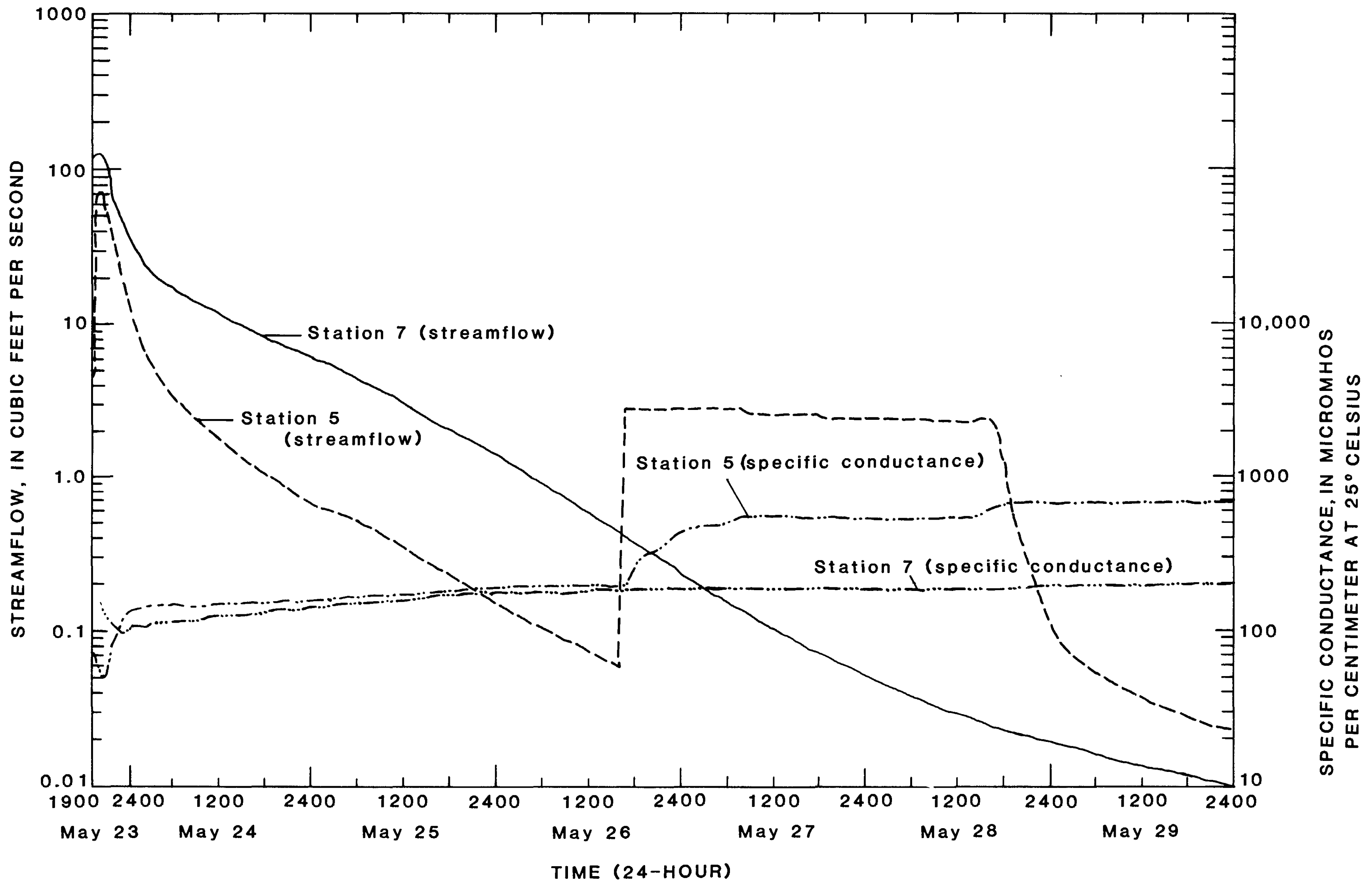

Figure 12.--Comparison of storm hydrographs and specific-conductance values for stations 5 and 7, showing effects of draining a sediment pond containing strip-mine effluent upstream from station 5, May 23-29, 1981.

The computed loads of dissolved solids were 441 tons at station 5 and 313 tons at station 7. The computed loads of sulfate were 122 tons at station 5 and 35.5 tons at station 7. The 41-percent greater load of dissolved solids and the 244-percent greater load of sulfate at station 5 were contributed by strip-mine effluent. Loads were not computed for station 6 because streamflow data were inadequate.

Suspended Sediment

Instream concentrations and loads of suspended sediment usually are increased by active strip mining. Results of correlation and regression analyses relating concentrations and loads of suspended sediment to streamflow for stations 5 and 7 are presented in table 4. The regression equations are of the form:

$$Y = bQ^m , \qquad (5)$$

where

Y is the predicted concentration, in milligrams per liter, or load, in tons per day, of suspended sediment computed by the regression equation;

b is a constant computed by the regression analysis that is the antilog of the Y intercept;

Q is the measured, instantaneous streamflow, in cubic feet per second; and

m is a constant computed by the regression analysis that is the slope of the regression line.

The Y-intercept values for the equations representing station 5, the actively mined basin, are larger, and the slopes of the regression lines are not as steep as those representing station 7, the unmined control basin. This indicates that concentrations and loads of suspended sediment were larger at station 5 than those at station 7 when streamflow was relatively low. But as streamflow increased, the differences in concentrations and loads of suspended sediment at stations 5 and 7 decreased. It can be assumed, because there is no reason to believe otherwise, that the variation between the relationships for stations 5 and 7 resulted from active strip mining, most likely the draining of sediment ponds containing runoff from cleared and disturbed areas.

Loads of suspended sediment at stations 5 and 7 were computed for the same time period represented by the flow-duration curves in the section on flow duration (fig. 10). These loads were computed by: (1) Inserting recorded mean daily streamflow in the load equations from table 4 to compute daily loads and (2) summing the loads for the period of record. Computed loads of suspended sediment were 1,576 tons at station 5, and 1,257 tons at station 7. The approximately 25-percent greater sediment load at station 5 compared to station 7 is significant considering the relatively small part of the drainage basin upstream from station 5 that is affected by the strip mine (fig. 6).

Table 4.--Results of correlation and regression analyses relating concentrations and loads of suspended sediment to streamflow at stations 5 and 7

[Concentrations of suspended sediment (SSC) are in milligrams per liter, loads of suspended sediment (SSL) are in tons per day, and streamflow (Q) is in cubic feet per second]

Station index number (figure 2)	Regression equation	Number of samples	Correlation coefficient	Standard error of estimate, in percent of predicted value	
				Above regression line	Below regression line
5	SSC = 428 $Q^{0.2543}$	19	0.67	86	46
7	SSC = 119 $Q^{0.4700}$	21	.91	64	39
5	SSL = 1.17 $Q^{1.252}$	19	.98	85	46
7	SSL = 0.334 $Q^{1.459}$	20	.98	66	40

SEDIMENT-POND DISCHARGE

Sediment-pond discharge is the primary factor affecting streamflow and water-quality characteristics in small streams draining actively mined basins in the study area. The effects of sediment ponds on streamflow characteristics were discussed in the sections on storm runoff and flow duration. Although high streamflow is decreased and low flow is increased, the total volume of streamflow is relatively unchanged. This is not the case with water-quality characteristics. Instream values of specific conductance and concentrations of dissolved solids, sulfate, suspended sediment, and total metals can be increased by discharge from the sediment ponds. The degree to which these water-quality characteristics are affected depends on how the sediment ponds are operated.

If the sediment ponds are only trapping surface runoff, the quality of their release is not much different than the natural streamflow except that suspended-sediment concentrations may be larger because the areas drained by the ponds have been cleared and disturbed. However, if the sediment ponds are being used for disposal of effluent pumped from the active strip mine, large values of specific conductance and concentrations of dissolved solids, sulfate, suspended sediment, and total metals can degrade the quality of the receiving stream.

A statistical summary of water-quality data collected from discharging sediment ponds is presented in table 5. Because the sediment ponds were sampled only a few times, data from all five ponds are grouped together in the summary.

The results of the statistical summary indicate a relatively wide range of variability in water-quality characteristics of the sediment-pond discharges even though there were only six samples collected. This variability is caused by effluent pumped from the strip mine being included in some of the sediment-pond discharges.

The effect of strip-mine effluent on water-quality characteristics of receiving streams is indicated by comparing maximum concentrations of selected water-quality constituents measured at stations 5 and 6, downstream from the active strip mine, to maximum concentrations measured at station 7, downstream from the unmined control basin (table 6). Examination of the maximum values in table 6 indicates that the constituents increased most by strip-mine effluent are dissolved solids and sulfate. However, larger concentrations of suspended sediment and total iron, manganese, and lead at either station 5 or 6 relative to station 7 indicate that these constituents also may be increased significantly by the effluent.

Table 5.--Statistical summary of water-quality data collected from discharging sediment ponds

[Includes samples from sediment ponds 22, 23, 24, 25, and 26]

Physical property or chemical constituent	Number of samples	Minimum value	Maximum value
Sediment-pond discharge, in cubic feet per second	6	0.5	5.5
Specific conductance, in micromhos per centimeter at 25° Celsius	6	101	541
pH, in standard units	6	7.3	8.2
Sulfate, in milligrams per liter	6	1.8	150
Dissolved solids, in milligrams per liter	6	65	441
Suspended sediment, in milligrams per liter	6	579	16,400
Total iron, in micrograms per liter	6	18,000	250,000
Total lead, in micrograms per liter	6	3.0	60
Total manganese, in micrograms per liter	6	150	3,500
Total zinc, in micrograms per liter	6	50	600

Table 6.--Maximum concentrations of selected chemical constituents at stations 5, 6, and 7 (see figure 2 for locations)

Chemical constituent	Maximum concentration at		
	station 5	station 6	station 7
Sulfate, in milligrams per liter	310	670	63
Dissolved solids, in milligrams per liter	606	1,330	254
Suspended sediment, in milligrams per liter	3,740	1,330	1,740
Total iron, in micrograms per liter	56,000	28,000	48,000
Total lead, in micrograms per liter	40	26	22
Total manganese, in micrograms per liter	990	1,900	720
Total zinc, in micrograms per liter	130	120	140

SUMMARY

The hydrologic responses of streams to coal-mining activities in the Mulberry coal reserves of eastern Kansas have been investigated by (1) an evaluation of water-quality data collected during a low-flow water-quality reconnaissance of streams draining the study area, with respect to coal-mining activities, (2) a comparison of streamflow characteristics of an actively mined basin with those of an unmined control basin, and (3) a comparison of water-quality characteristics of streams draining actively mined basins with those of a stream draining an unmined control basin.

An evaluation of the data from the low-flow water-quality reconnaissance, with respect to coal-mining activities, determined that streams draining the most extensively mined areas, Indian and North Sugar Creeks, have the largest instream concentrations of sulfate and dissolved solids. Streams draining basins that have been mined to a lesser degree have larger concentrations of sulfate than streams draining unmined areas. The major streams draining the study area, the Marais des Cygnes and Little Osage Rivers, have been affected only slightly.

Streamflow in an actively mined basin, North Sugar Creek tributary 1, is regulated by sediment ponds associated with the active strip mine. High streamflow is decreased and low streamflow is increased by the sediment ponds.

Water-quality characteristics that are affected most by active strip mining are specific conductance and concentrations and loads of dissolved solids, sulfate, and suspended sediment. Specific-conductance values and concentrations and loads of dissolved solids and sulfate are larger in the streams draining the actively mined basins. North Sugar Creek tributary 1, which drains an actively mined basin, had a 41-percent greater load of dissolved solids and a 244-percent greater load of sulfate than North Sugar Creek tributary 3, which drains an unmined control basin. These larger loads are caused by effluent pumped from the active strip mine.

Concentrations and loads of suspended sediment are larger in the streams draining the actively mined basins because of clearing and excavation activities associated with the active strip mine. North Sugar Creek tributary 1 had a 25-percent greater load of suspended sediment than North Sugar Creek tributary 3.

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