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THE QUALITY OF WATER DISCHARGING FROM THE NEW RIVER AND CLEAR F--ETC(U)
AUG 80 R S PARKER, W P CAREY
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U.S. Geological Survey, Water Resources Division
A-413 Federal Building - U.S. Courthouse
Nashville, Tennessee 37203

Prepared in cooperation with the U.S. [illegible] Conservation Service, Tennessee Valley Authority, [illegible] University of Tennessee at Knoxville

[illegible] Water discharging from the heavily [illegible] ized by neutral pH, low dissolved solids (<300 mg/L) and [illegible] pended sediment. Approximately 590,000 tons of [illegible] the New River basin in 1977, as compared to an [illegible] unmined Clear Fork basin. More than 90 percent of the [illegible] clay (<0.0625 mm).

In association with these fine-grained [illegible] metals. In 1977 the New River basin discharged [illegible] iron while Clear Fork only discharged [illegible] centration was found to be highly correlated [illegible] concentrations. This correlation coupled [illegible] that trace metals are transported primarily [illegible]

The most promising indicator of the [illegible] dissolved sulfate. All unmined basins, [illegible] concentrations less than 20 mg/L whereas all [illegible] centrations in excess of 20 mg/L regardless [illegible]

Coal mines*, water quality, [illegible] temperature, dissolved solids, [illegible]

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THE QUALITY OF WATER DISCHARGING FROM THE

NEW RIVER AND CLEAR FORK BASINS, TENNESSEE

By R. S. Parker [redacted] W. P. Carey

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 80-37

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Prepared in cooperation with the U.S.
Soil Conservation Service, the U.S. Army Corps
of Engineers, the Tennessee Valley Authority,
the University of Tennessee at Knoxville, and
the Tennessee Division of Geology

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UNITED STATES DEPARTMENT OF INTERIOR

CECIL D. ANDRUS, Secretary

GEOLOGICAL SURVEY

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CONVERSION FACTORS

Factors for converting inch-pound units to metric units are shown to four significant figures. However, in the text the metric equivalents are shown only to the number of significant figures consistent with the values for the inch-pound.

Inch-pound units	Multiply by	Metric units
ft (foot)	3.048×10^{-1}	m (meter)
ft (foot)	3.048×10^{2}	mm (millimeter)
ft^3	2.832×10^{-2}	m^3 (cubic meter)
mi (mile)	1.609	km (kilometer)
mi^2 (square mile)	2.590	km^2 (square kilometer)
ton (ton, short)	9.072×10^{2}	kg (kilograms)
°F = 9/5 (°C) + 32		°C = 5/9 (°F - 32)

Note:

National Geodetic Vertical Datum of 1929 (NGVD of 1929) is now being used in place of the term "mean sea level".

THE QUALITY OF WATER DISCHARGING FROM THE NEW RIVER AND CLEAR FORK BASINS, TENNESSEE

by R. S. Parker and W. P. Carey

ABSTRACT

The quality of water discharging from a strip-mined basin and a relatively unmined basin on the Cumberland Plateau in Tennessee are examined and compared. The chemical and aesthetic quality of these waters will directly affect the chemical and aesthetic quality of the water flowing through a proposed national river and recreation area.

Water from the heavily mined New River basin is characterized by neutral pH, low dissolved solids (less than 300 milligrams per liter), and high concentrations of suspended sediment. More than 90 percent of the suspended sediment is silt and clay. Suspended-sediment concentrations in the thousands of milligrams per liter are not uncommon for New River and often impart a highly turbid appearance to the water. Approximately 590,000 tons of suspended sediment were discharged from the New River basin in 1977, as compared to an estimated 20,000 tons from the relatively unmined Clear Fork basin.

In association with these fine-grain suspended sediments are sorbed trace metals. In 1977 the New River basin discharged an estimated 17,000 tons of suspended iron while Clear Fork discharged an estimated 600 tons. Suspended-sediment concentration was found to be highly correlated with both suspended and total trace-metal concentrations. This correlation coupled with the nearly neutral pH of the water indicates that trace metals are transported primarily in the suspended phase.

The most promising indicator of the presence of coal mining was found to be dissolved sulfate. All unmined basins sampled in this study showed dissolved sulfate concentrations less than 20 milligrams per liter, whereas all mined basins had dissolved-sulfate concentrations in excess of 20 milligrams per liter regardless of basin size or discharge.

INTRODUCTION

In Tennessee coal is mined primarily in the Cumberland Plateau physiographic region in east-central Tennessee. Within this region the largest concentration of coal mining is in the 382 mi^2 New River basin (fig. 1). Coal production from this basin alone accounted for 56 percent (4.9 million tons) of Tennessee's total production in 1974.

New River flows in a northwesterly direction and joins Clear Fork to form the Big South Fork Cumberland River (fig. 1). In 1974 the enactment of Public Law 93-251 by Congress authorized the establishment of the Big South Fork National River and Recreation Area. Since this area (fig. 1) is directly downstream from the confluence of the New River and Clear Fork basins, the water quality in the area is directly dependent upon the quality of the mixture of New River and Clear Fork water.

This report describes the water quality and sediment loads from the heavily mined New River basin during the period 1975-77. Some comparisons are made between the water quality and sediment loads of the New River basin and the 272 mi^2 Clear Fork basin, which is relatively unmined.

Purpose and Scope

The purpose of this report is to:

1. Generally characterize the water quality of the New River basin using the data from an initial water quality sampling program.

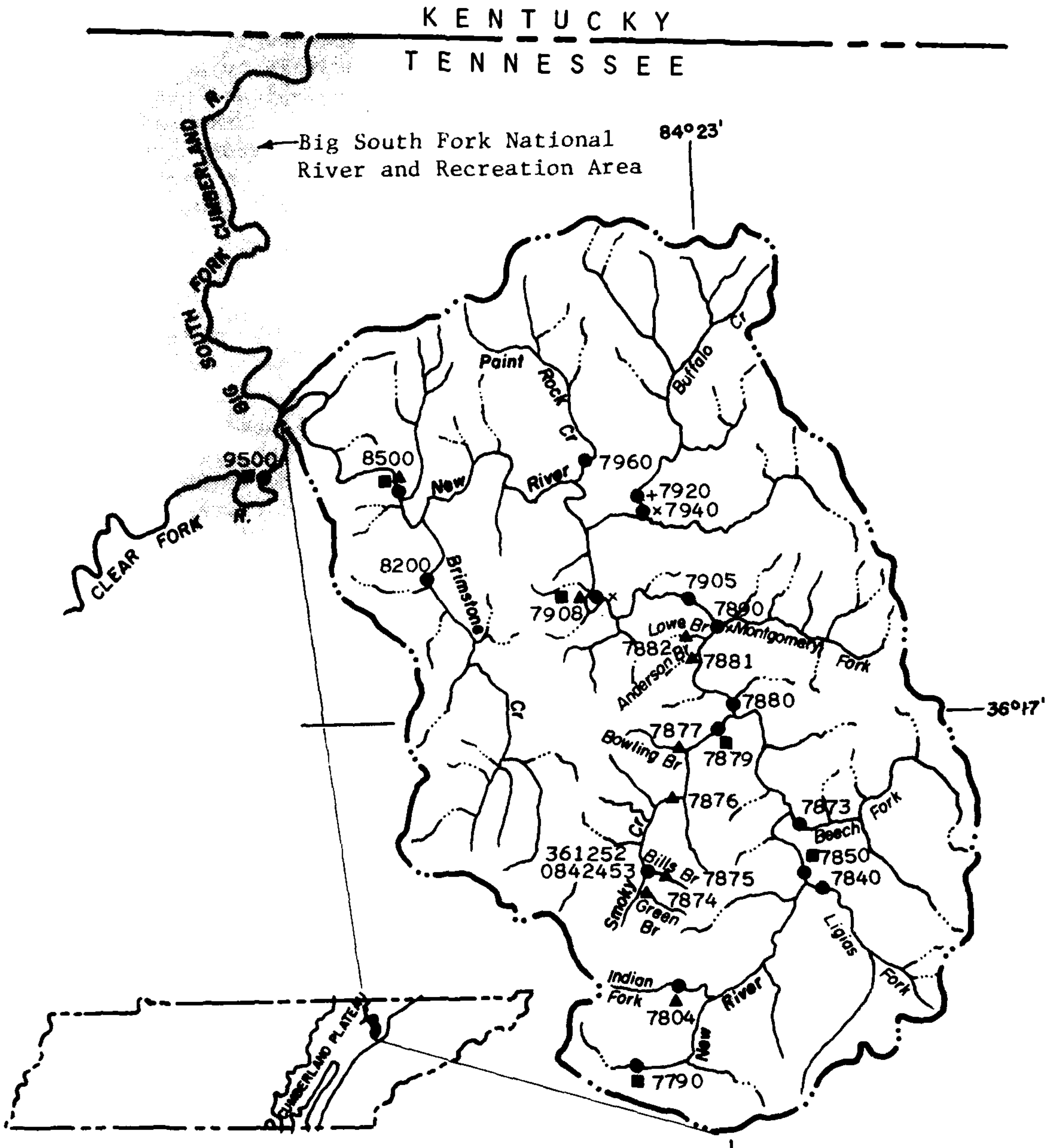
2. Present data on water quality and sediment yield near the mouth of the New River basin.

3. Compare the water quality data from New River with the limited data available from sampling in the essentially unmined Clear Fork basin.

No attempt has been made to analyze all the data from all sampling sites in detail. Instead the data collected near the mouth of both basins have been emphasized and, in the case of the New River basin, selected comparisons have been made with data collected within the basin.

Acknowledgments

Due to concentrated coal mining in the New River basin and the proposed recreation area downstream, many agencies and organizations, both State and Federal, have cooperated with the Geological Survey in this study. Agencies supporting the investigation through funding or services include the U.S. Soil Conservation Service, the U.S. Army Corps of Engineers, the Tennessee Valley Authority, the University of Tennessee at Knoxville, and the Tennessee Division of Geology.



EXPLANATION

- ● Low flow May and October 1975
- ●+ Low flow May only 1975
- ●× Low flow October only 1975
- ■ Monthly
- ▲ Gage

Figure 1.-- Location of New River Basin and Sampling Stations.

Units of Measurement

Data describing lengths and areas in this report are defined or dimensioned in inch-pound-second units. With the exception of discharge values, water-quality data are defined entirely by metric units. Thus, water temperatures are expressed in degrees Celsius (°C) and concentrations of suspended and dissolved constituents are given in milligrams per liter (mg/L). Suspended- and dissolved-constituent discharges are expressed in tons per year (tons/year). A list of inch-pound to metric conversions follows the "Contents" section of the report.

DESCRIPTION OF STUDY AREA

Physiography and Topography

The study basin is in the Northern Cumberland Plateau physiographic region of east-central Tennessee (fig. 1). This region is part of the Appalachian Plateau physiographic province which runs from southern New York to central Alabama. The Cumberland Plateau in Tennessee is a broad, relatively flat-topped plateau, with altitudes averaging between 1,700 and 2,000 feet.

The New River basin is located on the highly dissected eastern edge of this plateau. Altitudes in the basin range from 1,004 ft at the junction with Clear Fork to 3,543 ft on top of Cross Mountain which is located along the southeastern boundary of the basin. Relief within any 5 mi^2 area commonly exceeds 1,500 ft, and average slope within the basin is about 25 percent.

The physiography of the Clear Fork basin is quite different from that of the New River basin even though the two are adjacent and share a common drainage divide. In the Clear Fork basin, the altitude of the land surface between major streams generally ranges from 1,500 to 1,850 feet. This consistency in upland altitude gives the basin a flat-topped or plateau type appearance. This plateau type appearance is interrupted only at the southeastern corner of the basin where altitudes rise quickly to a basin high of 2,700 feet. This local disturbance forms Griffin Mountain and occurs along the common divide shared by the New River basin. The lowest altitude in the Clear Fork basin is 1,004 feet at the mouth of Clear Fork. Therefore, with the exception of the Griffin Mountain area, the Clear Fork basin is characterized by consistent relief and mild slopes. This is in direct contrast to the rugged relief and steep slopes of the New River basin.

Geology

The coal bearing rocks of the study area are of Early and Middle Pennsylvanian age and represent rocks of the Pottsville Series of this system* (Luther 1959, p 11).

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*Geologic names used in this report are those of the Tennessee Division of Geology and are not necessarily in agreement with names used by the U.S. Geological Survey.

"The Pennsylvanian rocks in Tennessee consist largely of alternating layers of sandstone and shale, but coal beds and very thin and sporadic limestone beds compose a minor percentage of the whole. On a gross scale the sequence is divisible into two major components, a lower part which consists largely of thick sandstones and conglomerates separated by approximately equal amounts of shale, and an upper part in which sandstones are mostly thin and discontinuous, and the intervening shales are thicker and more important. The upper part also contains a greater number of coal beds than the lower part. In general the upper shaly sequence of the Pennsylvanian is preserved only in the Cumberland Mountains region of the northeastern part of the Plateau, and the lower, sandy sequence caps the remaining flat-topped part of the Plateau (Luther 1959)".

The New River - Clear Fork study area is consistent with Luther's geologic description in that the upper shaly sequence is found in the mountainous New River basin while the plateau-like Clear Fork basin is capped by the lower sandy sequence. In reference to figure 2, the greater part of the Clear Fork basin is capped by rocks of the Crooked Fork Group and Crab Orchard Mountains Group with only minor occurrences of younger rocks. The surficial geology of the New River basin varies in age from the Crab Orchard Mountains Group which occurs near the mouth of New River to the Cross Mountain Group which occurs on mountain tops forming the eastern and southeastern perimeter of the basin.

Structurally, the New River basin is located in an area which has experienced relatively little tectonic disturbance. This area is known as the Wartburg Basin (fig. 3). The following description of the Wartburg Basin is quoted from Luther (1959) page 31.

> The Wartburg Basin is a structural low of considerable size which is centered around the area where Scott, Morgan, Anderson and Campbell Counties come closest to a common corner. It is bounded on the southeast by Walden Ridge (North) and on the east by the Jacksboro-Pine Mountain fault system. To the west it merges into the Northern Cumberland Plateau subprovince, and to the north it continues into Kentucky. Beds dip gently into the basin from the Nashville Dome to the west and the Cumberland Plateau overthrust system to the south, steeply into the zigzag east side of the basin off Walden Ridge (North), the Jacksboro fault, and the Pine Mountain Fault.

The Clear Fork basin is located on the transition between the Northern Cumberland Plateau subprovince and the Wartburg basin. The structure of this area is quite simply a gentle regional dip to the east.

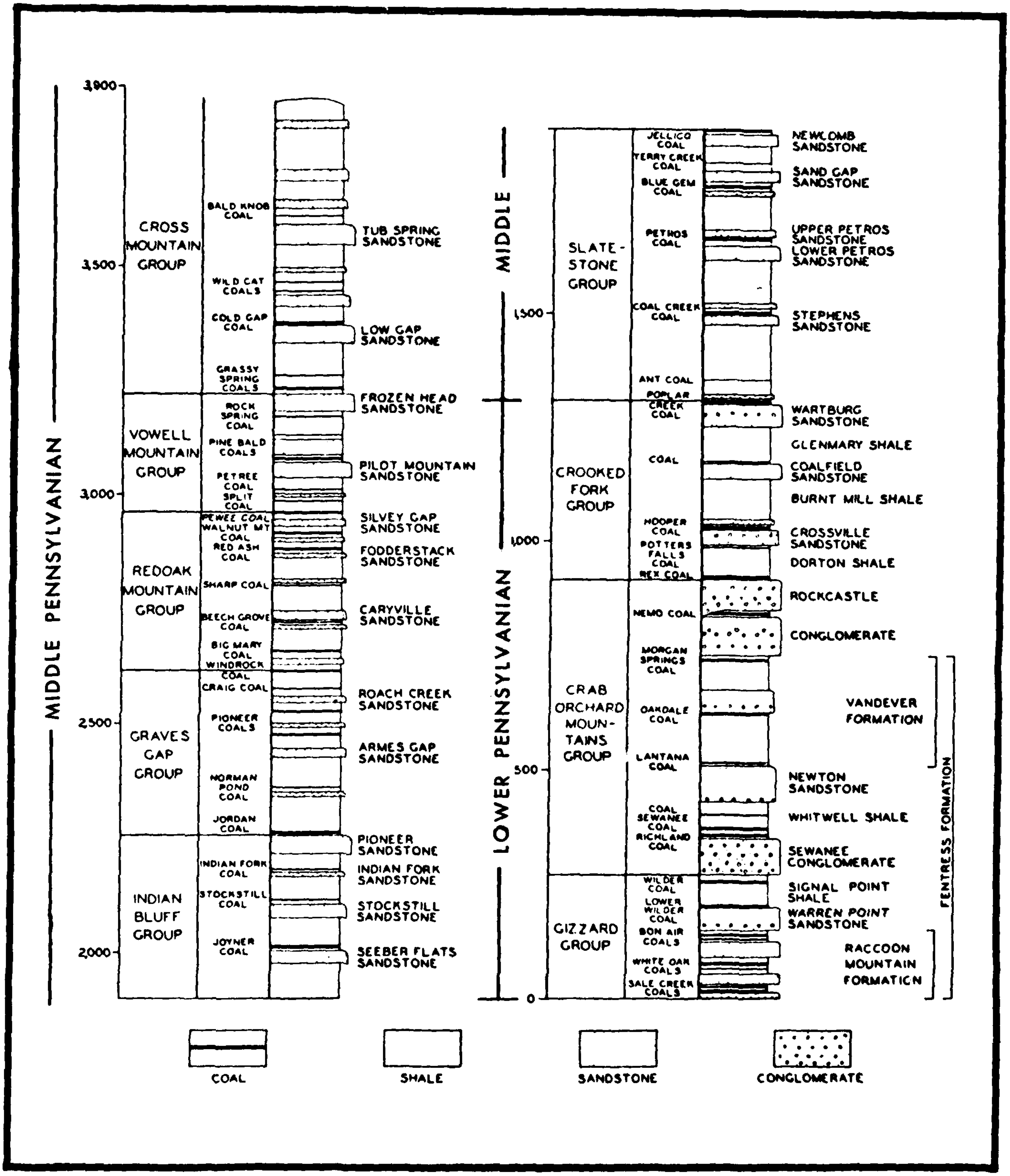

Figure 2.--Generalized stratigraphic sequence of Pennsylvanian rocks in Tennessee (from Luther 1959, p11)

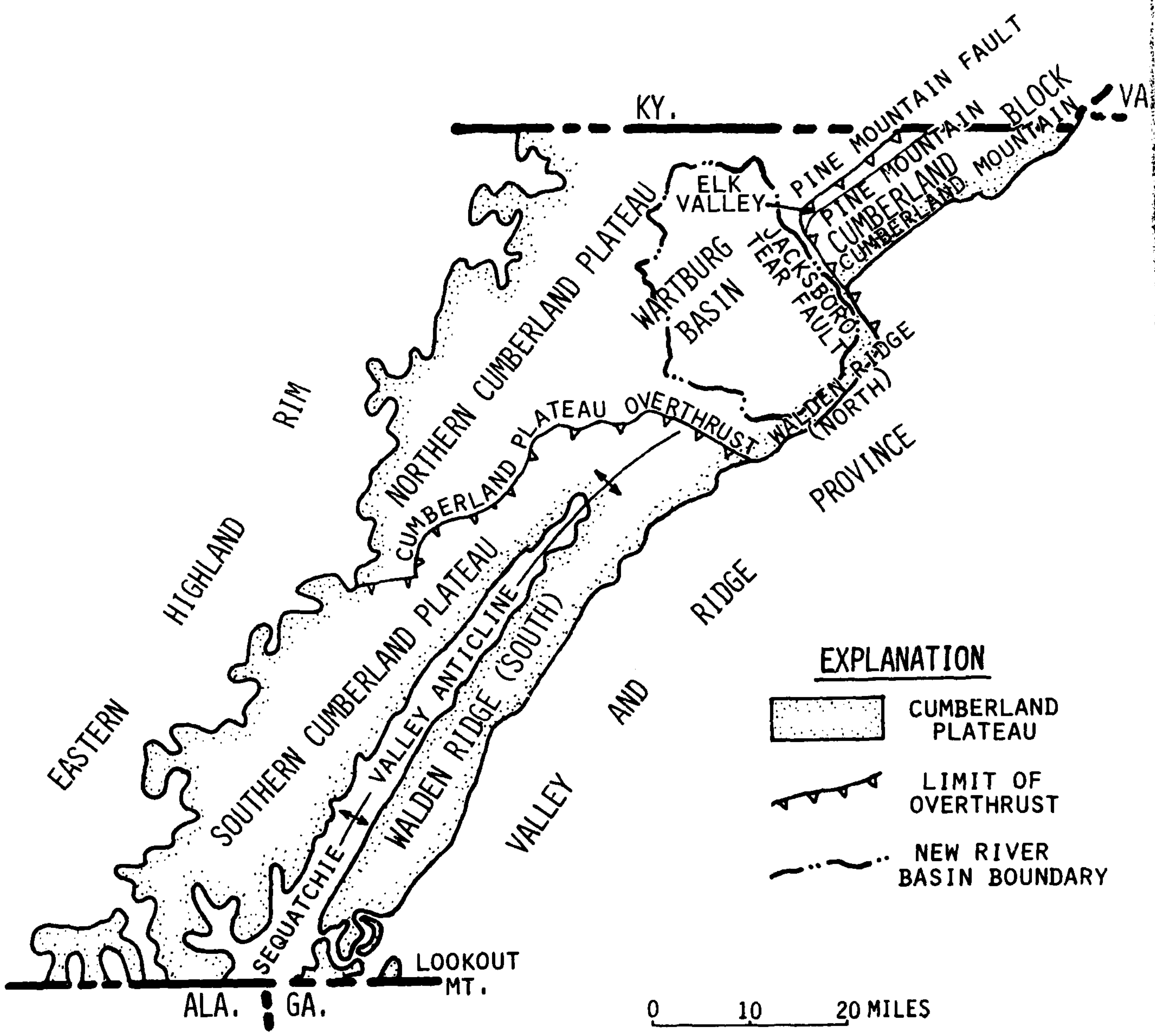

Figure 3.--Generalized structural featuies of the Cumberland Plateau in Tennessee (modified from Luther, 1959)

Climate

The New River and Clear Fork basins experience a moderate climate, with an average temperature of 58°F, an annual precipitation of approximately 54 inches, and an annual average snowfall of 9 inches. The largest amount of precipitation occurs in the winter and spring in association with the passage of frontal systems. Precipitation in the summer is generally limited to short but intense rainfall from afternoon and evening convective storms.

Land Use and Coal Mining Operations

The New River basin is predominately covered by hardwood forest (81 percent), while only 8 percent of the basin is covered by evergreen trees (Hollyday and Sauer, 1976). Strip mines make up about 7 percent of the basin area. Only 5 percent of the basin is in agriculture and this is primarily restricted to valleys of the major streams. At present, little data are available on land cover categories in the Clear Fork basin although the Tennessee Valley Authority is now preparing land use maps of this basin. In general, however, the Clear Fork basin is covered by hardwood forests. Agriculture is more prevalent in the Clear Fork basin and coal mining probably occurs on less than 1 percent of the land in the basin.

In the New River basin coal is typically extracted by the contour strip method. Some deep mining occurred in the past but little is being done today. The sequence of a mining operation is generally to strip along the contour within the economic limits of overburden depth, and to continue extraction of coal by augering back into the hillside.

In the Clear Fork basin the terrain is much less dissected, and therefore, the dominant type of mining is area mining. Typically, overburden is removed from a small area, the coal is extracted and the overburden replaced as the operation moves along in a particular direction.

Drainage Network

There are three components to the stream system in the New River basin. First, are the small streams (less than 8 mi^2 drainage area), which have very steep channels and valley sidewalls. Most of the contour strip mining is done in these basins. Any soil that is dislodged from these steep valley sidewalls is quickly delivered to the stream channel. The slopes of these channels provide little opportunity for deposition,and sediment is quickly transported toward the basin outlet.

The second stream component is the intermediate subbasins. These basins average 30 mi^2 drainage area and have much gentler slopes. This decrease in slope provides opportunities for deposition of the larger sediment particles delivered from the smaller upstream basins.

There are six major streams in this component. They are: Buffalo Creek, Paint Rock Creek, Montgomery Fork, Smoky Creek, Ligias Fork, and Brimstone Creek (fig. 1).

Finally, the third component is the New River mainstem, which exhibits extensive deposition of sand and gravel. It is also the conduit for fine-grained sediment (silt and clay), which is kept in suspension and transported out of the basin.

The Clear Fork drainage network is a much more homogeneous system than the New River network. Channel and valley-sidewall slopes in small upland subbasins are not as steep in the Clear Fork basin as in the New River basin. Thus, the downstream changes in channel slope and the associated changes in channel storage characteristics are not as drastic in the Clear Fork basin.

DATA COLLECTION

In order to establish a water quality data base for the New River basin, an intensive sampling program was conducted during low-flow periods in May and October 1975. Water was collected from each of the sampling sites shown in figure 1 and described in table 1. Each sample was analyzed for a total of 42 constituents (table 2). After this preliminary sampling, a monthly sampling program was established utilizing a reduced number of constituents (table 2) and only six sites (fig. 1). Four sites were located along the New River mainstem, distributed from the basin outlet to the headwaters. One site, Smoky Creek at Smoky Junction, was retained on an intermediate subbasin and a new site, Clear Fork near Robbins was added. These sites were sampled on a routine monthly schedule,and therefore,mostly low and intermediate discharges were sampled.

Two sites, New River at New River and Clear Fork near Robbins, were also sampled during storms. The list of constituents was further reduced for this effort as shown in table 2.

All suspended sediment and water quality samples were collected by standard U.S. Geological Survey depth-integrating methods as described by Guy and Norman (1970). Suspended sediment samples were analyzed by either the U.S. Geological Survey sediment laboratory in Harrisburg, Pa., or the U.S. Geological Survey district sediment laboratory in Nashville, Tenn. Water quality samples were analyzed by the U.S. Geological Survey Central Laboratory in Atlanta, Ga.

A continuous-recording water-quality station was established at the New River at New River surface-water gaging station. This station contains a USGS Water Quality Monitor which records the following parameters hourly; temperature, specific conductance, dissolved oxygen, pH, and turbidity. In addition, a PS-69 suspended sediment pumping sampler was installed in the shelter. The PS-69 is programmed to take two samples per day to define daily loads, plus a sample every half-foot of rise or fall in stage to define storm loads.

Table 1. -- Sampling stations

Station No.	Latitude	Longitude	Location Remark	Drainage Area (mi^2)
03407790	36°07'28" N.	84°25'32" W.	New River at Fork Mountain, at boundary of Morgan State Forest	3.37
03407804	36°09'37" N.	84°23'15" W.	Indian Fork above Braytown, just below mouth of Joe Branch	4.32
03407840	36°12'26" N.	84°19'12" W.	Ligias Fork at Stainville, at first bridge above mouth at mi. 0.4	20.4
03407850	36°12'34" N.	84°19'18" W.	New River at Stainville, at State Highway 116 bridge	66.0
03407873	36°14'17" N.	84°19'49" W.	Beech Fork at Shea, at county road at Shea	27.9
03407874	36°12'09" N.	84°24'59" W.	Green Branch near Hembree, on left bank 1.9 mi south of Hembree	1.38
03407875	36°12'39" N.	84°24'19" W.	Bills Branch near Hembree, on right bank 1.5 mi southeast of Hembree	0.67
361252084245300	36°12'52" N.	84°24'53" W.	Bills Branch at mouth, near Hembree	1.17
03407876	36°14'23" N.	84°24'48" W.	Smoky Creek at Hembree, on left bank 0.9 mi northeast of Hembree	17.2
03407877	36°16'14" N.	84°24'17" W.	Bowling Branch above Smoky Junction, on left bank 2.5 mi southeast of Smoky Junction	2.19
03407879	36°16'38" N.	84°22'27" W.	Smoky Creek at Smoky Junction, 0.9 mi upstream from mouth of Smoky Creek	32.5
03407881	36°18'34" N.	84°23'14" W.	Anderson Branch near Montgomery, on left bank 1.3 mi southwest of Montgomery	0.69

Table 1. -- Sampling stations (continued)

Station No.	Latitude	Longitude	Location Remark	Drainage Area (mi^2)
03407882	36°19'04" N.	84°23'07" W.	Lowe Branch near Montgomery on right bank 1.0 mi southwest of Montgomery	0.92
03407880	36°17'13" N.	84°22'01" W.	New River at Smoky Junction, at county road bridge 0.3 mi below Smoky Junction	146
03407890	36°19'43" N.	84°22'01" W.	Montgomery Fork at Montgomery, at county highway bridge	22.1
03407905	36°20'09" N.	84°23'29" W.	New River at Norma, at County road ford, 0.3 mi SW of Norma	179
03407908	36°20'10" N.	84°27'06" W.	New River at Cordell at county highway bridge	198
03407920	36°23'16" N.	84°25'13" W.	Buffalo Creek near Winona, at Buffalo Bridge on State Highway 63	42.5
03407940	36°22'18" N.	84°26'55" W.	Buffalo Creek at Winona, at county highway bridge	64.9
03407960	36°24'14" N.	84°26'59" W.	Paint Rock Creek near Huntsville, at State Highway 63 bridge at Newtown	21.5
03408200	36°20'43" N.	84°32'22" W.	Brimstone Creek near Robbins, 3.0 mi east of Robbins at Walker Bridge	48.7
03408500	36°23'08" N.	84°33'17" W.	New River at New River, on left bank at Bridge on U. S. Highway 27	382
03409500	36°23'18" N.	84°37'49" W.	Clear Fork near Robbins, 3.3 mi northwest of Robbins at Burnt Mill Bridge	272

Table 2. -- Parameters analyzed during intensive, monthly, and storm sampling

Intensive Study Parameters		Monthly Parameters	Storm Parameters
Alkalinity as $CaCO_3$	Mercury, total	Alkalinity as $CaCO_3$	Arsenic, total
Aluminum, total	Nickel, total	Bicarbonate	Chloride
Arsenic, total	Nitrite plus nitrate, total as N	Calcium, dissolved	Chromium, total
Bicarbonate	Nitrogen, ammonia plus organic, total as N	Carbonate	Copper, total
Cadmium, total	Oxygen, dissolved	Carbon dioxide	Iron, dissolved
Calcium, dissolved	pH	Chloride, dissolved	Iron, total
Carbon, total organic	Phosphorous, total as P	Hardness, non-carbonate as $CaCO_3$	Lead, total
Carbonate	Potassium, dissolved	Hardness, total as $CaCO_3$	Manganese, total
Carbon dioxide	Selenium, total	Iron, dissolved	Mercury, total
Chloride, dissolved	Silica, dissolved	Iron, total	Nickel, total
Chromium, total	Sodium adsorption ratio	Magnesium, dissolved	Sediment, suspended
Cobalt, total	Sodium, dissolved	Manganese, total	Sediment, suspended, percent sand
Copper, total	Sodium, percent	Nickel, total	Selenium, total
Fluoride, dissolved	Solids, dissolved, ROE @ 180°C	Oxygen, dissolved	Solids, dissolved, ROE @ 180°C
Hardness, non-carbonate as $CaCO_3$	Specific conductance	pH	Streamflow
Hardness, total as $CaCO_3$	Streamflow	Sediment, suspended	Sulfate
Iron, dissolved	Sulfate, dissolved	Sediment, suspended, percent sand	Temperature, water
Iron, total	Tannin and lignin	Solids, dissolved, ROE @ 180°C	Turbidity
Lead, total	Temperature, water	Specific conductance	
Magnesium, dissolved	Turbidity	Streamflow	
Manganese, total	Zinc, total	Sulfate, dissolved	
		Temperature, water	
		Turbidity	

The turbidity sensor was installed at the request of the U.S. Army Corps of Engineers. This sensor utilizes both the light transmitted (T) and the light scattered (S) to obtain a turbidity reading. The response of each photocell is integrated into a single reading by division (S/T) which is performed electronically in the control unit. Calibration to Jackson turbidity units (JTU) is done by using Formazin turbidity standard.

As of 1975 only two of the sampling stations, New River at New River and Clear Fork near Robbins, had long-term surface-water records. The New River station has continuous record from 1934 to present,and the Clear Fork station has continuous record from 1930 to 1971 and was reactivated in 1975.

STREAMFLOW CHARACTERISTICS

The following discussion on streamflow characteristics is based on data compiled from 1934 to 1975 for the New River at New River station. The flow duration curve (fig. 4) shows the median flow to be 233 ft^3/s (stage of 2.95 ft above datum at the gage). The steep, straight slope of the curve indicates a highly variable stream whose flow is largely derived from direct runoff (Searcy, 1959, p. 22).

The flood frequency curve (fig. 5) is obtained by using Water Resources Council recommended procedures (U.S. Water Resources Council, 1976). The mean annual flood (2.33-year recurrence interval) is approximately 27,000 ft^3/s which is 23.96 ft above datum at the gage. During a storm that was sampled on April 5, 1977, peak discharge was 46,840 ft^3/s. This peak discharge has a return period of approximately 15 years. The stage at this peak discharge was 32.16 ft above datum.

The flow duration curve for Clear Fork near Robbins is shown in figure 6. This curve was constructed from flow data collected during the period 1930 to 1971. A comparison of the Clear Fork and New River flow duration curves shows similar steep slopes.

A plot of flood frequency for the gage near the outlet of Clear Fork is shown in figure 7. The shape of the flood frequency curve for Clear Fork is very similar to the one for New River. Discharges for an equivalent recurrence interval are lower on Clear Fork primarily because of Clear Fork's smaller drainage area.

WATER QUALITY

The data discussed in the following sections were obtained from samples collected at the two gaging stations near the outlet of each basin. However, where appropriate, additional data gathered within the New River basin will be used. These additional data will be identified as they are introduced to the discussion.

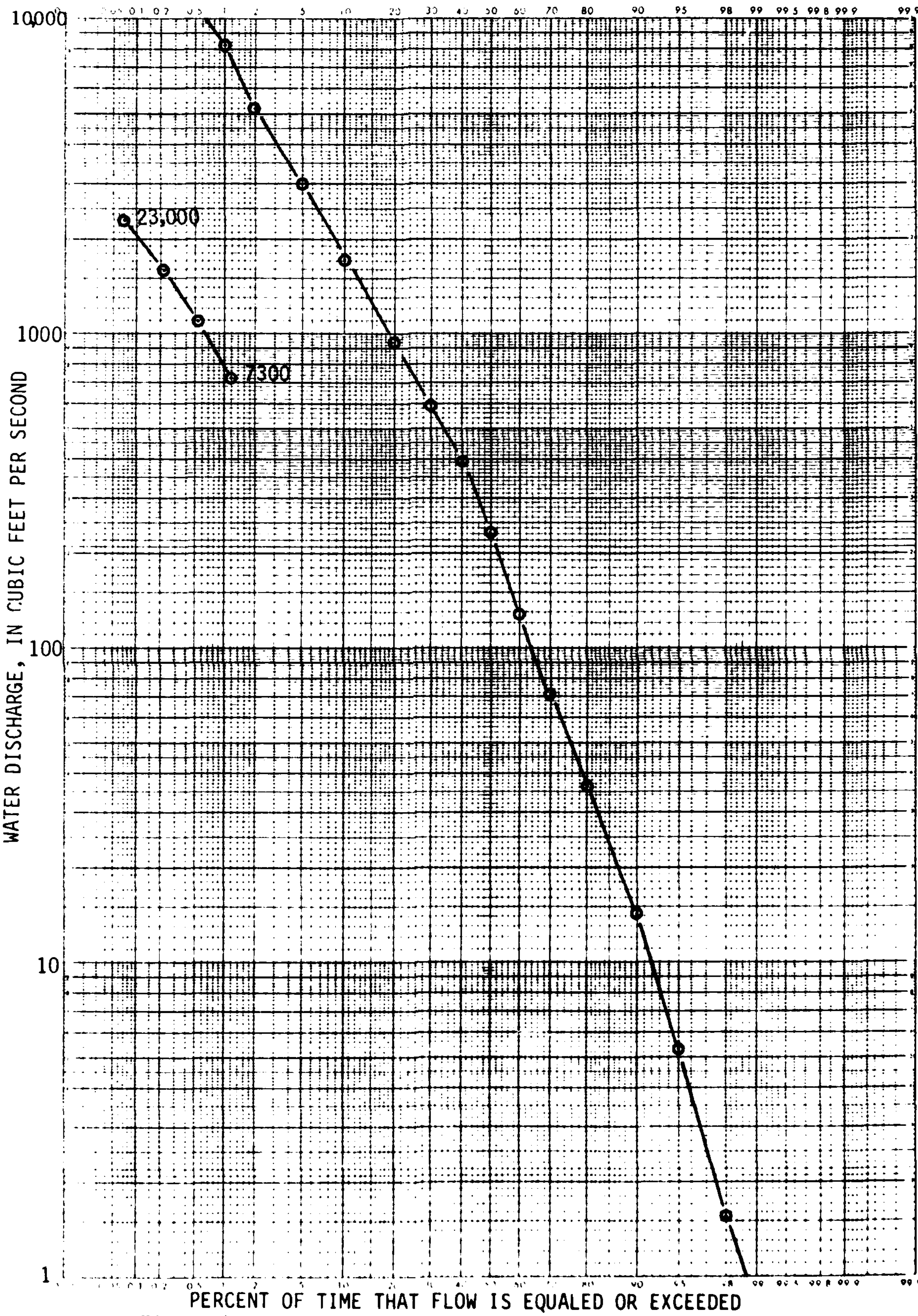

Figure 4.-- Flow duration curve for New River at New River

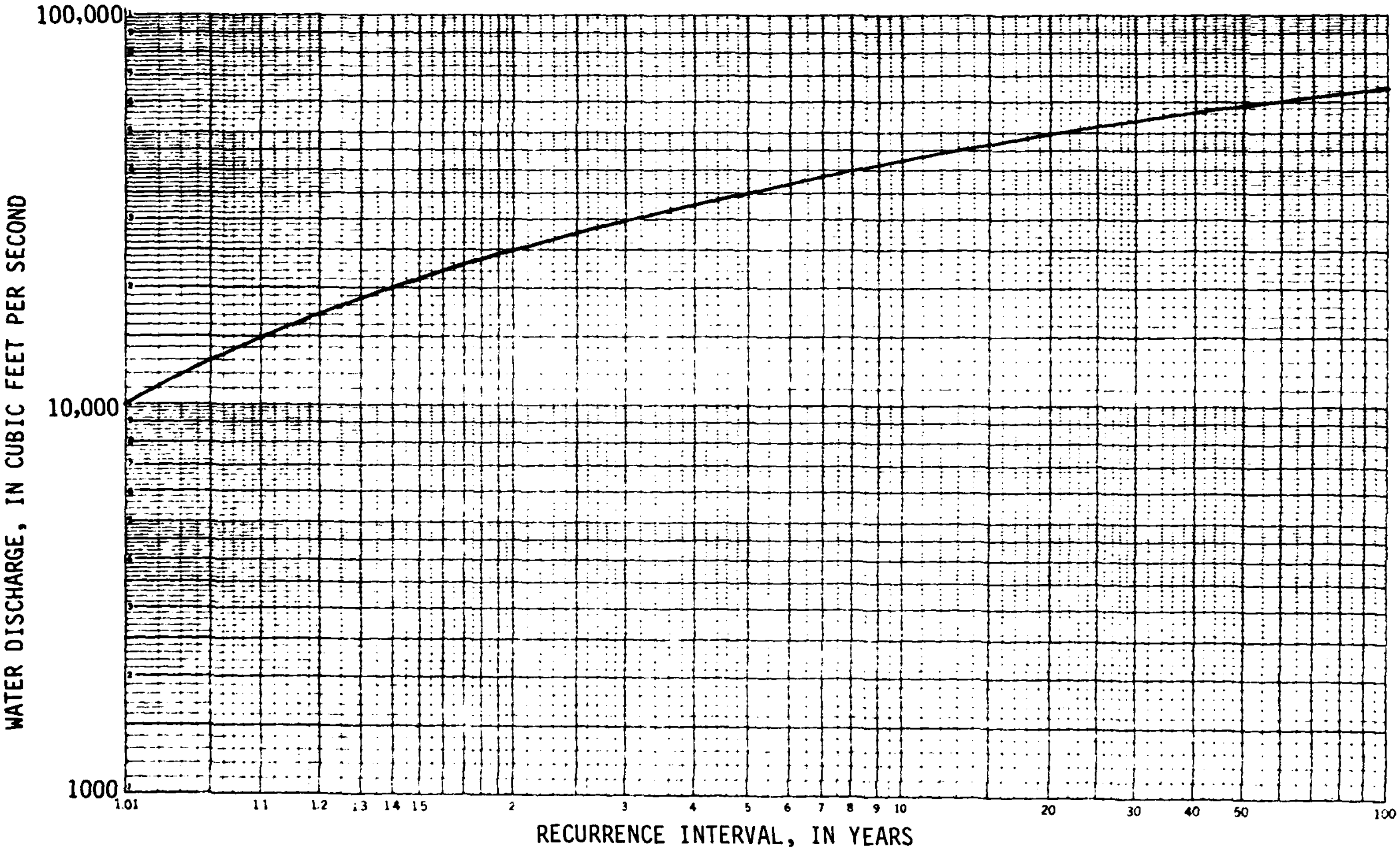

Figure 5.-- Flood flow frequency curve for New River at New River

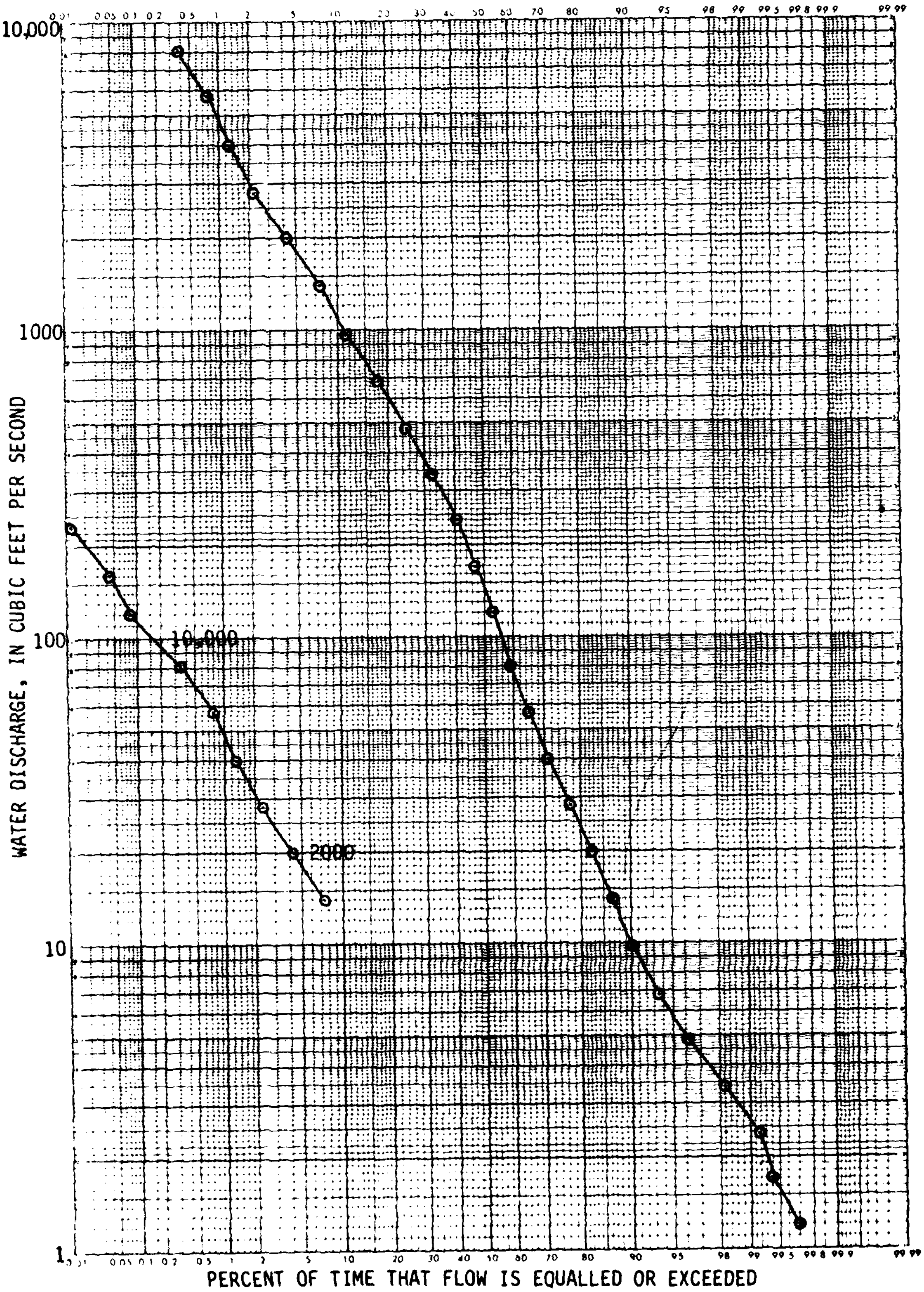

Figure 6.-- Flow duration curve for Clear Fork near Robbins

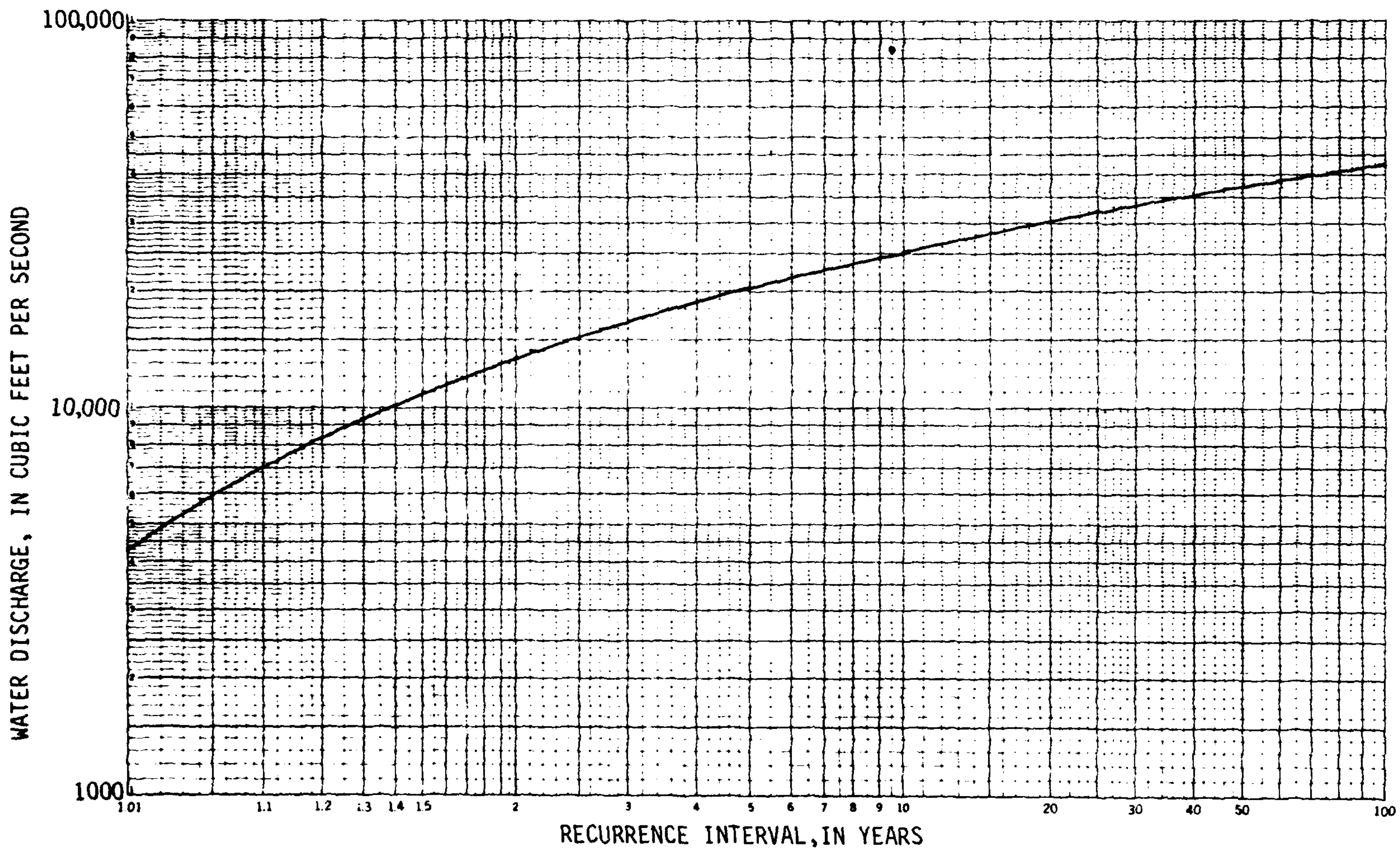

Figure 7.-- Flood flow frequency curve for Clear Fork near Robbins

Water Quality Monitor Data

Temperature

Water temperature of New River at New River is measured hourly by the water-quality monitor. Mean daily values for the 1977 water year are given in table 3. These data can be easily summarized by a least-squares sine-wave curve (Steele, 1978).

$$\hat{T}_w = 13.84 + 12.8 \sin (0.017t + 2.93), \qquad (1)$$

where t = days (Oct. 1 = 1 and Sept. 30 = 365 or 366), and $\hat{T}_w$ = predicted mean daily water temperature (°C). The explained variability of this equation is 92 percent. Since the data represent only 1 year, the relation may be modified as more data become available.

pH

The water-quality monitor at New River at New River recorded pH throughout the 1977 water year. The values of pH ranged from 6.7 to 7.7 but were consistently above 7.0 (table 4). Because of this nearly neutral system, most of the metals present are sorbed onto sediment.

Turbidity

Turbidity is monitored at the New River station as previously discussed. The turbidity sensor is calibrated so that the conversion to the more common measure of JTU's is one to one.

The turbidity data correlate well with the suspended-sediment concentration data from this station. The reason for this good correlation, and the limitations of using turbidity to predict suspended-sediment concentrations, will be discussed in the section on the suspended system.

Specific Conductance

The specific conductance of a water sample can be directly related to the sample concentration of total dissolved solids. Once this relationship has been established for many samples from a particular site, the continuous record of specific conductance from a water-quality monitor can be analyzed to make direct inferences about the concentration of total dissolved solids.

Using the monthly and storm sampling data from New River at New River a plot was made of dissolved solids versus specific conductance (fig. 8). A least squares fit of these data leads to the relation:

Table 3. -- Maximum, minimum, and mean daily water temperature, in degrees Celsius for New River at New River during the 1977 water year

Day	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
		October			November			December			January	
1	---	---	---	9.5	9.0	9.0	3.0	1.5	2.0	0.5	0.0	0.5
2	---	---	---	9.0	8.0	8.5	2.0	1.5	1.5	0.5	0.0	0.5
3	---	---	---	8.5	8.0	8.5	2.0	1.5	1.5	0.5	0.5	0.5
4	---	---	---	8.5	7.5	8.0	2.0	1.0	1.5	0.5	0.5	0.5
5	---	---	---	7.0	6.0	7.0	2.0	1.0	1.5	0.5	0.5	0.5
6	---	---	---	6.5	5.5	6.0	2.5	1.5	2.0	0.5	0.5	0.5
7	---	---	---	6.5	5.5	6.0	6.5	2.5	5.0	0.5	0.5	0.5
8	---	---	---	6.0	5.0	5.5	6.5	4.5	6.0	0.5	0.5	0.5
9	---	---	---	6.0	5.0	5.5	4.5	3.0	3.5	1.0	0.5	0.5
10	---	---	---	7.0	5.5	6.0	3.0	2.5	3.0	1.5	1.0	1.0
11	---	---	---	6.0	5.5	5.5	5.0	3.5	4.0	1.0	0.5	0.5
12	---	---	---	5.5	5.0	5.5	7.0	5.0	6.0	0.5	0.5	0.5
13	---	---	---	5.0	4.0	4.5	7.0	6.5	7.0	0.5	0.0	0.5
14	---	---	---	4.0	3.5	3.5	6.5	4.5	5.0	0.5	0.5	0.5
15	---	---	---	3.5	3.5	3.5	5.0	4.5	4.5	1.0	0.5	0.5
16	---	---	---	5.0	4.0	4.5	5.0	5.0	5.0	1.5	0.5	1.0
17	---	---	---	5.0	4.0	4.5	5.0	4.5	5.0	0.5	0.0	0.5
18	---	---	---	5.5	4.0	5.0	5.0	4.5	4.5	0.5	0.5	0.5
19	---	---	---	6.0	5.0	5.5	5.0	4.0	4.5	0.5	0.0	0.5
20	---	---	---	6.0	5.5	5.5	5.5	5.0	5.0	0.5	0.5	0.5
21	11.5	10.5	11.0	5.5	5.0	5.5	5.0	2.5	3.5	0.5	0.5	0.5
22	11.0	10.0	10.5	5.0	4.5	4.5	2.5	1.0	1.5	0.5	0.5	0.5
23	10.0	9.0	9.5	4.5	3.5	4.0	1.5	0.5	1.5	0.5	0.5	0.5
24	10.5	10.0	10.0	4.0	3.5	4.0	1.0	0.5	1.0	0.5	0.5	0.5
25	12.5	10.5	11.0	5.0	3.0	4.0	1.0	0.5	0.5	0.5	0.5	0.5
26	13.0	11.5	12.5	5.5	4.5	5.0	1.5	0.5	1.0	0.5	0.5	0.5
27	11.0	9.5	10.0	7.5	5.5	6.5	2.0	1.5	1.5	0.5	0.5	0.5
28	9.5	8.0	8.5	7.5	7.0	7.5	3.0	2.0	2.5	0.5	0.5	0.5
29	8.0	7.0	7.5	7.0	4.5	6.0	3.0	2.0	2.5	---	---	---
30	8.0	7.5	7.5	4.5	3.0	3.5	2.0	1.0	1.5	---	---	---
31	9.0	8.0	8.5	---	---	---	1.5	0.5	1.0	---	---	---
Month				9.5	3.0	5.5	7.0	0.5	3.0	1.5	0.0	0.5

Table 3. -- Maximum, minimum, and mean daily water temperature, in degrees Celsius for New River at New River during the 1977 water year (continued)

Day	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
		February			March			April			May	
1	---	---	---	---	---	---	13.5	12.0	12.5	17.0	15.5	16.0
2	---	---	---	---	---	---	13.5	12.5	13.0	17.5	16.5	17.0
3	---	---	---	4.5	4.0	4.5	15.0	13.5	14.0	17.5	16.5	17.0
4	1.0	0.5	1.0	7.5	5.0	6.0	14.0	11.0	12.0	17.5	17.0	17.0
5	0.5	0.5	0.5	8.0	7.5	8.0	12.0	10.5	11.5	18.5	17.0	18.0
6	1.0	0.0	0.5	7.5	7.0	7.0	---	---	---	19.5	18.0	18.5
7	---	---	---	7.0	6.0	6.5	---	---	---	19.5	19.0	19.5
8	---	---	---	6.5	5.5	6.0	11.5	11.0	11.0	20.5	19.0	19.5
9	1.0	0.5	1.0	7.5	6.0	7.0	12.0	10.5	11.5	20.0	18.5	19.5
10	---	---	---	8.5	7.0	8.0	13.0	11.5	12.0	19.0	17.5	18.0
11	---	---	---	10.0	8.5	9.5	14.5	12.5	13.5	18.5	16.5	17.5
12	---	---	---	11.5	10.0	10.5	---	---	---	18.5	16.0	17.0
13	---	---	---	11.5	10.0	11.0	---	---	---	19.5	16.0	17.5
14	---	---	---	17.0	11.0	13.5	---	---	---	19.5	17.0	18.0
15	---	---	---	18.0	10.5	12.5	---	---	---	20.5	17.5	19.0
16	---	---	---	13.0	11.5	12.0	---	---	---	21.0	18.5	19.5
17	---	---	---	11.5	10.5	11.0	---	---	---	21.5	19.5	20.5
18	---	---	---	12.5	10.5	11.5	---	---	---	22.0	20.0	21.0
19	---	---	---	11.5	10.5	11.0	18.5	18.0	18.5	22.5	20.0	21.0
20	---	---	---	11.0	10.0	10.5	19.5	18.0	18.5	23.0	21.0	22.0
21	---	---	---	11.0	9.5	10.0	19.5	18.5	19.0	24.0	21.5	22.5
22	---	---	---	9.5	8.5	9.0	19.0	18.5	19.0	23.0	22.0	22.5
23	---	---	---	8.0	7.0	8.0	18.5	17.5	18.0	23.0	21.5	22.0
24	---	---	---	8.5	7.5	8.0	17.0	15.5	16.0	23.0	21.5	22.0
25	---	---	---	9.5	7.5	8.5	15.5	14.0	14.5	23.0	21.0	21.5
26	---	---	---	10.5	8.5	9.5	14.0	13.5	13.5	24.0	21.5	22.5
27	---	---	---	11.5	10.0	11.0	14.0	12.5	13.5	24.0	22.5	23.0
28	---	---	---	13.0	11.5	12.0	14.5	13.5	14.0	24.0	22.5	23.5
29	---	---	---	14.5	12.5	13.5	14.5	13.5	14.0	24.5	22.5	23.5
30	---	---	---	17.0	14.5	15.5	15.5	14.0	15.0	24.5	22.5	23.5
31	---	---	---	17.0	13.5	15.5	---	---	---	25.5	23.0	24.5
Month				18.0	4.0	10.0				25.5	15.5	20.0

Table 3. -- Maximum, minimum, and mean daily water temperature, in degrees Celsius for New River at New River during the 1977 water year (continued)

Day	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
		June			July			August			September	
1	25.5	23.5	24.5	26.0	24.5	25.0	27.0	25.0	26.0	---	---	---
2	25.0	23.0	24.0	26.0	24.5	25.5	27.5	25.0	26.0	---	---	---
3	25.5	23.5	24.5	26.0	24.5	25.0	27.0	25.5	26.5	---	---	---
4	26.0	23.0	24.0	27.0	24.5	25.5	28.0	25.0	26.5	---	---	---
5	26.5	23.5	24.5	27.5	25.0	26.0	26.5	25.5	26.0	---	---	---
6	25.5	23.5	24.5	28.0	25.5	27.0	27.0	23.0	25.5	---	---	---
7	24.5	22.5	23.5	29.0	26.0	27.5	27.0	23.5	25.0	---	---	---
8	23.5	21.5	22.5	30.0	26.5	28.0	27.5	25.0	26.0	---	---	---
9	22.5	21.0	22.0	29.5	27.0	28.0	25.0	23.5	24.0	---	---	---
10	23.0	21.0	22.0	29.5	27.5	28.0	25.5	23.0	24.5	---	---	---
11	24.0	20.5	22.0	29.0	27.0	27.5	24.0	23.0	23.5	---	---	---
12	24.0	21.5	22.5	27.5	26.5	27.0	24.5	23.5	24.0	22.0	21.5	21.5
13	25.0	22.5	23.0	29.0	26.0	27.0	24.5	23.0	23.5	22.0	21.0	21.5
14	23.5	22.5	23.0	29.5	26.5	28.0	24.0	23.5	23.5	21.5	21.0	21.0
15	24.5	22.0	23.0	30.5	27.5	29.0	24.5	23.0	24.0	22.5	21.0	21.5
16	25.5	23.0	24.0	31.0	27.5	29.0	25.0	23.5	24.5	22.0	21.0	21.0
17	25.0	24.0	24.5	31.5	27.5	29.0	25.0	24.5	24.5	21.0	20.5	20.5
18	26.0	23.5	24.5	31.0	28.0	29.5	25.0	23.5	24.0	22.0	21.0	21.5
19	25.5	24.0	24.5	30.5	27.5	29.0	24.5	23.5	24.0	22.0	21.0	21.5
20	25.0	23.5	24.0	31.0	27.5	29.0	25.0	22.5	23.5	22.0	21.0	21.5
21	25.5	24.0	24.5	30.0	27.5	29.0	24.5	22.5	23.5	22.0	21.0	21.5
22	24.0	24.0	24.0	28.5	27.5	28.0	26.0	23.0	24.0	22.0	20.5	21.0
23	24.5	24.0	24.5	30.5	27.0	28.5	26.0	23.5	25.0	22.5	20.0	21.0
24	24.5	23.5	24.0	28.5	27.0	27.5	25.0	22.0	24.0	21.5	21.0	21.0
25	24.0	22.0	23.0	27.0	24.0	26.5	24.5	23.0	24.0	21.5	20.5	21.0
26	21.5	20.5	21.0	26.5	25.5	26.0	26.0	24.0	24.5	20.5	19.5	20.0
27	22.0	20.5	21.5	26.5	25.0	25.5	26.5	24.0	25.0	19.5	19.0	19.0
28	23.5	22.0	23.0	26.0	24.5	25.5	27.5	24.5	26.0	19.0	18.0	18.5
29	24.0	23.5	23.5	25.5	24.5	25.0	28.0	24.5	26.0	18.5	17.5	18.0
30	25.5	23.5	24.5	27.0	24.5	25.5	28.5	25.0	26.5	17.5	17.0	17.5
31	---	---	---	28.0	24.5	26.0	27.0	25.5	26.0	---	---	---
Month	26.5	20.5	23.5	31.5	24.0	27.0	28.5	22.0	25.0			
Year	31.5	0.0	14.5										

Table 4. -- Mean 1/daily pH values for New River at New River for 1977 water year

Mean Values

Day	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
1	---	7.3	7.6	7.3	---	---	7.2	7.1	7.6	7.1	7.7	---
2	---	7.3	7.5	7.3	---	---	7.2	7.1	7.5	7.2	7.7	---
3	---	7.3	7.5	7.2	---	7.1	7.1	7.2	7.5	---	7.7	---
4	---	7.3	7.4	7.2	7.2	7.1	6.7	7.2	7.5	---	7.6	---
5	---	7.3	7.4	7.2	7.2	7.2	6.7	7.2	7.6	---	7.6	---
6	---	7.4	7.4	7.2	7.2	7.1	---	7.3	7.7	7.1	7.4	---
7	---	7.4	7.1	7.2	---	7.1	---	7.3	7.5	7.1	7.4	---
8	---	7.4	7.0	7.2	---	7.1	---	7.3	7.6	7.2	7.4	---
9	---	7.4	7.1	7.2	7.2	7.2	---	7.3	7.6	7.4	7.3	---
10	---	7.4	7.1	7.2	---	7.2	---	7.3	7.5	7.6	7.1	---
11	---	7.4	7.1	7.2	---	7.2	---	7.4	7.5	7.6	7.0	---
12	---	7.4	7.1	7.1	---	7.2	---	7.4	7.5	7.5	7.1	7.3
13	---	7.5	7.2	7.1	---	7.0	---	7.5	7.4	7.4	7.0	7.3
14	---	7.5	7.2	7.1	---	7.0	---	7.5	7.3	7.5	7.1	7.3
15	---	7.5	7.1	7.2	---	7.0	---	7.5	7.2	7.5	7.1	7.4
16	---	7.5	7.1	7.2	---	7.1	---	7.5	7.5	7.6	7.2	7.2
17	---	7.5	7.2	7.2	---	7.1	---	7.5	7.4	7.6	7.2	7.2
18	---	7.4	7.2	7.1	---	7.1	---	7.6	7.4	7.6	7.2	7.3
19	---	7.5	7.2	7.1	---	7.2	7.3	7.6	7.4	7.5	7.2	7.3
20	---	7.5	7.2	7.1	---	7.2	7.3	7.6	7.3	7.5	7.2	7.3
21	7.2	7.5	7.3	7.1	---	7.2	7.2	7.7	7.3	7.4	7.4	7.3
22	7.3	7.5	7.4	7.1	---	7.3	7.2	7.6	7.3	7.5	7.5	7.3
23	7.3	7.5	7.4	7.1	---	7.3	7.2	7.6	7.2	7.4	7.6	7.3
24	7.2	7.5	7.4	7.1	---	7.3	7.1	7.6	7.2	7.4	7.5	7.3
25	7.1	7.5	7.3	7.1	---	7.3	7.1	7.6	7.2	7.3	7.1	7.3
26	6.9	7.5	7.3	7.1	---	7.3	7.1	7.5	6.9	7.2	7.3	7.1
27	7.0	7.5	7.3	7.1	---	7.3	7.2	7.5	7.0	7.3	7.3	7.0
28	7.1	7.5	7.2	7.2	---	7.3	7.2	7.7	7.1	7.5	7.3	7.1
29	7.2	7.5	7.3	---	---	7.3	7.1	7.7	7.1	7.5	7.4	7.1
30	7.2	7.5	7.3	---	---	7.2	7.1	7.7	7.1	7.5	7.4	7.2
31	7.2	---	7.3	---	---	7.3	---	7.7	---	7.6	7.4	---

Water year 1977 Max 7.7 Min 6.7

Note: Number of missing days of record exceeded 20% of year.

1/Mean daily pH is the daily arithmetic mean of 24 hourly pH readings.

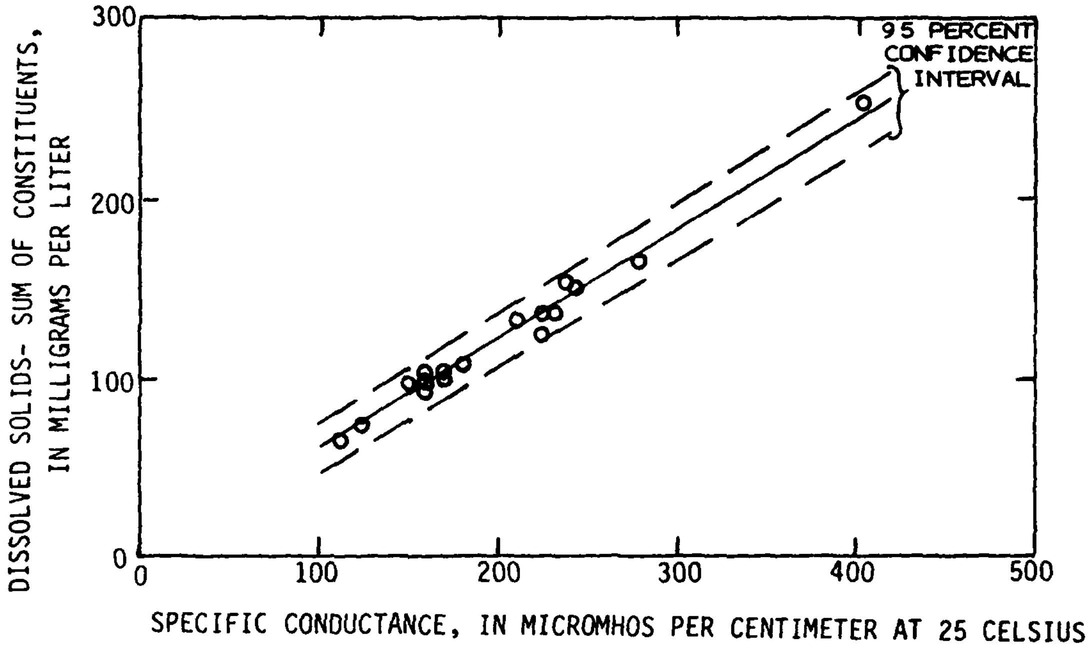

Figure 8.-- Dissolved solids versus specific conductance for New River at New River

$$DS = 0.61\ Sc \tag{2}$$

$$r = 0.99$$

where DS = dissolved solids in milligrams per liter, Sc = specific conductance in micromhos, and r = correlation coefficient. This form of the equation was suggested by Hem (1970, 2nd ed. p. 99.) who reported that the coefficient in the equation generally ranges between 0.55 and 0.75 for natural waters. The higher values usually are associated with waters high in sulfate concentration. This relationship (eq. 2) has a standard error of estimate of 6.2 percent. Therefore, within the range sampled, the error of prediction is approximately 35 mg/L.

Figure 9 shows a plot of specific conductance versus discharge for New River at New River. A least squares fit to these data yields the equation:

$$Sc = 753.65\ Q^{-0.21} \tag{3}$$

$$r = 0.85$$

where Q = discharge in cubic feet per second. Data from the upstream stations of New River at Stainville and New River at Cordell (fig. 1) are also plotted in figure 9; however, they were not used to develop equation 3. The data from Stainville and Cordell follow the overall relation obtained for New River at New River. Thus, the concentrations of dissolved solids along the mainstem of New River become more dilute as the discharge increases.

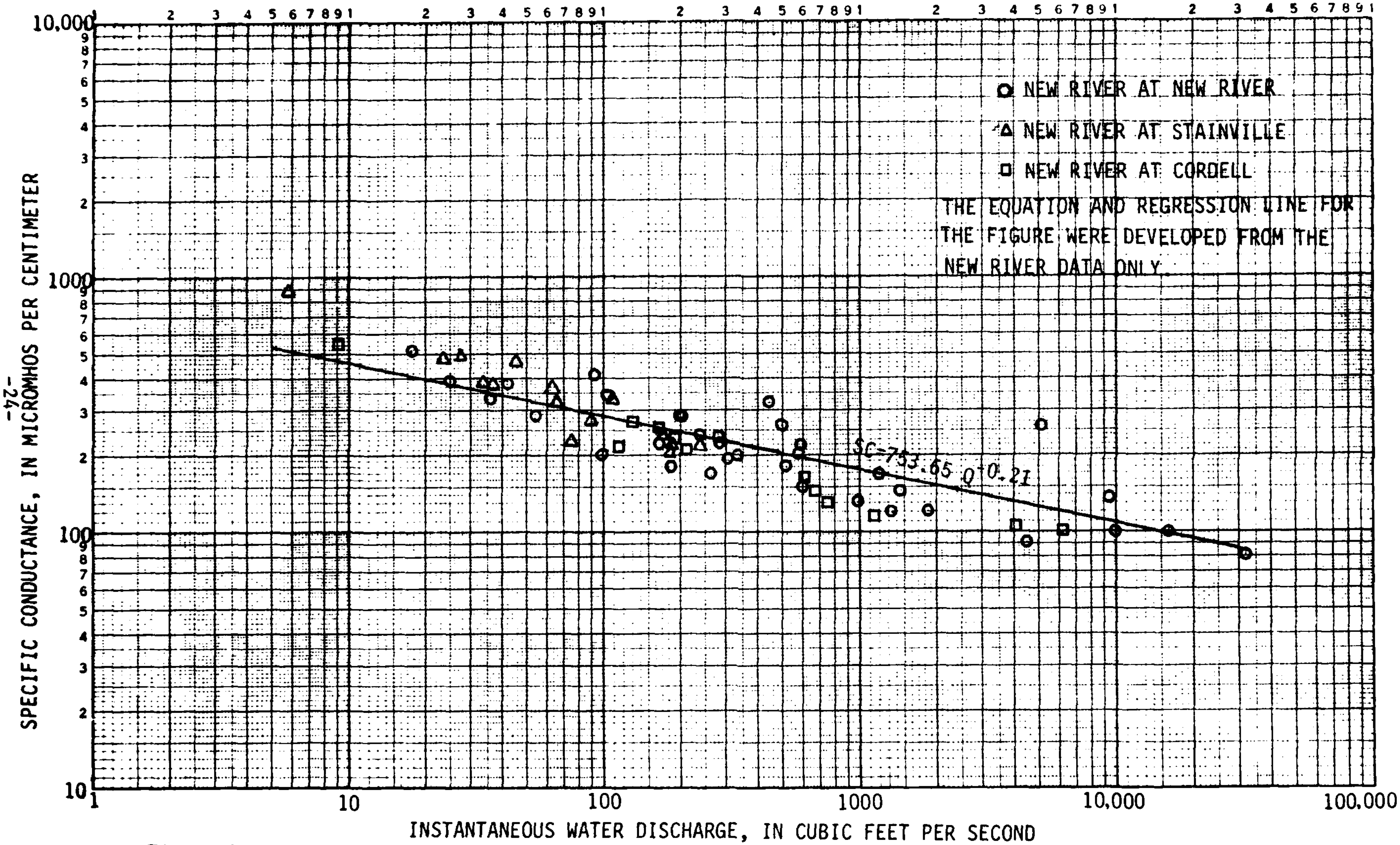

Figure 9.-- Specific conductance versus discharge for New River at New River, New River at Cordell, and New River at Stainville.

The Dissolved System

The general problems and processes of coal mine drainage have been known for some time. During coal mining, pyritic materials, predominantly iron pyrite (FeS_2), are exposed to water and air. The pyrite reacts with oxygen and water to form ferrous sulfate ($FeSO_4$) and sulfuric acid (H_2SO_4). The chemical breakdown of pyrite usually increases the concentration of iron, sulfate, and hydrogen ions in the water. The resulting low pH values (acidity) are a common characteristic of many coal mine drainage waters (Biesecker and George, 1966, p. 3). Reaction of this acidic mine drainage with carbonate minerals reduces the acidity, increases the total dissolved solids concentration, and adds calcium and magnesium ions to the water. Thus, some measure of the impact of the coal mine drainage on a surface stream would be provided by examining the pH, sulfate concentration, calcium and magnesium concentration, and total dissolved solids.

For New River at New River, the major dissolved constituents are bicarbonate, sulfate, calcium, and magnesium. The relation of specific conductance to the concentrations of these constituents are shown graphically in figure 10. The regression equations for each of these constituents are:

$$C_{SO_4} = 4.52 + 0.29\ Sc \qquad (4)$$

$$r = 0.95$$

where C_{SO_4} = dissolved sulfate concentration in milligrams per liter.

$$C_b = 7.76 + 0.08\ Sc \qquad (5)$$

$$r = 0.82$$

where C_b = bicarbonate (HCO_3) concentration in milligrams per liter.

$$C_{Ca} = 1.4 + 0.082\ Sc \qquad (6)$$

$$r = 0.91$$

where C_{Ca} = dissolved calcium concentration in milligrams per liter.

$$C_{Mg} = 1.24 + 0.029\ Sc \qquad (7)$$

$$r = 0.92$$

where C_{Mg} = dissolved magnesium concentration in milligrams per liter.

The regression equations above were applied to mean daily specific conductance records available for the water year 1977 at the New River outlet. Using a computer program documented by Steele (1973) monthly discharge-weighted chemical loads (table 5) of these major constituents were determined. From this table the mean monthly concentrations of the major constituents (table 6) were determined.

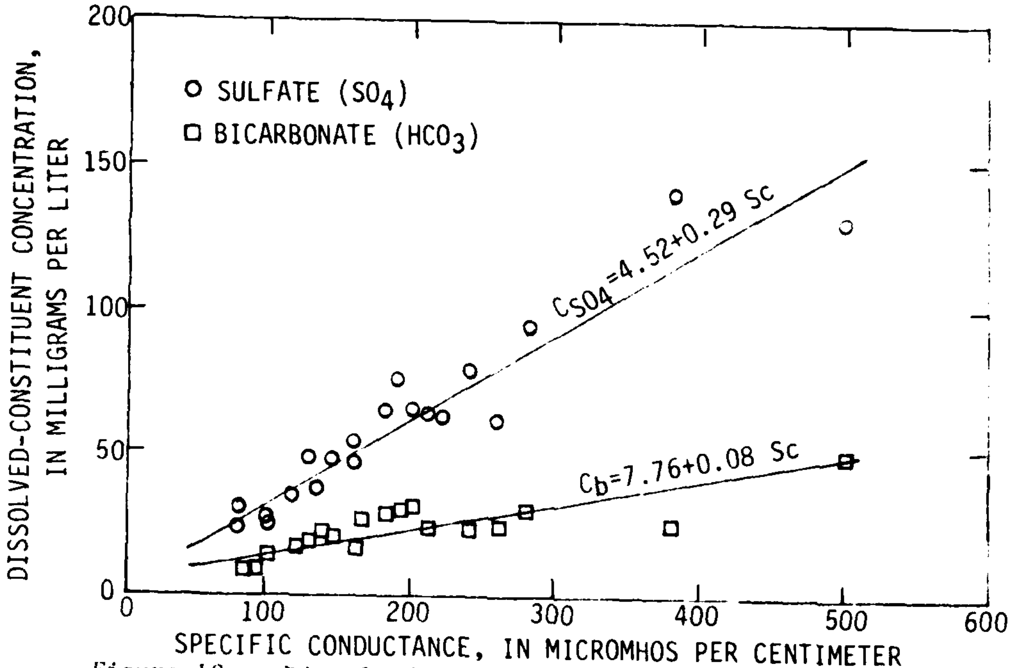

Figure 10a.--Dissolved-constituent concentration versus specific conductance for New River at New River

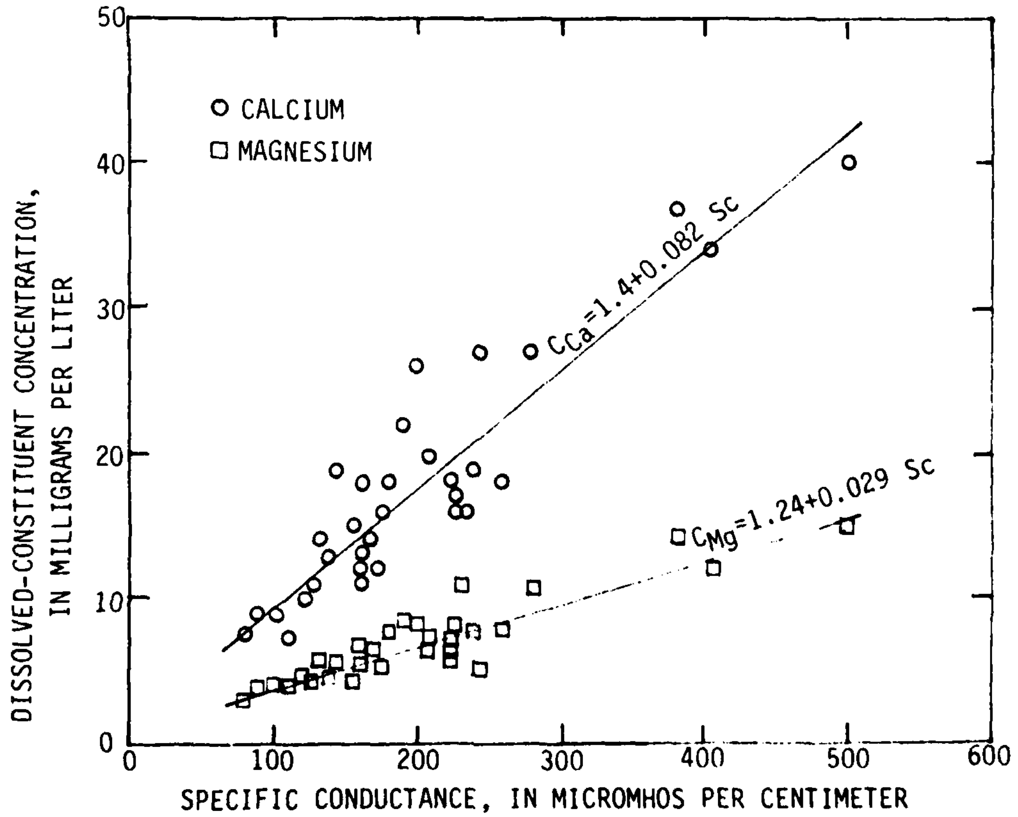

Figure 10b.--Dissolved-constituent concentration versus specific conductance for New River at New River

Table 5. -- Estimated discharge - weighted chemical loads of major constituents for New River at New River for water year 1977 (constituents, in tons)

Constituents	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Total Year
Dissolved solids (sum of constituents)	4410	2300	5750	4350	4390	8420	11400	2470	3360	1170	2470	4780	55300
Bicarbonate[1/] (HCO_3)	839	421	1250	969	901	1860	3150	476	620	205	426	888	12000
Dissolved calcium (Ca)	651	334	881	672	651	1300	1880	365	492	169	354	694	8440
Dissolved Magnesium (Mg)	254	129	357	274	261	528	818	143	190	65	135	270	3420
Dissolved sulfate (SO_4)	2280	1170	3080	2350	2280	4540	6640	1280	1730	597	1250	2440	29600

1/Note that individual constituents in this table cannot be arithmetically summed to obtain an estimate of dissolved solids because of the conversion of some bicarbonate to carbonate.

Table 6. -- Estimated mean monthly concentrations of major constituents for New River at New River for water year 1977 (constituent concentrations in milligrams per liter)

Constituents	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
Dissolved solids (sum of constituents)	138	156	95	90	107	92	55	133	154	180	197	146
Bicarbonate (HCO_3)	26	29	21	20	22	20	15	26	28	32	34	27
Dissolved calcium (Ca)	20	23	14	14	16	14	9.0	20	22	26	28	21
Dissolved Magnesium (Mg)	8.0	8.8	5.9	5.6	6.3	5.8	3.9	7.7	8.7	10	11	8.2
Dissolved sulfate (SO_4)	72	80	51	48	55	50	32	69	79	92	100	74

Table 6 shows the mean monthly concentration is highest during the low flow period of June, July, and August. However, the total chemical loads (table 5) are greatest during the high-flow periods of March and April. By calculation, approximately 55,000 tons of dissolved solids were transported out of the New River basin in 1977. The major constituents of this material were sulfate and bicarbonate.

Samples were also collected at Clear Fork near Robbins for comparison with New River at New River. The least-squares relation between discharge and specific conductance for Clear Fork is:

$$Sc = 125.67\ Q^{-.13} \tag{8}$$

$$r = 0.85$$

The plot of this equation and its 95 percent confidence intervals are shown in figure 11, along with a similar plot and confidence intervals for the New River data. Notice that for the same discharge New River has considerably higher specific conductances. Sufficient data are not available to construct a relationship between specific conductance and total dissolved solids for Clear Fork. However, the existing data suggest that equation 2 is a reasonable approximation for Clear Fork. Based on this assumption,a calculation comparing Clear Fork and New River showed that for median flow in 1977 New River discharged four times more total dissolved solids per day per square mile than Clear Fork.

The regressions of major dissolved constituents with respect to specific conductance for Clear Fork are shown in figure 12. This figure can be compared with figure 10 which shows the equivalent data at the New River outlet.

Even though there are only eight data points to each of the relationships in figure 12, the data were collected during instantaneous discharge between 24 and 25,000 ft^3/s. The problem with these relations is that the independent variable (specific conductance) changes very little in that large interval of discharge. Thus, the regression equations are somewhat tenuous. These relationships do, however, indicate that compared to New River, Clear Fork seems to have a greater amount of dissolved bicarbonate and less sulfate for an equivalent specific conductance. For Clear Fork the relations are:

$$C_{SO_4} = 0.422 + 0.166\ Sc \tag{9}$$

$$r = 0.93$$

$$C_b = 0.441 + 0.289\ Sc \tag{10}$$

$$r = 0.85$$

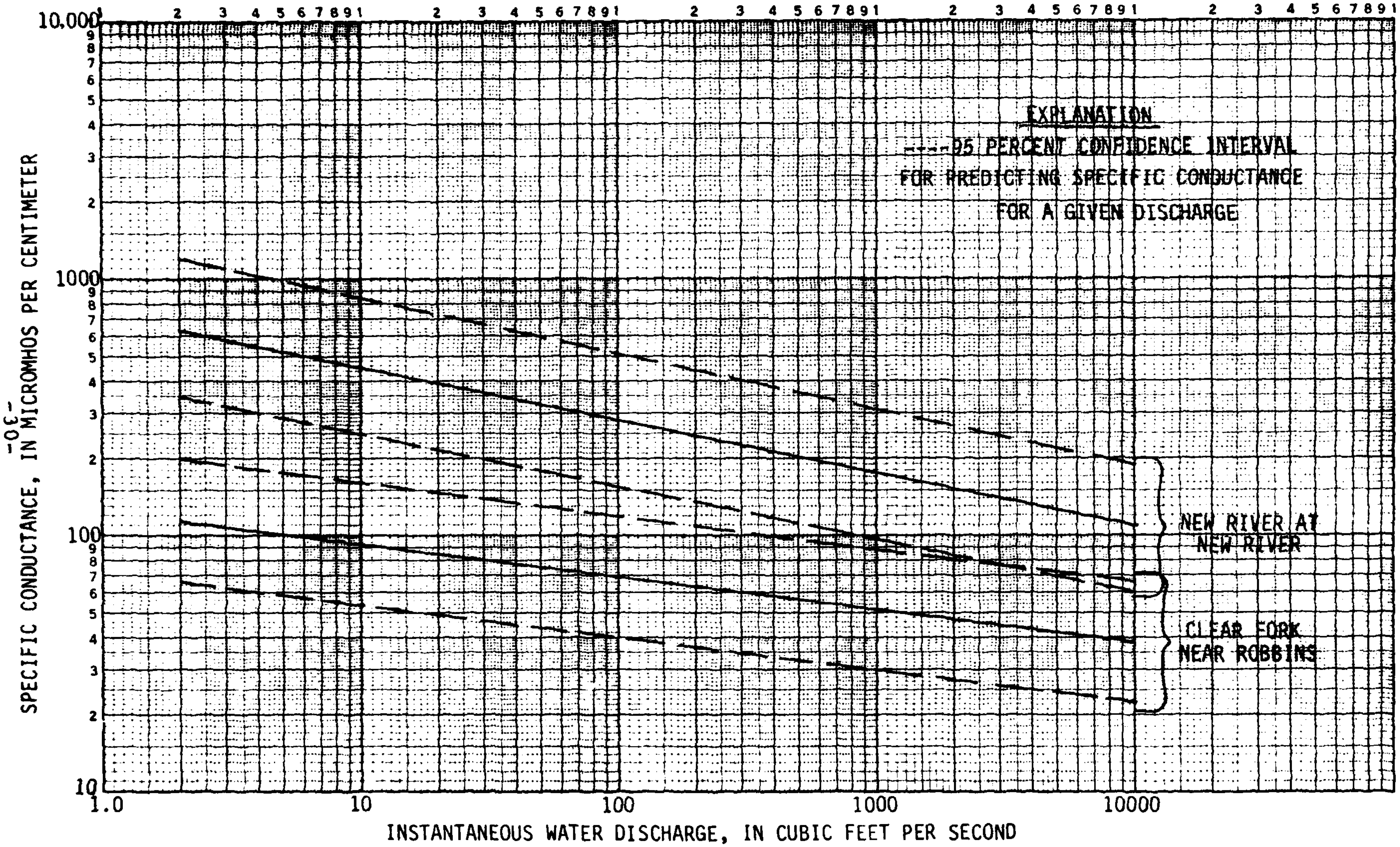

Figure 11.--Specific conductance versus discharge for New River at New River and Clear Fork near Robbins

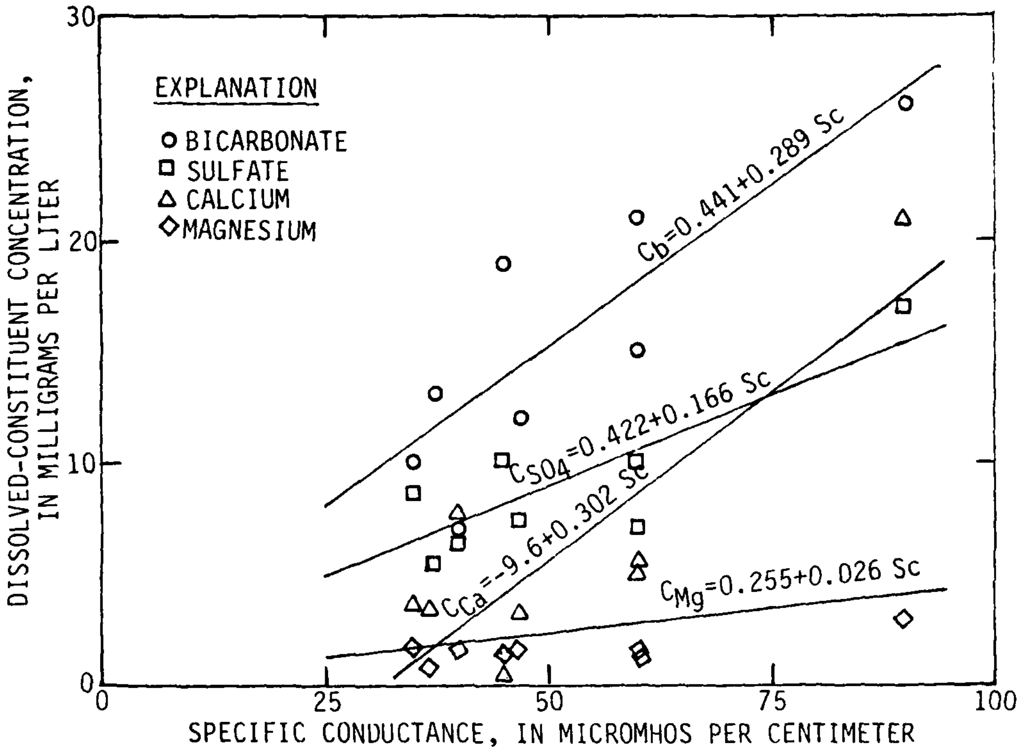

Figure 12.-- Dissolved-constituent concentration verus specific conductance for Clear Fork near Robbins

$$C_{Ca} = -9.6 + 0.302\ Sc \qquad (11)$$

$$r = 0.87$$

$$C_{Mg} = 0.255 + 0.026\ Sc \qquad (12)$$

$$r = 0.71$$

Because the concentration of sulfate is low in Clear Fork and even lower in the small unmined basins, it would seem to be a good indicator of mining within this geologic area. To examine the distribution of sulfate values from unmined basins, data from Anderson Branch and Lowe Branch in the New River basin (fig. 1) were combined with the Clear Fork data. These two small basins (0.69 and 0.92 mi^2, respectively) were unmined at the time these data were obtained. The frequency of occurrence of these sulfate values is shown in figure 13. The distribution of the 139 values of sulfate concentration appears normal and the calculated mean is 9.46 mg/L with a standard deviation of 3.57. No value exceeded 18 mg/L.

If all the sulfate values from the New River mainstem, major tributaries to New River and the two small mined basins of Indian Fork and Green Branch are combined, the 268 samples yield a highly skewed distribution with a calculated mean of 202 mg/L and a range of

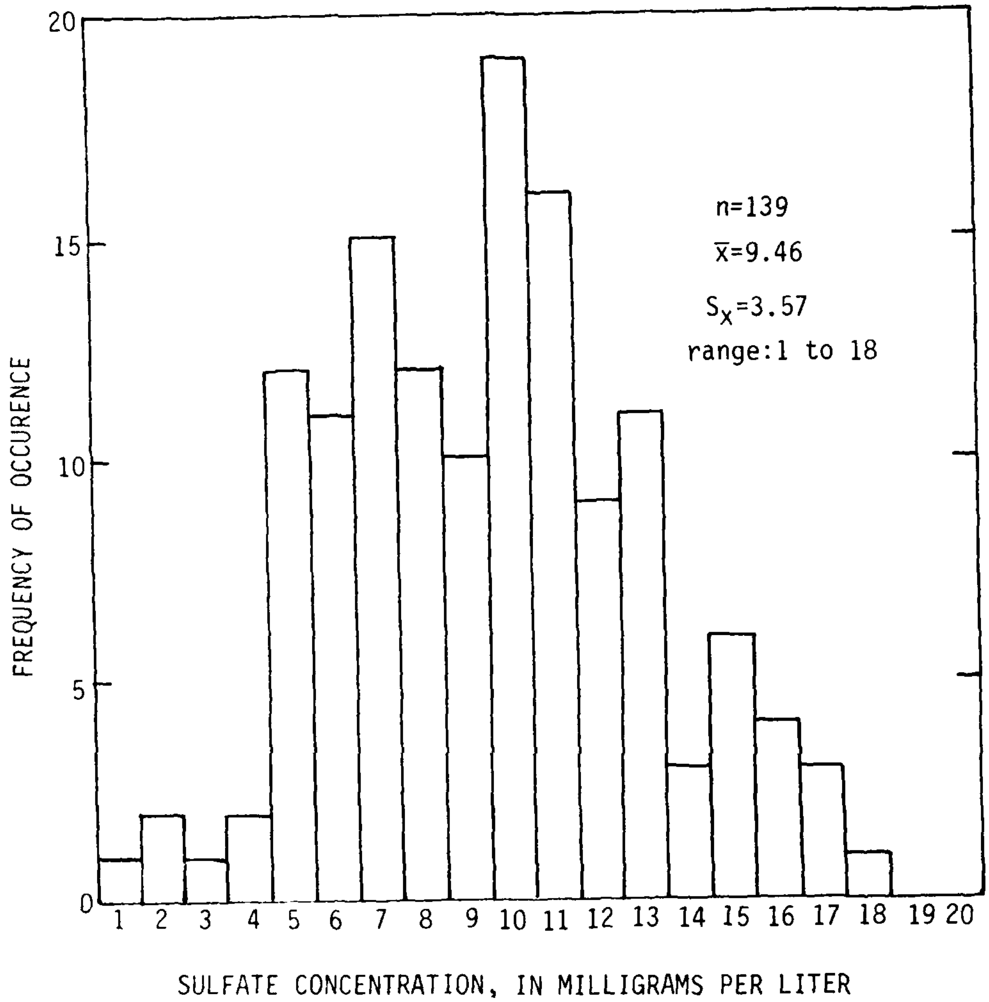

Figure 13.-- Frequency of occurence of sulfate concentrations for Anderson Branch, Lowe Branch, and Clear Fork

concentrations from 17 to 1250 mg/L. With the exception of the 17 mg/L value all other sulfate values from mined basins were greater than 23 mg/L.

It may be argued that higher sulfate values result from the greater percentage of shale found in the upper part of the section, while the lower sandstone part of the section would be expected to yield lower sulfate values. However, both Anderson Branch and Lowe Branch are in the upper more shaly section and yet their sulfate values compare to Clear Fork. Therefore, it appears that the upper more shaly section does not contribute significantly more sulfate than the lower section if undisturbed.

Without regard to size of basin or discharge, sulfate values from unmined basins were less than 20 mg/L. All other sampling sites had some past or present mining activity upstream and all these sites had sulfate concentrations greater than 20 mg/L, regardless of basin size or discharge.

Sulfate data from Bills Branch were not used in the analysis of mined and unmined basins, because mining started in Bills Branch at about the same time as data collection. This coincidence of mining and data collection provides a unique opportunity to examine the hypothesis that sulfate concentration is a good indicator of mining activity.

Mining in the Bills Branch basin (0.69 mi^2) began in December 1974 and water quality data collection began in January 1975. The 16 samples collected between January 7, 1975, and April 24, 1975, had a mean sulfate concentration of 16 mg/L and a range of 11-20 mg/L. After May 1, 1975, sulfate concentrations increased to over 22 mg/L, and have consistently remained above this value ever since. Of the 82 samples collected at Bills Branch between May 1975 and September 1977, only 3 have had sulfate concentrations below 22 mg/L. Thus, the data from Bills Branch seem to support the hypothesis that consistent sulfate concentrations of less than 20 mg/L are indicative of a stream that has not been affected by coal mining activity. The data also show that the effects of coal mining on water quality are not immediate and in fact may exhibit a considerable lag time even in small steep basins.

The Suspended System

Data from the automatic suspended-sediment sampler at New River at New River are used to calculate the mean daily suspended-sediment concentration and load for each day of the water year, as shown in table 7 (Porterfield, 1972). These mean daily values can then be summed to obtain the annual, suspended-sediment load for the station (table 7).

The total suspended-sediment load leaving the New River basin during the 1977 water year was about 590,000 tons (table 7). This suspended-sediment load represents a yield of about 1,500 tons per square mile. Approximately 76 percent of the total for the year occurred on April 3, 4, and 5, 1977, during a storm with a peak return period of approximately 15 years. Much of this suspended material was very fine grained. The percentage of silt and clay (diameter of 0.0625 mm or less) in a suspended sediment sample generally was over 90 percent.

Table 7. -- Mean daily water discharge, mean daily suspended-sediment concentration and mean daily suspended-sediment discharge for New River at New River during water year 1977

Day	Mean Discharge (CFS)	Mean Concen-tration (MG/L)	Sediment Discharge (tons/day)	Mean Discharge (CFS)	Mean Concen-tration (MG/L)	Sediment Discharge (tons/day)	Mean Discharge (CFS)	Mean Concen-tration (MG/L)	Sediment Discharge (tons/day)
		October			November			December	
1	244	70	46	789	89	190	335	18	16
2	123	25	8.3	516	28	39	306	8	6.6
3	77	9	1.9	373	17	17	270	2	1.5
4	55	5	.74	295	12	9.6	237	2	1.3
5	43	2	.23	236	7	4.5	214	2	1.2
6	36	2	.19	192	5	2.6	219	20	12
7	36	2	.19	162	12	5.2	3990	482	6170
8	99	7	1.9	144	18	7.0	2480	165	1100
9	248	75	50	128	12	4.1	1150	42	130
10	372	110	110	118	25	8.0	773	26	54
11	163	40	18	116	17	5.3	603	15	24
12	109	20	5.9	115	8	2.5	845	18	41
13	81	10	2.2	114	5	1.5	1280	48	166
14	63	6	1.0	102	4	1.1	992	38	102
15	53	5	.72	96	5	1.3	818	13	29
16	46	3	.37	102	2	.55	716	11	21
17	43	2	.23	106	2	.57	570	8	12
18	39	2	.21	97	2	.52	479	4	5.2
19	37	2	.20	92	2	.50	400	2	2.2
20	42	2	.23	90	1	.24	391	4	4.2
21	78	10	2.1	87	2	.47	476	9	12
22	110	25	7.4	83	1	.22	343	6	5.6
23	75	9	1.8	78	1	.21	370	6	6.0
24	62	6	1.0	72	1	.19	332	16	14
25	2070	500	2790	69	1	.19	330	7	6.2
26	4450	850	10200	70	1	.19	652	20	35
27	925	140	350	82	1	.22	712	26	50
28	481	60	78	132	2	.71	634	23	39
29	312	22	19	352	3	2.9	568	12	18
30	277	18	13	439	4	4.7	434	5	5.9
31	953	41	105	---	---	---	554	6	9.0
Total	11802	---	13815.81	5447	---	311.08	22473	---	8099.90

Table 7. -- Mean daily water discharge, mean daily suspended-sediment concentration and mean daily suspended-sediment discharge for New River at New River during water year 1977 (continued)

Day	Mean Discharge (CFS)	Mean Concen-tration (MG/L)	Sediment Discharge (tons/day)	Mean Discharge (CFS)	Mean Concen-tration (MG/L)	Sediment Discharge (tons/day)	Mean Discharge (CFS)	Mean Concen-tration (MG/L)	Sediment Discharge (tons/day)
		January			February			March	
1	439	4	4.7	156	18	7.6	1120	80	242
2	523	6	8.5	142	18	6.9	876	22	52
3	470	4	5.1	143	16	6.2	725	16	31
4	443	2	2.4	161	16	7.0	1350	55	200
5	452	4	4.9	204	15	8.3	2170	304	1840
6	542	7	10	175	11	5.2	1390	62	233
7	702	15	28	134	15	5.4	1030	28	78
8	672	25	45	119	11	3.5	790	27	58
9	664	20	36	118	6	1.9	642	14	24
10	1210	64	209	129	8	2.8	545	14	21
11	1120	80	242	139	10	3.8	479	11	14
12	874	41	97	196	10	5.3	591	15	24
13	754	15	31	640	15	26	7440	1300	26100
14	750	14	28	661	16	29	2300	350	2170
15	1320	81	289	592	12	19	1340	130	470
16	1100	63	187	479	10	13	970	60	157
17	633	22	38	393	10	11	742	25	50
18	834	22	50	394	10	11	658	20	36
19	607	8	13	379	10	10	584	15	24
20	518	17	24	346	10	9.3	655	20	35
21	487	6	7.9	304	10	8.2	650	15	26
22	395	4	4.3	275	10	7.4	643	16	28
23	374	5	5.0	281	10	7.6	606	12	20
24	299	5	4.0	2380	350	2250	541	13	19
25	290	5	3.9	2150	300	1740	496	25	33
26	268	6	4.3	1300	110	386	452	18	22
27	266	4	2.9	1360	130	477	404	15	16
28	267	6	4.3	1510	160	652	372	9	9.0
29	282	20	15	---	---	---	390	19	20
30	223	20	12	---	---	---	666	258	1010
31	186	20	10	---	---	---	2340	1690	10800
Total	17964	---	1426.20	15260	---	5720.40	33957	---	43862.00

Table 7. -- Mean daily water discharge, mean daily suspended-sediment concentration and mean daily suspended sediment discharge for New River at New River during water year 1977 (continued)

Day	Mean Discharge (CFS)	Mean Concen-tration (MG/L)	Sediment Discharge (tons/day)	Mean Discharge (CFS)	Mean Concen-tration (MG/L)	Sediment Discharge (tons/day)	Mean Discharge (CFS)	Mean Concen-tration (MG/L)	Sediment Discharge (tons/day)
		April			May			June	
1	1150	295	916	880	45	107	73	10	2.0
2	853	60	138	673	40	73	57	10	1.5
3	3940	1130	12000	571	35	54	47	10	1.3
4	25000	2350	177000	581	30	47	41	8	.89
5	26200	2720	262000	475	25	32	36	8	.78
6	3080	480	3990	403	20	22	34	10	.92
7	1710	250	1150	339	15	14	34	14	1.3
8	1220	100	329	316	10	8.5	115	23	7.1
9	920	48	119	251	10	6.8	71	19	3.6
10	744	38	76	202	11	6.0	56	14	2.1
11	617	52	87	175	9	4.3	47	14	1.8
12	522	75	106	155	6	2.5	45	22	2.7
13	458	70	87	137	6	2.2	49	22	2.9
14	413	60	67	124	4	1.3	69	21	3.9
15	376	55	56	115	7	2.2	122	32	11
16	334	45	41	106	8	2.3	91	26	6.4
17	295	40	32	97	3	.79	79	20	4.3
18	264	30	21	86	5	1.2	112	20	6.0
19	249	15	10	80	6	1.3	114	15	4.6
20	226	8	4.9	76	4	.82	291	34	27
21	205	14	7.7	72	7	1.4	264	26	19
22	192	10	5.2	70	8	1.5	160	13	5.6
23	582	52	118	87	19	4.5	252	32	22
24	2000	234	1280	122	12	4.0	345	92	86
25	1170	168	531	130	12	4.2	894	185	447
26	776	50	105	95	10	2.6	2470	2500	16700
27	575	25	39	89	12	2.9	1040	1500	4210
28	454	18	22	83	10	2.2	571	600	925
29	1190	78	251	78	9	1.9	323	260	227
30	1220	50	165	132	72	26	209	133	75
31	---	---	---	103	16	4.4	---	---	---
Total	76935	---	460753.8	6903	---	444.81	8111	---	22808.69

Table 7. -- Mean daily water discharge, mean daily suspended-sediment concentration and mean daily suspended sediment discharge for New River at New River during water year 1977 (continued)

Day	Mean Discharge (CFS)	Mean Concen-tration (MG/L)	Sediment Discharge (tons/day)	Mean Discharge (CFS)	Mean Concen-tration (MG/L)	Sediment Discharge (tons/day)	Mean Discharge (CFS)	Mean Concen-tration (MG/L)	Sediment Discharge (tons/day)
		July			August			September	
1	168	84	38	42	12	1.4	38	28	2.9
2	289	77	60	38	12	1.2	114	75	23
3	219	54	32	38	12	1.2	113	48	15
4	137	47	17	32	14	1.2	76	54	11
5	105	43	12	48	11	1.4	95	63	16
6	87	40	9.4	123	375	361	68	25	4.6
7	72	37	7.2	131	458	229	148	19	7.6
8	62	16	2.7	54	48	7.0	601	94	153
9	55	19	2.8	105	65	18	271	132	97
10	46	20	2.5	425	205	235	145	124	49
11	42	24	2.7	652	247	435	101	110	30
12	62	37	6.2	201	145	79	77	80	17
13	51	55	7.6	185	205	102	62	84	14
14	49	81	11	146	107	42	90	78	19
15	41	42	4.6	241	85	55	415	190	213
16	33	58	5.2	250	75	51	1230	497	1950
17	28	32	2.4	187	72	36	906	834	2160
18	25	11	.74	231	74	46	513	176	244
19	22	12	.71	170	84	39	311	123	103
20	20	15	.81	115	76	24	229	95	59
21	18	22	1.1	100	51	14	168	88	40
22	19	59	3.0	66	37	6.6	129	58	20
23	16	22	.95	52	35	4.9	106	40	11
24	15	19	.77	160	62	27	88	30	7.1
25	33	43	3.8	380	144	148	94	40	10
26	312	85	72	160	44	19	1320	888	7660
27	162	26	11	97	35	9.2	1960	2370	12800
28	82	16	3.5	70	45	8.5	1560	1040	4180
29	54	17	2.5	56	46	7.0	700	180	340
30	42	18	2.0	52	67	9.4	425	60	69
31	39	13	1.4	41	25	2.8	---	---	---
Total	2405	---	327.58	4648	---	2021.80	12153	---	30325.20
Year	218058		589917.27						

This large load of fine-grained material permits the use of turbidity to assess the concentration of suspended sediment. Figure 14 shows the relationship between suspended-sediment concentration and turbidity for New River at New River. This relationship was developed using suspended-sediment concentrations equal to or greater than 30 mg/L. Concentrations less than 30 mg/L produce wide scatter in the turbidity data and therefore were deleted. The least squares equation for these data is:

$$C_s = 1.33\ T^{0.936} \qquad (13)$$

where C_s = suspended-sediment concentration in milligrams per liter, and T = turbidity in Jackson turbidity units. The correlation coefficient (r) for this relation is 0.92. Good correlations such as this are possible at sites where much of the material transported is fine grained.

It would be economically desirable to use turbidity to predict suspended-sediment concentration at this site. The problem here is that the turbidity monitor has a maximum value of 1,000 S/T. Equation 11 shows that turbidity can be used to predict suspended-sediment concentration to approximately 850 mg/L before the turbidity instrumentation reaches its limit. Instantaneous suspended-sediment concentrations are consistently higher than 850 mg/L during storms. The turbidity data, however, can be used to estimate missing data during times of non-storm flow.

Automatic sediment sampling equipment was not available to monitor the sediment discharge from the Clear Fork basin. However, several suspended-sediment samples were obtained at Clear Fork near Robbins by field personnel. These samples are distributed over a wide range of discharges as shown in figure 15. A least squares equation was fitted to the data to yield a sediment rating curve (fig. 15). The least squares equation is:

$$C_s = 1.28\ Q^{0.46} \qquad (14)$$

$$r = 0.87$$

where C_s = suspended-sediment concentration in milligrams per liter, and Q = discharge in cubic feet per second.

This equation and the mean daily water discharges for 1977 were used to calculate mean daily sediment discharges for each day of the water year. The mean daily sediment discharge values were then summed to obtain the monthly and annual values of load and yield shown in table 8. This technique is essentially a one-year approximation of the flow-duration sediment-rating curve method (Miller 1951, Colby 1956).

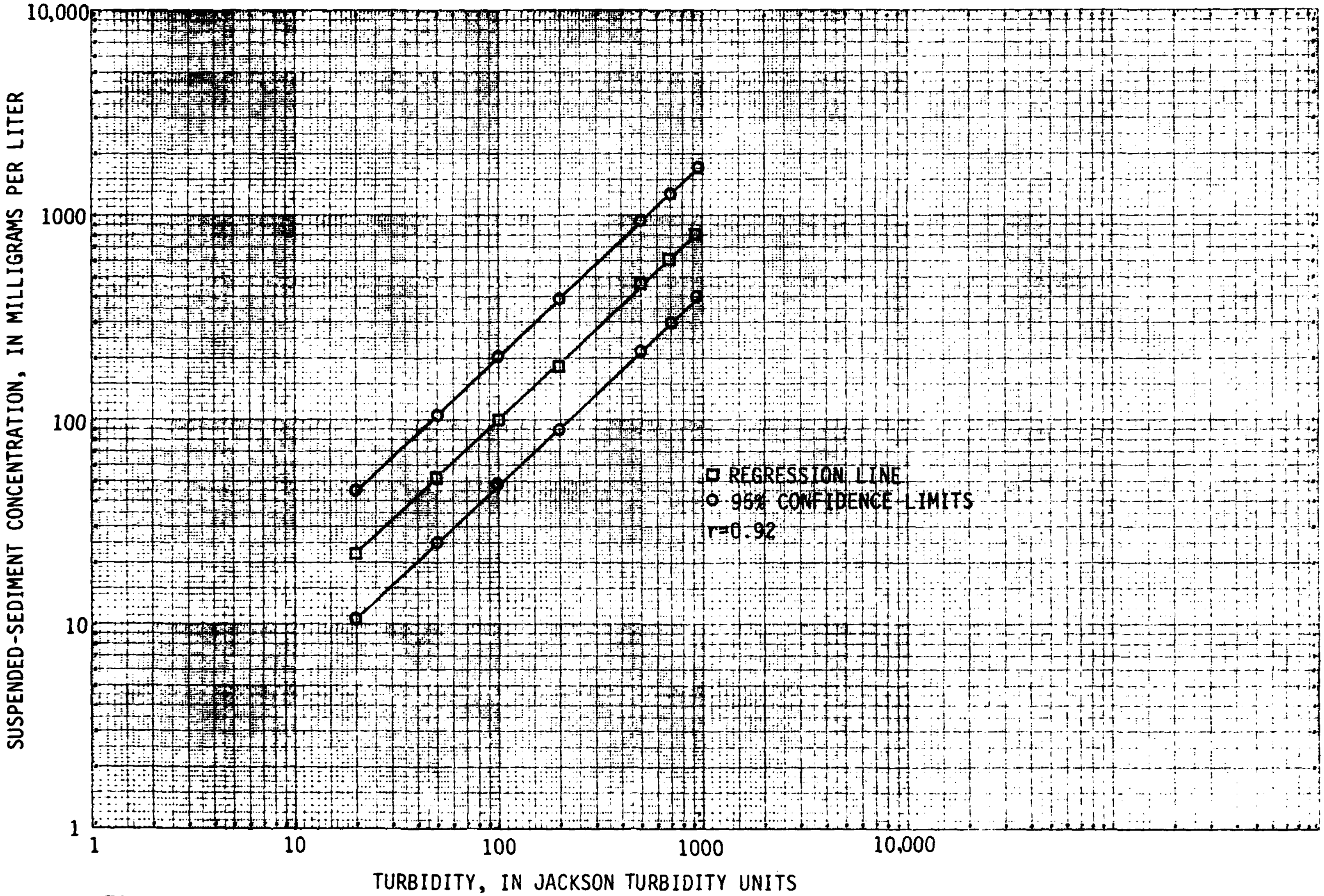

Figure 14.-- Suspended-sediment concentration versus turbidity for New River at New River

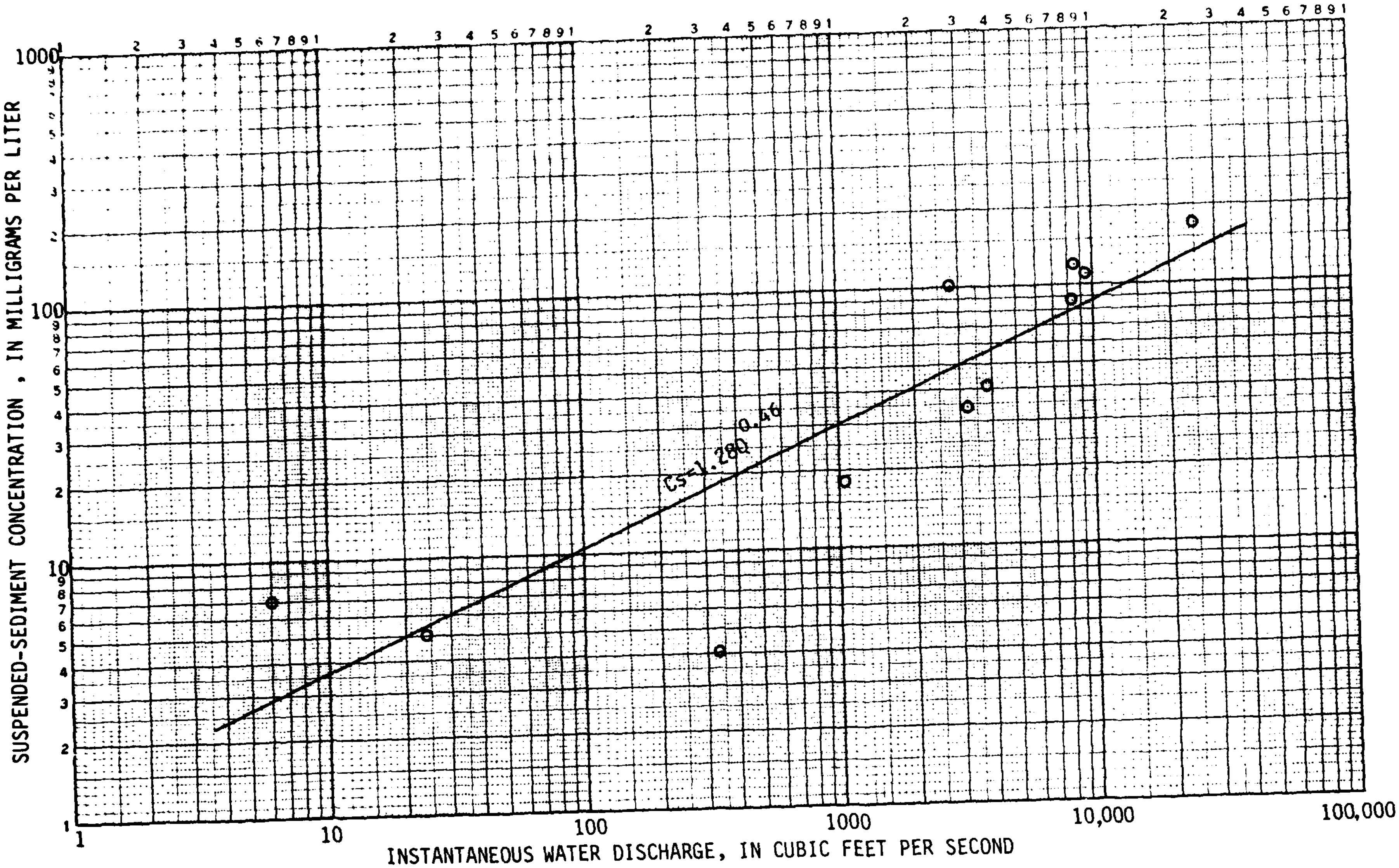

Figure 15.-- Suspended-sediment concentration versus instantaneous water discharge for Clear Fork near Robbins

Table 8. -- Calculated monthly suspended-sediment loads and yields for Clear Fork near Robbins and a comparison with measured yields for New River at New River

Month	Clear Fork nr Robbins: Calculated suspended sediment load (tons)	Clear Fork nr Robbins: Calculated yield per month (tons/mi^2)	New River at New River: Measured yield per month (tons/mi^2)
Oct.	352	1.29	36.17
Nov.	140	0.51	0.81
Dec.	763	2.81	21.20
Jan.	845	3.11	3.73
Feb.	672	2.47	14.97
Mar.	3,396	12.49	114.82
Apr.	12,884	47.37	1206.16
May	239	0.88	1.16
June	278	1.02	59.71
July	23	0.08	0.86
Aug.	48	0.18	5.29
Sept.	735	2.70	79.39
Total	20,375	74.91	1544.29

The calculated load for Clear Fork during the 1977 water year was 20,000 tons. The annual load measured at the New River outlet for water year 1977 was 590,000 tons or 30 times that of Clear Fork. The calculated 1977 annual yield for Clear Fork is 75 tons/mi^2 and the 1977 measured yield for New River is 1,500 tons/mi^2. New River basin discharged 20 times as much suspended sediment per square mile as did Clear Fork. Over 80 percent of the annual load for both basins were derived in the two months of March and April (table 8).

Average annual suspended-sediment yield was also calculated for Clear Fork near Robbins using a slightly modified version of the flow-duration sediment-rating curve method (Miller 1951). To calculate average annual yield by Miller's method, the flow-duration curve is divided into several ranges of water discharge. The mean water discharge value for each of these ranges is then used to obtain a corresponding sediment discharge from the sediment-rating curve. These sediment-discharge values are then multiplied by the percentage of time that the flow is within the range that they correspond to. These values are then summed, divided by 100, and multiplied by 365 to obtain average annual suspended-sediment discharge.

The average annual sediment-discharge value used in this report was obtained by entering each mean water discharge value into equation 14 to obtain a suspended-sediment concentration value. These concentration values were then multiplied by their corresponding water discharge value and by the factor 0.0027, to transform them into sediment discharge values.

These sediment-discharge values were then multiplied by the percentage of time that the flow is within the range that they correspond to. These products were then summed, divided by 100, and multiplied by 365 to obtain average annual suspended-sediment discharge.

The average annual suspended-sediment discharge calculated by the modified Miller method for Clear Fork near Robbins is 16,000 tons per year and the average annual yield is 59 tons per square mile per year. These values show close agreement with those calculated for the 1977 water year.

The suspended-sediment discharge from both basins is dominated by a high percentage of silt and clay. This abundant load of fine-grained sediment not only affects the aesthetic quality of the water but it also carries with it a correspondingly large load of sorbed metals.

The relationship between suspended sediment and the transport of sorbed metals has already been briefly introduced in the discussion of pH. Figure 16 shows the relation between suspended-sediment concentration and suspended-iron concentration for New River at New River. Although the relation could be more definitive with additional data from storms, the regression equation for the data yields an r value of 0.95. The least squares equation is:

$$Fe_s = 831.73 + 28.5\ C_s \qquad (15)$$

where Fe_s = suspended-iron concentration in micrograms per liter, and C_s = suspended-sediment concentration in milligrams per liter. The slope coefficient in equation 15 gives the weight of suspended iron per gram of sediment. Thus, 28.5 mg of suspended iron travels from the basin per gram of suspended sediment.

Three other trace metals are also examined. Data for these additional plots are available as total trace metal concentrations only. The least squares relation for total manganese (fig. 17) is:

$$Mn_T = 221 + 0.48\ C_s \qquad (16)$$

$$r = 0.94$$

where Mn_T = total manganese concentration in micrograms per liter. The relation for total nickel (fig. 18) is:

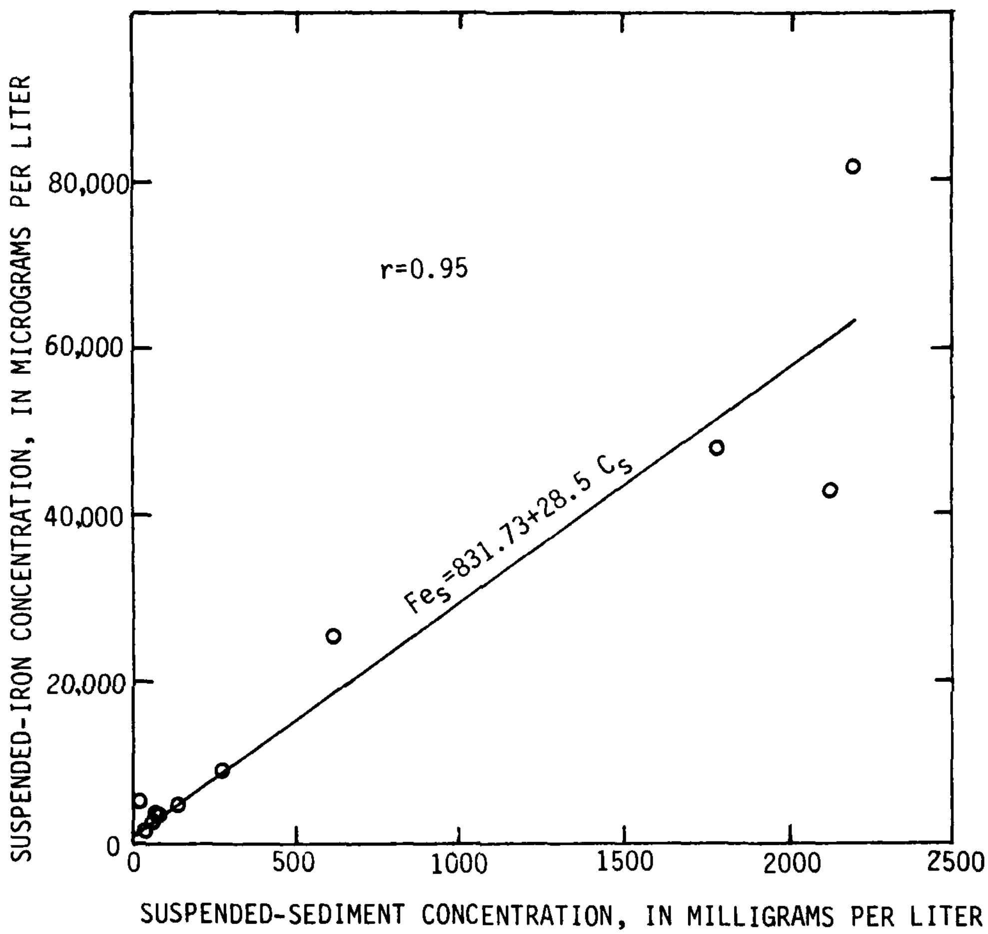

Figure 16.-- Suspended-iron concentration versus suspended-sediment concentration for New River at New River

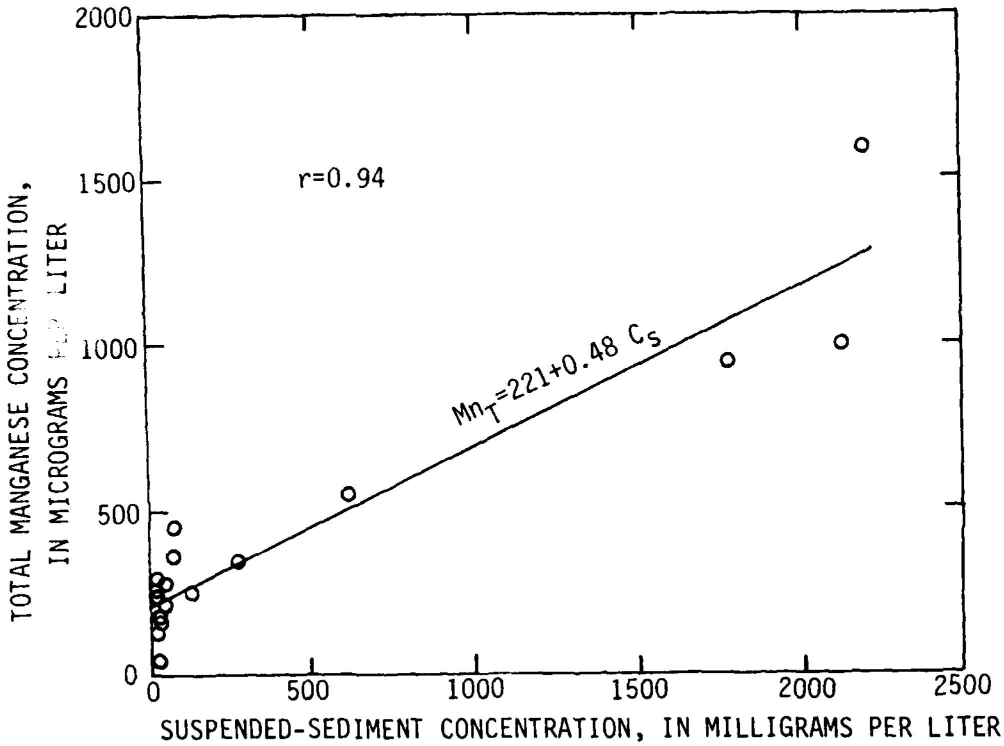

Figure 17.--Total manganese concentration versus suspended-sediment concentration for New River at New River

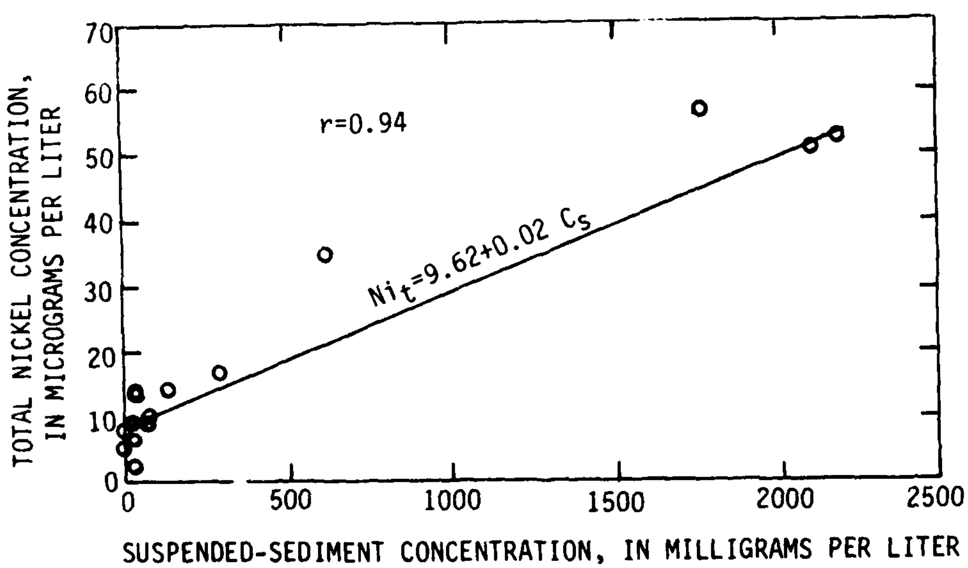

Figure 18.--Total nickel concentration versus suspended-sediment concentration for New River at New River

$$Ni_T = 9.62 + 0.02\ C_S \qquad (17)$$

$$r = 0.94$$

where Ni_T = total nickel concentration in micrograms per liter. The relationship between total lead and suspended sediment is shown in figure 19. No regression equation was derived because of insufficient data.

Although fewer trace-metal data were collected at the Clear Fork outlet, the same relationships shown for the New River outlet can be generated for the Clear Fork near Robbins site. The least squares relation for suspended-iron and suspended-sediment concentration (fig. 20) is:

$$Fe_S = 28.23 + 27.97\ Cs \qquad (18)$$
$$r = 1$$

Again, the slope coefficient for equation 18 represents the milligrams of suspended iron removed from the basin per gram of sediment. The slope coefficient for Clear Fork is essentially the same as for the New River basin (eq. 15). Thus, the difference in iron yields between the basins is dependent on the difference in sediment yields from each basin.

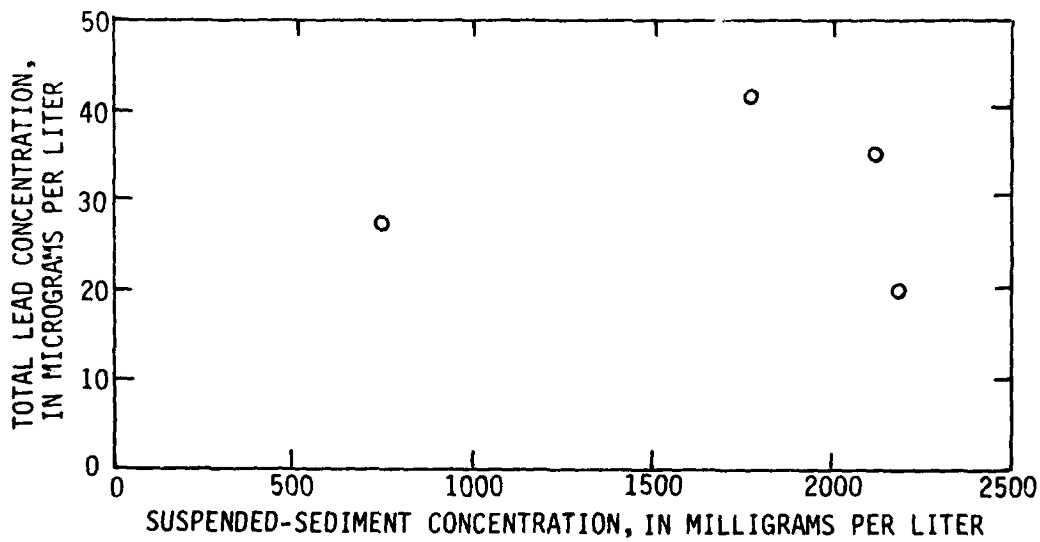

Figure 19.-- Total lead concentration versus suspended-sediment concentration for New River at New River

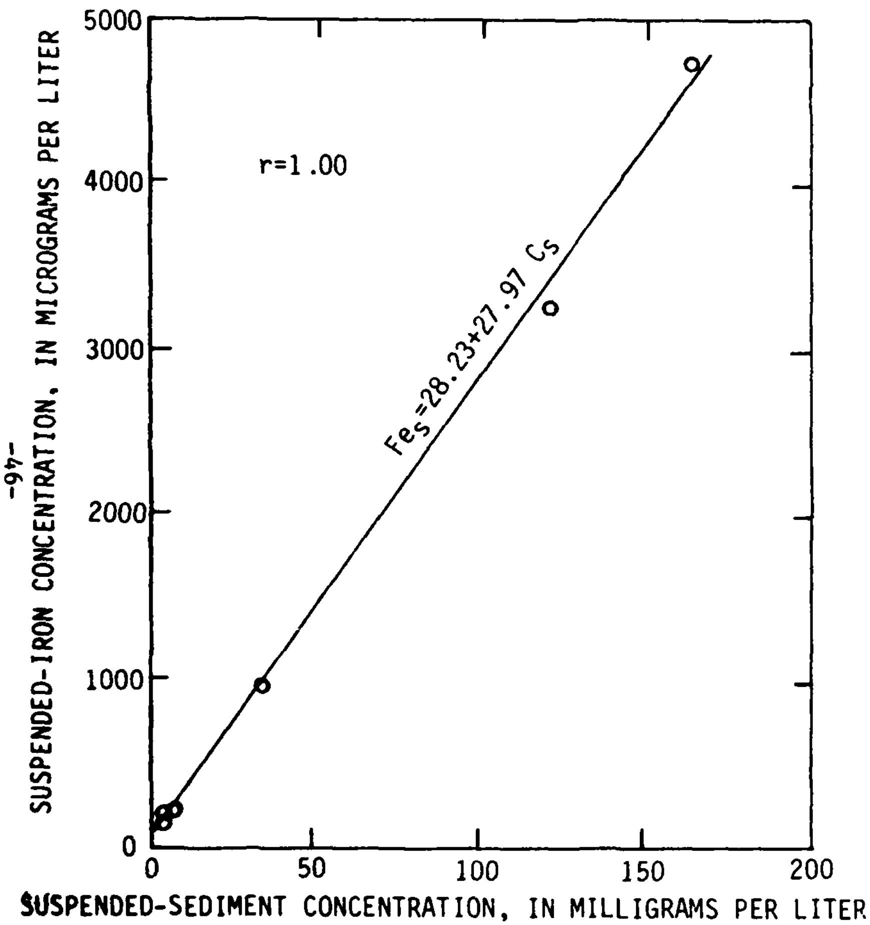

Figure 20.-- Suspended-iron concentration versus suspended-sediment concentration for Clear Fork near Robbins

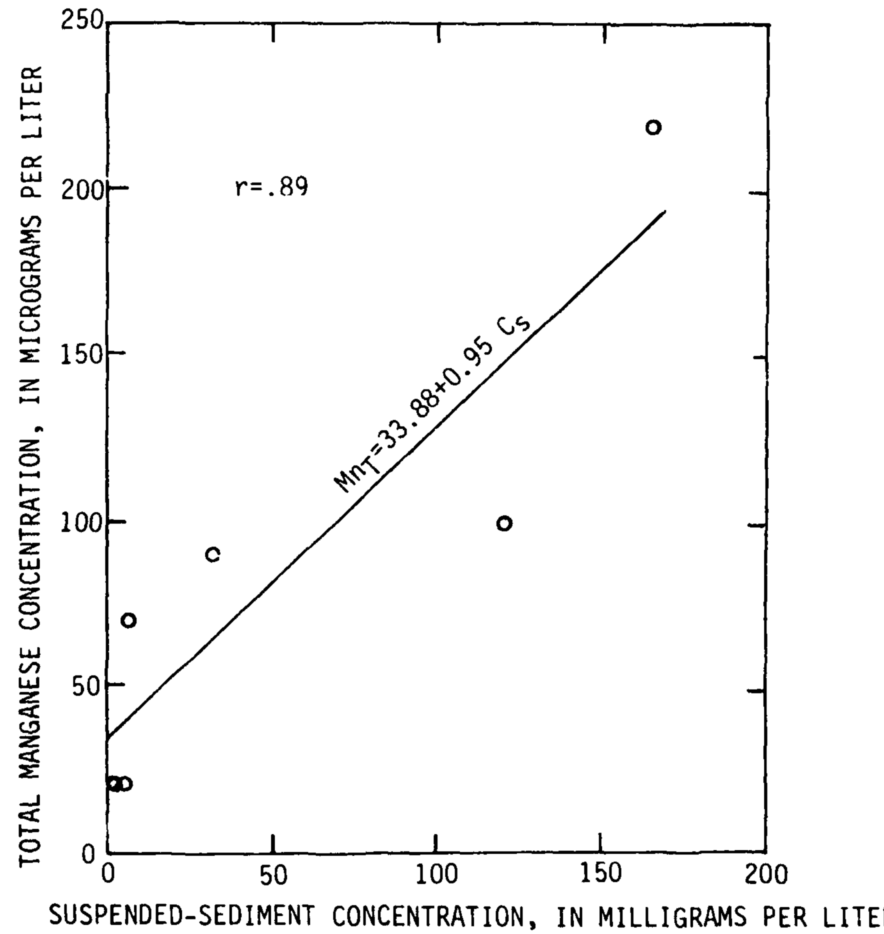

Figure 21.-- Total manganese concentration versus suspended-sediment concentration for Clear Fork near Robbins

The least squares relation between suspended sediment and total manganese for Clear Fork (fig. 21) is:

$$Mn_T = 33.88 + 0.95\ Cs \qquad (19)$$

$$r = 0.89$$

The relation for total nickel (fig. 22) is:

$$Ni_T = 1.50 + 0.09\ Cs \qquad (20)$$

$$r = 0.86$$

Again a relation between suspended-sediment concentration and total lead is shown in figure 23 without least squares calculations.

With values for suspended sediment for each basin, it is possible to estimate the loads for the various metals examined previously. The slope coefficients from equations 15 to 20 give the milligrams of trace metal per gram of sediment. These slope coefficients were used to calculate metal loads from the total suspended load for the 1977 water year (table 9). Although the concentration of suspended iron per gram of suspended sediment is equal between the two basins, the total load for suspended iron in New River for the year is 30 times that of Clear Fork. These loads translate into yields of 44 tons per square mile for the New River basin and 2.1 tons per square mile for the Clear Fork basin.

Table 9. -- Comparison of annual trace-metal loads between New River at New River and Clear Fork near Robbins for water year 1977

Constituent	Estimate for New River at New River		Estimate for Clear Fork nr Robbins	
	(tons)	($tons/mi^2$)	(tons)	($tons/m^2$)
Suspended iron	16800	44	570	2.1
Total manganese	280	0.74	19	0.07
Total nickel	12	0.03	2	0.01

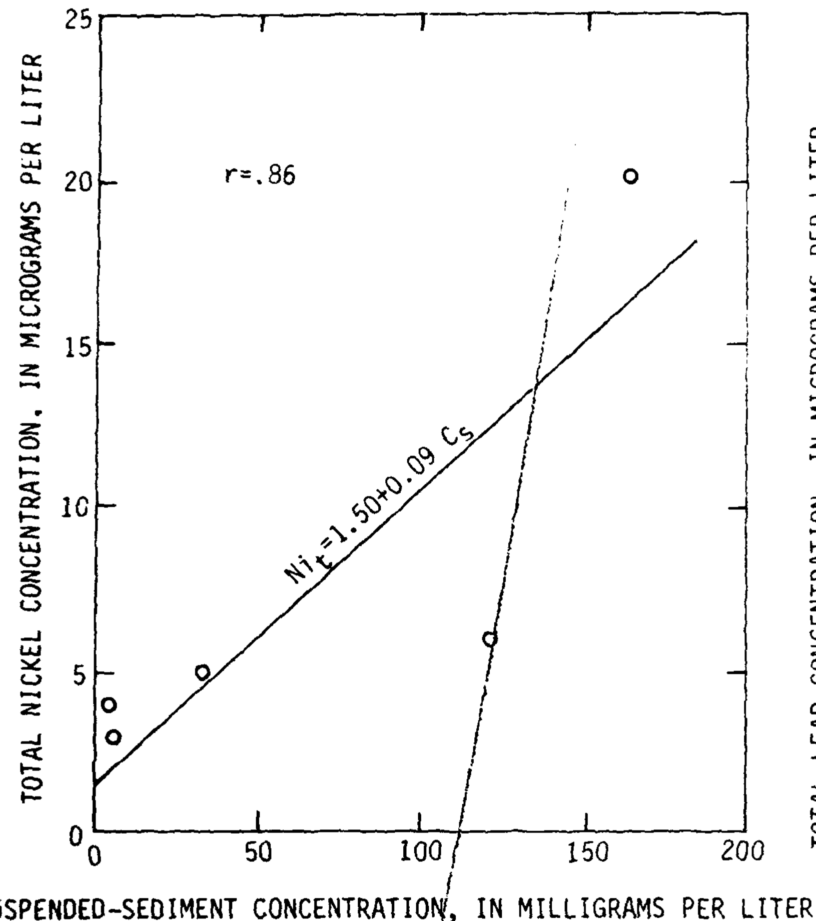

Figure 22.-- Total nickel concentration versus suspended-sediment concentration for Clear Fork near Robbins

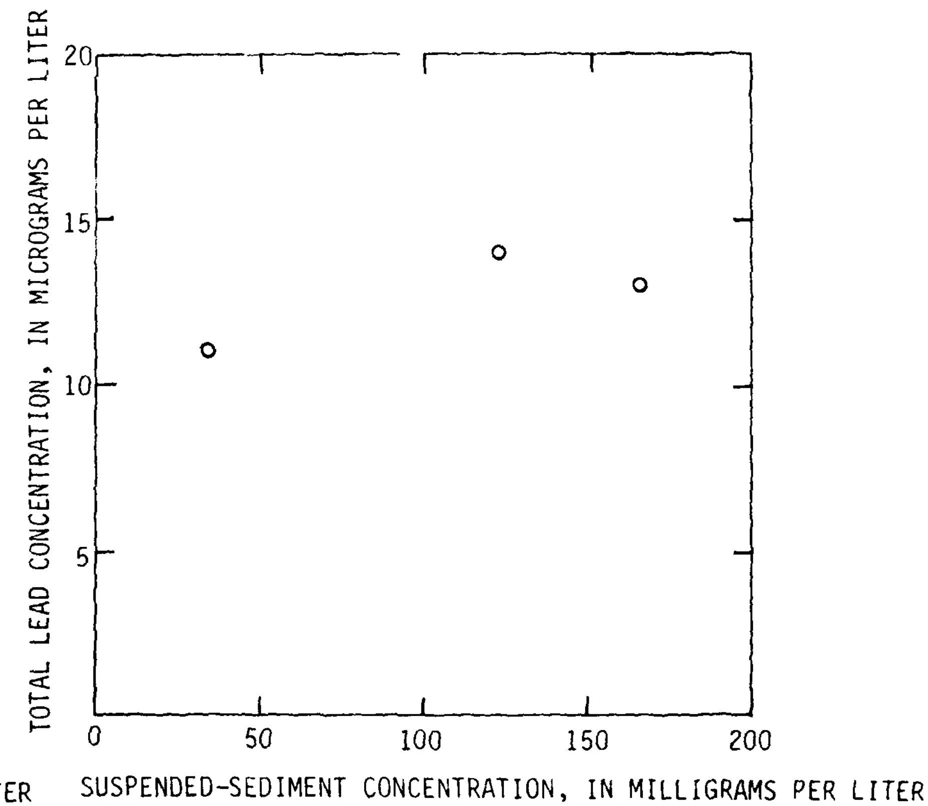

Figure 23.--Total lead concentration versus suspended-sediment concentration for Clear Fork near Robbins

CONCLUSIONS

This report summarizes the water quality at the outlets of the New River and Clear Fork basins. Because these basins adjoin, some useful water-quality comparisons can be made. However, these basins are both large, and water quality at the outlet represents the integrated impact of each basin's various land use patterns. It is not possible to ascribe water-quality differences to any particular land use or basin characteristics with the data available. In order to identify specific impacts, data must be collected on much smaller watersheds.

Sufficient values of sulfate concentrations were available from both small and large basins to show that sulfate concentration appears to be a good indicator of coal-mining activity. Of those basins sampled, all unmined basins showed concentrations less than 20 mg/L. Mined basins all had higher concentrations without regard to basin size or discharge. In Bills Branch where mining commenced in December 1974, sulfate concentrations did not consistently exceed 20 mg/L until May 1975. Thus, some time lag after mining commences is evident.

The general water quality of the outlets of the two basins of New River and Clear Fork can be shown by summarizing the relations given in this report. The summary of water-quality relationships for New River is shown in figure 24. Because this station has a water-quality monitor, much more information is measured directly. Values that can be obtained directly from the monitor are shown in squares. Values that are calculated from a known value are shown in circles. On lines between the boxes and circles are the equations used to calculate the unknown circled value. Note that some measured variables also have a relation determined. These variables are denoted by hexagons.

In figure 25 the summary of water quality for Clear Fork at Robbins is shown. Only discharge is monitored at this site. Therefore, all other constituents must be predicted from discharge.

Concentrations and loads for each basin can be calculated from the equations. It must be considered that only one year of data was available for many parameters at New River and only a few samples were available for Clear Fork. As more data becomes available, these relations may change. For the present, figures 24 and 25 allow one to summarize the water quality at New River, Clear Fork, and make some direct inferences about the quality of water entering the Big South Fork of the Cumberland River.

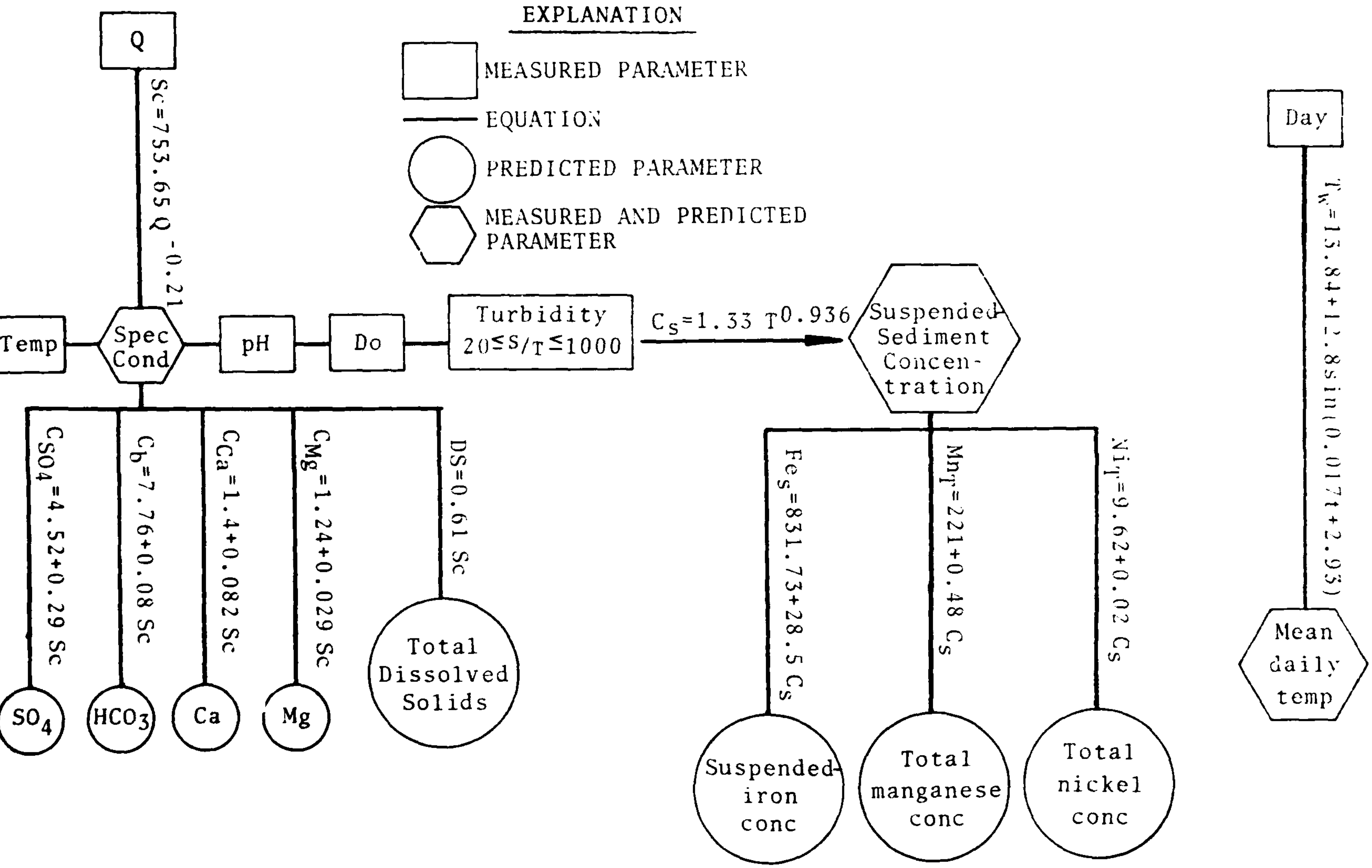

Figure 24.-- Summary of New River at New River water-quality relations.

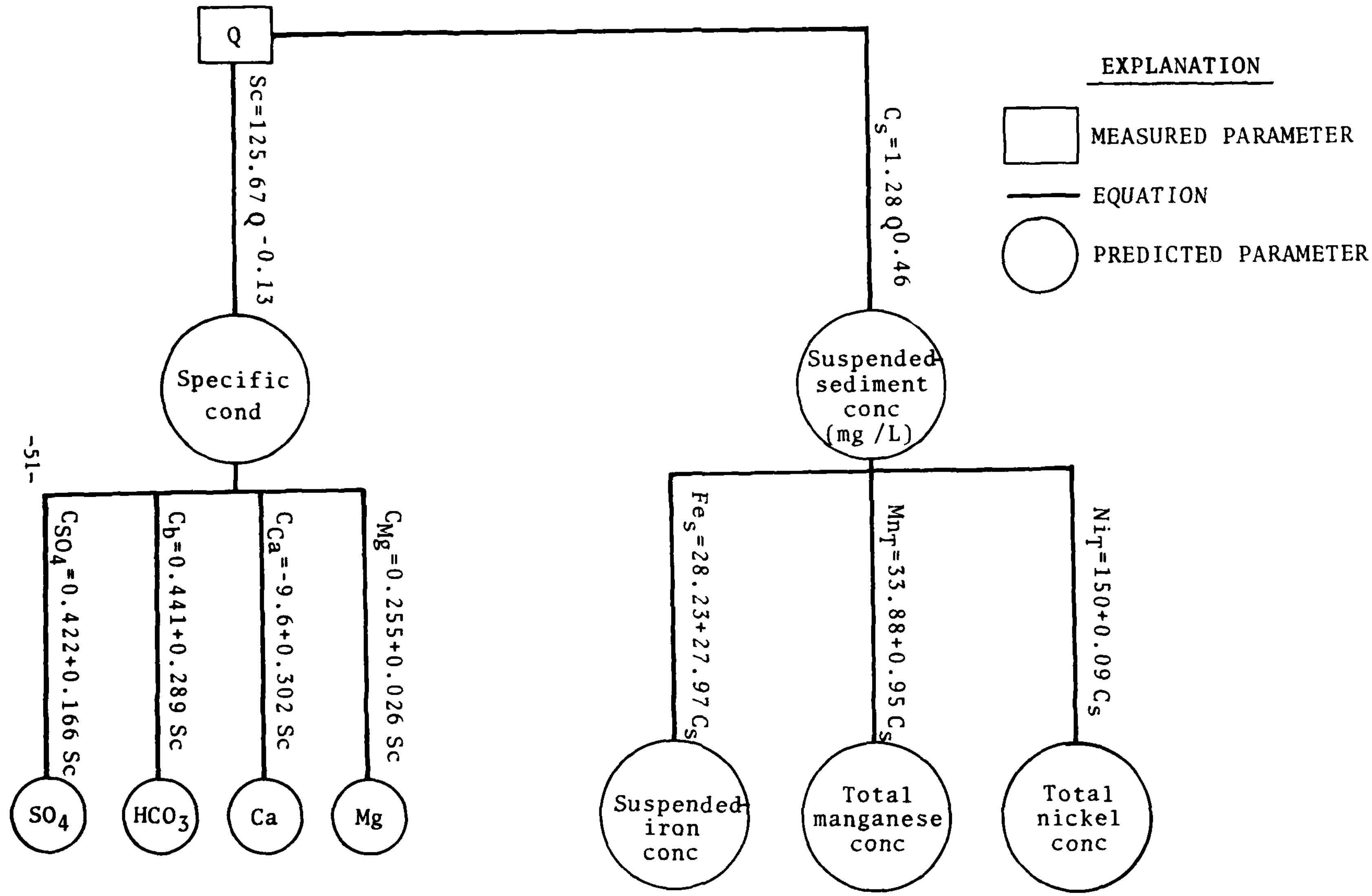

Figure 25.-- Summary of Clear Fork near Robbins water-quality relations.

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