Influences of Strip Mining on the Hydrologic Environment of Parts of Beaver Creek Basin, Kentucky, 1955–66

GEOLOGICAL SURVEY PROFESSIONAL PAPER 427–C

Prepared in collaboration with the U.S. Department of the Interior, Bureau of Sport Fisheries and Wildlife; U.S. Department of Agriculture, Forest Service and Soil Conservation Service; Department of the Army, Corps of Engineers; and Commonwealth of Kentucky, University of Kentucky and Department of Fish and Wildlife Resources

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Edited by C. R. COLLIER, R. J. PICKERING, *and* J. J. MUSSER

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PREFACE

This report is the third of a series on the environmental effects of strip mining of coal in Cane Branch basin, McCreary County, Ky. The series of reports, which is being published by the U.S. Geological Survey as Professional Paper 427, is the product of a cooperative study by several Federal and State agencies. The physical environment of the study areas and the history of mining in the basin are described in the first report, Professional Paper 427–A (Musser, 1963). Results obtained during the study period 1955–59 and definitions of terms are given in the second report, Professional Paper 427–B (Collier and others, 1964). The present report describes the results of the investigation since 1955, with emphasis on the period 1959–66.

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Edited by C. R. COLLIER, R. J. PICKERING, and J. J. MUSSER

SUMMARY OF RESULTS

By C. R. COLLIER, R. J. PICKERING, and J.J. MUSSER

Strip mining of coal in the Beaver Creek basin in south-central Kentucky has significantly increased the acidity and mineralization of surface and ground water and increased the sediment content of streams in the mined area. These effects, in turn, have reduced or eliminated aquatic life in the streams. Influences of mining on the hydrologic environment are limited largely to the Cane Branch basin and to Hughes Fork downstream from Cane Branch. Beaver Creek, 3 miles downstream from the mined area, is relatively unaffected.

Mining, which began in 1955, was intermittent, but by the time the last operation ceased in 1959, 44.6 acres, or 10.4 percent, of the Cane Branch study area had been strip mined, and 1.3 acres, or 0.8 percent, of the West Fork Cane Branch study area had been disturbed by prospecting. Some underground mining had been done in one of the stripped areas as well. The basin of Helton Branch remained unaffected by mining and useful as an indicator of natural conditions within the upper Beaver Creek basin.

Gross runoff characteristics in the Cane Branch and Helton Branch basins have been similar throughout the study period. In both basins, approximately 40 percent of the precipitation was removed as runoff, and approximately 60 percent was lost through evapotranspiration. However, some measurable differences were observed. Cane Branch had greater peak flows per square mile of drainage area and more rapid changes in discharge, but Helton Branch had greater base flows. Lack of data for the Cane Branch basin prior to mining prohibited separation of differences in runoff characteristics between the two basins into those due to strip mining and those caused by natural differences. An examination of the hydrologic data for a progressive change in runoff characteristics of Cane Branch that could be related to the history of mining in the basin failed to indicate any such change.

There have been no significant changes in the occurrence and movement of ground water in bedrock and spoil in the vicinity of the southwest spoil bank since observations began in 1958. Pools formed in the mining cuts adjacent to the spoil bank represent links between ground water in the bedrock and ground water in the spoil bank, and serve as sources of continuous recharge to the spoil bank, from which ground water discharges into drainage ditches. Shallow ground water in bedrock moves from topographically high areas to discharge into the pools and into streams. Ground-water levels in both bedrock and spoil respond to recharge from precipitation within 24 hours. Changes in ground-water levels in the spoil bank during the summer and autumn are the net result of variations in water levels in the pools and variations in direct infiltration of precipitation. Changes in ground-water levels during the winter and spring are due primarily to variations in direct infiltration of precipitation, because the pools are full most of the time.

Although the amount of ground water in the southwest spoil bank and adjacent bedrock areas has changed seasonally, there has been little overall change for the period of record. A small overall loss in storage for the study period is assumed to be due to deficient precipitation in 1963, 1964, and 1966, but it may also be due in part to deepening of gullies in the spoil bank and increased transpiration by vegetation.

Variations in solute concentrations in ground water in the southwest spoil bank are due primarily to changes in the relative amounts of recharge from three chemically different sources—direct infiltration of precipitation, pools formed between the spoil bank and the highwall, and ground water in bedrock of the adjacent ridges. Seepage and runoff from the spoil bank areas and overflow from the adjacent pools are the sources of the acid, highly mineralized water that characterizes Cane Branch.

Cane Branch became an acid, highly mineralized stream in the spring of 1956 as a result of strip mining of coal in the southwestern part of the basin. Following cessation of mining, concentrations of dissolved constituents in the water slowly decreased during 1957 and 1958 as the more easily leached weathering products were transported from the mined area. In 1959, mining in the northwestern part of the basin resulted in an increase in the rate of chemical weathering in the newly mined area and a twofold increase in dissolved-solids concentrations in the stream, as compared with 1958 concentrations. After mining in that area was stopped in 1959, concentrations of dissolved constituents in Cane Branch began to decrease, and by 1962 they had reached the level that occured in 1957. There was little change in the rate of chemical weathering or in the chemical composition of the water in Cane Branch from 1962 to 1966. Water in Helton Branch, which was not affected by mining, remained relatively unmineralized and had a near-neutral pH throughout the study period.

During the period 1957–62, Cane Branch transported a net dissolved-solids load of approximately 1,370 tons per square mile of drainage area, as compared with about 111 tons per square mile transported by Helton Branch. Thus, the rate of chemical degradation in the Cane Branch study area was about 12 times faster than that in the Helton Branch study area. During the same period, the spoil banks alone contributed a net dissolved-solids load of approximately 14,000 tons per square mile. This represented a rate of chemical degradation of the spoil banks that was about 126 times the rate for the unmined Helton Branch area.

As acid water from the Cane Branch study area moves downstream, it is diluted and neutralized by inflow from streams containing bicarbonate alkalinity. The effects of the mine drainage are almost undetectable in Beaver Creek, 3 miles downstream from the mined area.

Sediment yields from the strip-mined areas have been exceedingly high. Slow, natural revegetation has not been sufficient to reduce the rate of weathering and erosion of the spoil material, and the spoil banks have continued to be the predominant source of sediment in the Cane Branch basin. Both sheet erosion and gully erosion were active on the spoil banks. Large gullies eroded into the steep outer edges of the spoil banks were the source of much of the material removed. From 1958 to 1966, the top of the southwest spoil bank was lowered 0.3 foot by sheet erosion. Part of the spoil bank, whose steep outer slope was rilled and partly terraced, was eroded at an average annual rate of 14.8 cubic yards per acre, while in an area drained by a large gully, the annual rate of erosion was 159 cubic yards per acre. Gully erosion in the spoil banks has increased with time, whereas sheet erosion has decreased with time.

Much of the sediment that was eroded from the spoil banks by surface runoff was transported into Cane Branch and greatly increased the sediment concentrations and sediment discharges of that stream. Sediment concentrations in Cane Branch during the study period commonly exceeded 30,000 ppm (parts per million) during storms, whereas the maximum concentration was only 553 ppm in 2½ years of record at Helton Branch. The annual sediment yield from areas not affected by mining averaged about 25 tons per square mile compared with an average of more than 1,900 tons per square mile for Cane Branch during the 4 years following cessation of mining, 1959–62. The average annual sediment yield from the spoil banks was about 27,000 tons per square mile during this period, more than a thousand times greater than the yield from undisturbed areas. Most of the sediment is transported by Cane Branch during intense storms in the warm months, whereas most of the dissolved-solids load is transported in the winter.

Significant changes occurred in the sediment discharge of Cane Branch as additional parts of the basin were strip mined. In the spring of 1956, sediment concentrations due to direct runoff from summer storms averaged nearly 4,800 ppm. Sediment concentrations in direct runoff remained at that level until shortly after strip mining began on the northeast side of the basin in 1958. This new strip mining caused an increase in the amount of sediment transported by Cane Branch in the summer of 1959, and the mean concentration of direct runoff from summer storms averaged 19,900 ppm. By the summer of 1960, mining had ceased, and average concentrations from summer storms had decreased to about 5,600 ppm. Sediment concentrations remained at that level through 1966. Further reductions in sediment concentrations and loads in Cane Branch are not likely to occur until revegetation of the spoil banks is sufficient to reduce the rate of weathering and to protect the banks from erosion.

Some of the sediment eroded from the spoil banks has been deposited in pools and on the flood plain of Cane Branch. These deposits vary in thickness from a few inches to more than 2 feet. Prior to 1959, they consisted primarily of silt- and clay-size particles, but deposits formed since 1959 contain a somewhat higher percentage of sand-size particles. Sediment deposits resulting from spoil-bank erosion have been observed in Hughes Fork, downstream from the mouth of Cane Branch.

Acid water and heavy sediment loads originating in the strip-mined areas of the Cane Branch basin have caused a decrease in the variety and abundance of invertebrate bottom fauna in Cane Branch and in Hughes Fork downstream from Cane Branch. Both the total population and the number of orders of benthic organisms are markedly less in the two streams than in streams that were unaffected by mining.

Cane Branch supported an average of only 30 benthic organisms per square foot of riffle during the 1959–65 period. Larvae of mayflies and caddis flies, the primary food for most small stream fish, were almost entirely absent. The population of organisms was somewhat higher in Hughes Fork, below Cane Branch, averaging 48 per square foot of riffle. In Helton Branch and Little Hurricane Fork, which are unaffected by mining, the populations averaged 178 and 211 organisms per square foot, respectively.

The only change in fauna that indicated a trend toward recovery from the conditions created by the strip mining was a noticeable increase in the number of caddis-fly larvae in Hughes Fork in 1964. This increase was accompanied by greater algal growth on the stream bottom and reestablishment of *Dianthra,* a higher form of aquatic vegetation, along the edge of the stream.

Alternate deposition and erosion of sediment and the killing of aquatic vegetation by acid water have resulted in an unstable stream substrate. Aquatic life will not return to these streams until the stream habitat has been restored. During the 6-year period following cessation of mining, no repopulation of aquatic fauna was observed in Cane Branch, and only limited repopulation was observed in Hughes Fork.

Both the total population and the number of species of fish are less in streams in the Beaver Creek basin that receive acid mine drainage than in streams that do not receive acid mine drainage. There are no fish in Cane Branch and only small seasonal populations in the most downstream portion of Hughes Fork. Fish production in streams that do not receive acid mine drainage ranges from 5 to 370 pounds per acre and consists primarily of creek chubs and darters.

The pH of Cane Branch water, commonly 3 to 4, is lethal to fish. The pH of water in Hughes Fork downstream from Cane Branch ranges from 5 to 6 and should not be toxic to fish. The meager fish population in Hughes Fork may be due to the limited availability of bottom organisms that serve as food for the fish.

Differences in chemical composition between Cane Branch and Helton Branch have produced differences in their microflora. The acid-producing bacterium *Ferrobacillus ferrooxidans* is prominent in Cane Branch but of minor importance in Helton Branch. The reverse is true concerning the saprophytic bacteria. Filamentous fungi are more numerous and diversified in Cane Branch than in Helton Branch, and the yeast *Rhodotorula* and the alga *Bumilleria,* both of which appear to be associated with acid conditions, occur only in Cane Branch.

A study of tree growth suggested the possibility of a detrimental effect of mine drainage on growth rate. Natural reforestation of the southwest spoil bank was much less advanced in 1964 than was natural reforestation of adjacent farmland abandoned just prior to strip mining in the area, possibly because of toxic minerals in the spoil.

INTRODUCTION

Strip mining of coal has altered natural processes and affected natural resources in many places in the Cumberland Mountains of southeastern Kentucky. Strip mining in the previously undisturbed basin of Cane Branch, a small stream in the Beaver Creek basin of McCreary County, Ky., afforded an opportunity to document some of these effects. A study by several Federal and State agencies was begun in the Cane Branch basin in 1955.

The nearby basins of Helton Branch and West Fork Cane Branch were studied also. No mining was done in the Helton Branch area, and only minor prospecting was done in the West Fork Cane Branch area. The natural conditions in these two areas were contrasted with conditions resulting from mining in the Cane Branch study area.

The objective of the investigation was to document the effects of strip mining on the hydrologic environment of the study area. No attempt has been made to judge the effects of mining as either beneficial or detrimental to the environment or man. The data and interpretations resulting from the study pertain only to the specific area studied and do not necessarily apply to all strip-mined areas. However, many of the principles and processes defined in the study are applicable to other areas with a similar environment.

Only summary tables and special tables have been included with the text of this report. Tables of supplemental data are given at the end of the report. Basic data collected in the course of the study are too detailed and voluminous to be reported here. Data on streamflow, precipitation, and chemical and physical quality of water are contained in annual reports of the U.S. Geological Survey. Specific references are given in the body of this report. Unpublished data on other phases of the study are on file in the offices of the agencies responsible for that particular phase. The physical characteristics of the Beaver Creek basin and the results of the study during the period 1955–59 have been described in two earlier reports of this series (Musser, 1963; Collier and others, 1964).

ACKNOWLEDGMENTS

The study was conceived by Donald E. Whelan, U.S. Forest Service, whose efforts were also instrumental in organizing the investigation. Much of the early planning was done by personnel of the U.S. Forest Service as part of an effort to obtain factual data on which to base a policy in relation to strip mining on National Forest lands. As the broad scope of the problem became evident other agencies were asked to participate in the study, and the interagency Beaver Creek Work Group Committee was formed to direct and coordinate the study. E. L. Hendricks, chief hydrologist, U.S. Geological Survey, served as chairman of the committee.

Agencies that participated in the study include: U.S. Forest Service; U.S. Army Corps of Engineers; U.S. Bureau of Sport Fisheries and Wild life; U.S. Soil Conservation Service; U.S. Bureau of Mines; U.S. Geological Survey; Ohio River Valley Water Sanitation Commission; Kentucky Department of Commerce; Kentucky Department of Fish and Wildlife Resources; University of Kentucky, Department of Microbiology and Kentucky Geological Survey; Kentucky Strip Mining and Reclamation Commission; Kentucky Division of Water; and Kentucky Water Pollution Control Commission.

The study required the services of many consultants who advised and participated in planning, development, and operations. Consultants for the U.S. Geological Survey, Water Resources Division, during the period 1959–66 included P. C. Benedict, L. M. Brush, Jr., R. W. Carter, and Thomas Maddock, Jr.

In field studies conducted by U.S. Geological Survey personnel during the period 1959–66, G. W. Whetstone, C. R. Collier, J. J. Musser, and R. J. Pickering were responsible for geochemical and sedimentation studies; F. F. Schrader, N. O. Thomas, J. A. McCabe, and C. H. Minehan conducted streamflow and precipitation surveys; R. V. Cushman, H. T. Hopkins, D. S. Mull, and D. V. Whitesides made ground-water studies; and R. S. Sigafoos and R. L. Phipps investigated the effects of mining on tree growth.

For the U.S. Forest Service, R. F. Collins, forest supervisor, Daniel Boone National Forest, was active in organization of the project and provided support and guidance. N. R. Tripp, E. A. Johnson, R. A. Tobiaski, R. F. May, G. L. Varney, and M. J. Williamson assisted in planning and coordinating the investigations. Acknowledgment is also due U.S. Forest Service staffs at Winchester and Berea, Ky., for their contributions to the study, and particularly the district rangers for their continued assistance in the field.

Braden Pillow, M. A. Smith, and J. R. Sheridan, U.S. Bureau of Sport Fisheries and Wildlife, made fish population surveys of streams in the Beaver Creek basin.

J. W. Roehl, A. B. Rogers, L. M. Lackey, J. D. Alexander, and A. S. Johnson, U. S. Soil Conservation Service, conducted the surveys of soils and changes in vegetal cover and served as consultants to the project.

Other Federal agency consultants on the project from 1959 to 1966 included the following: H. J. Blazek, U.S. Army Corps of Engineers; J. J. Dowd, W. T. Boyd, and A. H. Reed, Jr., U.S. Bureau of Mines; H. O. Boles, U.S. Bureau of Sport Fisheries and Wildlife; J. W. Beverage, J. A. Curry, James Smallshaw, A. A. Foster, and E. H. Lesesne, Tennessee Valley Authority.

B. T. Carter and J. P. Henley, Kentucky Department of Fish and Wildlife Resources, conducted studies of bottom fauna in streams in the Beaver Creek basin. H. D. Nash and R. H. Weaver, University of Kentucky, studied the microscopic flora and fauna of the streams.

Consultants for the Commonwealth of Kentucky included W. W. Hagan, Preston McGrain, J. M. Stapleton, Robert Montgomery, E. C. Grimm, R.W. Smith, and W. W. Smither.

Others advising the Work Group Committee on specific studies were J. M. Crowl and C. K. Spurlock, Kentucky Reclamation Association, and S.A. Braley, Mellon Institute.

PRECIPITATION AND RUNOFF

By J. A. McCabe, U.S. Geological Survey

INTRODUCTION

The objectives of this phase of the study were to determine the runoff characteristics of Cane Branch and Helton Branch basins and to relate any observed differences between the two basins to differences in their exposure to strip mining. The drainage basin of Cane Branch includes strip-mined areas, whereas the drainage basin of Helton Branch has not been disturbed by strip mining.

Data on precipitation and runoff in the project study areas during water years 1956–58 were reported by Nathan O. Thomas (in Collier and others, 1964, p. B4–B19). Data collected during the period 1959–66 are included in "Supplemental Data" in the present report. Data for both periods were used in making the comparisons of streamflow and watershed characteristics that are described in the following pages.

INSTRUMENTATION

Two stream-gaging stations with dependent-type tipping-bucket rain gages, one partial-record station, and four recording precipitation stations were continued in operation from the earlier phase of the investigation. The water-stage recorder at the West Fork Cane Branch station was removed in October 1961, and the two recording precipitation stations in the same basin were discontinued in November 1961. A crest-stage indicator was continued in operation at the West Fork Cane Branch station. The locations of all data-collection points are shown on plates 1 and 2.

DATA AVAILABLE

Records of daily mean flow at the gaging stations, Cane Branch near Parkers Lake and Helton Branch at Greenwood, were published by the U.S. Geological Survey in its Water-Supply Paper series (1957–60) and in its series of annual State reports (1961–66) and are not given herein. Monthly values of runoff and precipitation are given in tables 22, 23, and 24 for the water years 1959–66. (See "Supplemental Data.") Comparable data prior to the 1959 water year were given by Thomas (in Collier and others, 1964, p. B5–B6).

Maximum precipitation amounts recorded in Cane and Helton Branch basins since the 1958 water year are listed in table 25. Storms are listed when the storm precipitation exceeded 2 inches at one of the four recording precipitation stations.

RUNOFF CHARACTERISTICS

The average runoff for the period of record and the distribution of average monthly runoff are shown in figure 1 for the basins of Cane Branch, Helton Branch, and Pitman Creek, which is about

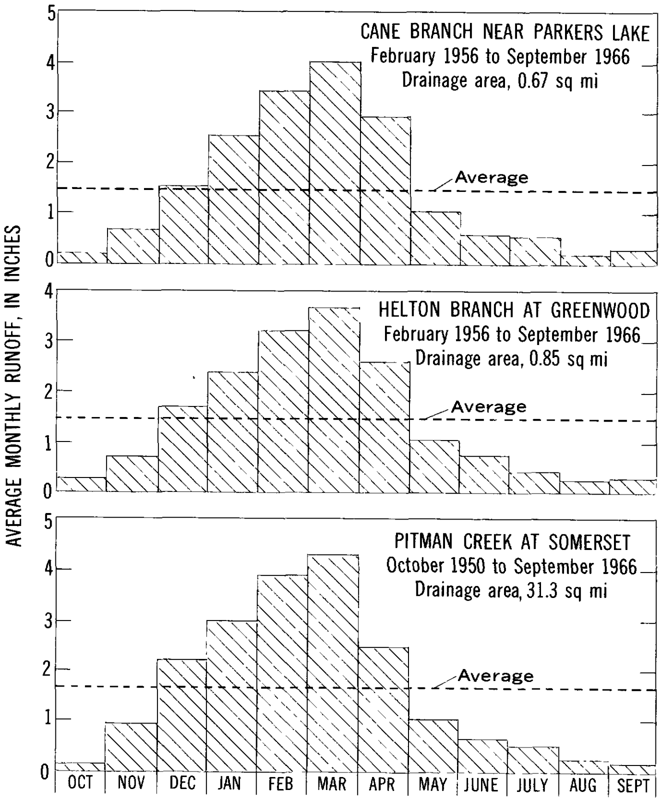

FIGURE 1.—Average runoff for the period of record and distribution of average monthly runoff for the basins of Cane Branch, Helton Branch, and Pitman Creek.

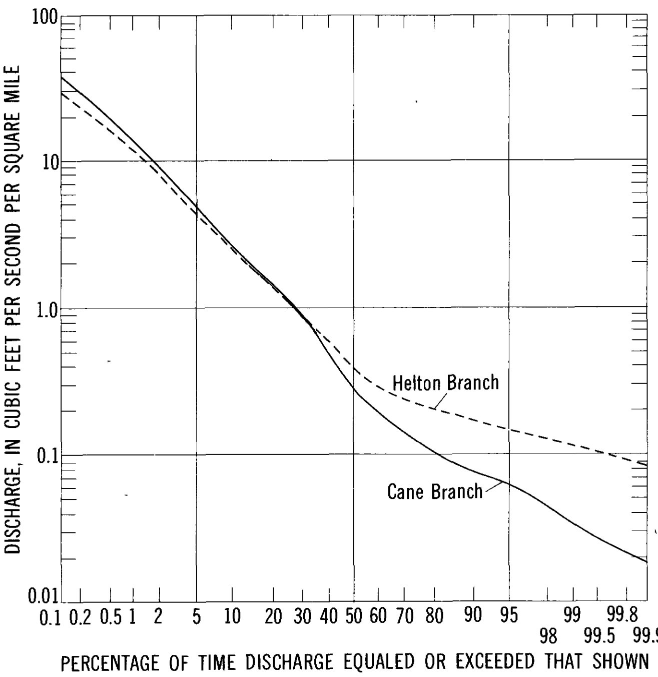

FIGURE 2.—Flow-duration curves, Cane and Helton Branches, water years 1957–66.

25 miles northwest of the study area and for which a longer streamflow record is available. A comparison of these runoff characteristics for Helton Branch with those for Pitman Creek indicates a gross similarity between the two basins. This gross similarity suggests that the Helton Branch basin is representative of natural runoff conditions in that general region of Kentucky and is thus an acceptable basin for use in detecting the effects of mining on the Cane Branch basin.

A comparison of these same runoff characteristics for the Cane Branch basin with those for the Helton Branch basin indicates a gross similarity between those basins also, and thus implies that mining has produced no detectable gross changes in the runoff characteristics of the Cane Branch basin. The results of more detailed comparisons of the two basins using other runoff characteristics are discussed in the following sections.

FLOW DURATION AND VARIABILITY

A comparison of the variability in runoff of Cane Branch and Helton Branch basins is shown in figure 2 by flow duration curves. These curves are cumulative frequency curves that show the percentage of time during which specific discharges were equaled or exceeded, without regard to sequence of flow.

The flood flows per square mile of drainage area in Cane Branch exceed the flood flows in Helton Branch for corresponding frequencies. However, during dry weather, Helton Branch has considerably greater flow per square mile than Cane Branch. This relationship is shown by the lesser slope of the duration curve for Helton Branch at low discharges and indicates that the Helton Branch basin has greater ground-water storage. Seepage of this ground water into Helton Branch sustains the flow of the stream during periods of dry weather.

PEAK DISCHARGES

Peak discharges in excess of specified bases for the period of record are listed for Cane and Helton Branches in tables 26 and 27; and annual maximum discharges for each water year are listed for West Fork Cane Branch, a small tributary to Cane Branch, in table 28.

The annual maximum discharges for the three stations were analyzed by the annual flood method (Dalrymple, 1960). Plotting positions were compiled using the equation $T = \frac{n+1}{m}$, where T is the recurrence interval, in years; n is the number of years of record (10 for this period of record); and m is the magnitude of the flood (the highest was 1 and lowest was 10 for this period of record). The recurrence interval for each flood at each of the three stations was plotted against the discharge of the flood, in cubic feet per second per square mile, and smooth curves were fitted by eye to the plots for each of the stations (fig. 3). For a given recurrence interval and on a square mile basis, floods in Cane Branch are greater than floods in Helton Branch.

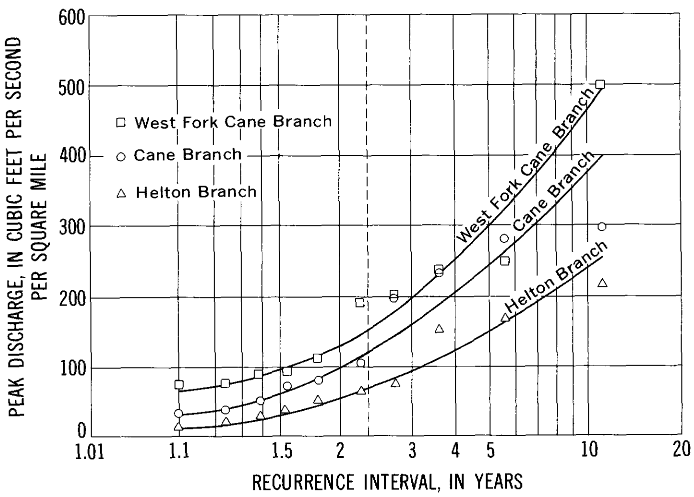

FIGURE 3.—Frequency of annual floods, water years 1957–66.

Data for West Fork Cane Branch indicate higher floods on a square mile basis than in either Cane or Helton branches. This diffference is probably attributable to the large difference in size between the West Fork Cane Branch basin and the other two basins—0.26 square mile as compared with 0.67 and 0.85 square mile for Cane and Helton Branches, respectively.

Time intervals from the beginning of flood rises to the peaks of the floods were determined by Thomas for Cane and Helton Branches for the 1958–59 period. He found that the lag at Cane Branch was about 1 hour and 10 minutes less than at Helton Branch. The additional years of record since the 1959 water year have not changed this average difference. Thus, it appears that the 1959 mining in the northeastern part of the Cane Branch basin had no measurable effect on the rate at which flood peaks moved downstream.

MONTHLY RUNOFF

A comparison of concurrent monthly runoffs between Cane Branch and Helton Branch during water years 1959–66 is shown by the solid line in figure 4. The dashed line in figure 4 is the equal yield line. Points plotted below this line represent months in which the runoff per square mile of Helton Branch exceeded that of Cane Branch, and points plotted above the line represent months in which the runoff per square mile of Cane Branch exceeded that of Helton Branch. The relationship shown by the solid line is similar to that shown by the duration curves in figure 2, where runoff of Cane Branch exceeded that of Helton Branch for the higher flows, and the reverse was true for the lower flows.

CORRELATION ANALYSES

Runoff from Cane Branch was correlated with runoff from Helton Branch using (1) mean runoff for each 6-month period ending April 30 for the period of record, (2) mean runoff for each 6-month period ending October 31 for the period of record, and (3) mean runoff for each water year for the period of record. Also correlated were 7-day annual minimum flows and 30-day annual minimum flows at the two stations for corresponding years.

Coefficients for the first three correlations were above 0.90, but coefficients for the last two correlations, which were not for truly concurrent periods, were considerably less.

In order to examine the accumulated data for evidence of a progressive change with time in the runoff relationship between the two basins, the same correlations were repeated with the addition of a term to allow for a constant change in the characteristics of Cane Branch with time. Introduction of this time factor did not improve the correlations. These results suggest that the runoff relationship between the two basins changed very little during the 11-year study period.

Similar correlations of Cane Branch runoff with precipitation for the 6-month periods ending April 30 and October 31 and for the water years were not improved by adding a time factor either, thus supporting the conclusion that there has been no detectable progressive change in runoff characteristics for Cane Branch basin since 1956, when the first period of mining ended.

ANNUAL SUMMARIES OF PRECIPITATION AND RUNOFF

Table 1 contains annual summaries of precipitation, runoff, changes in base-flow storage, and computed evapotranspiration for Cane Branch and Helton Branch basins for the period of record. Annual values of precipitation and runoff were taken

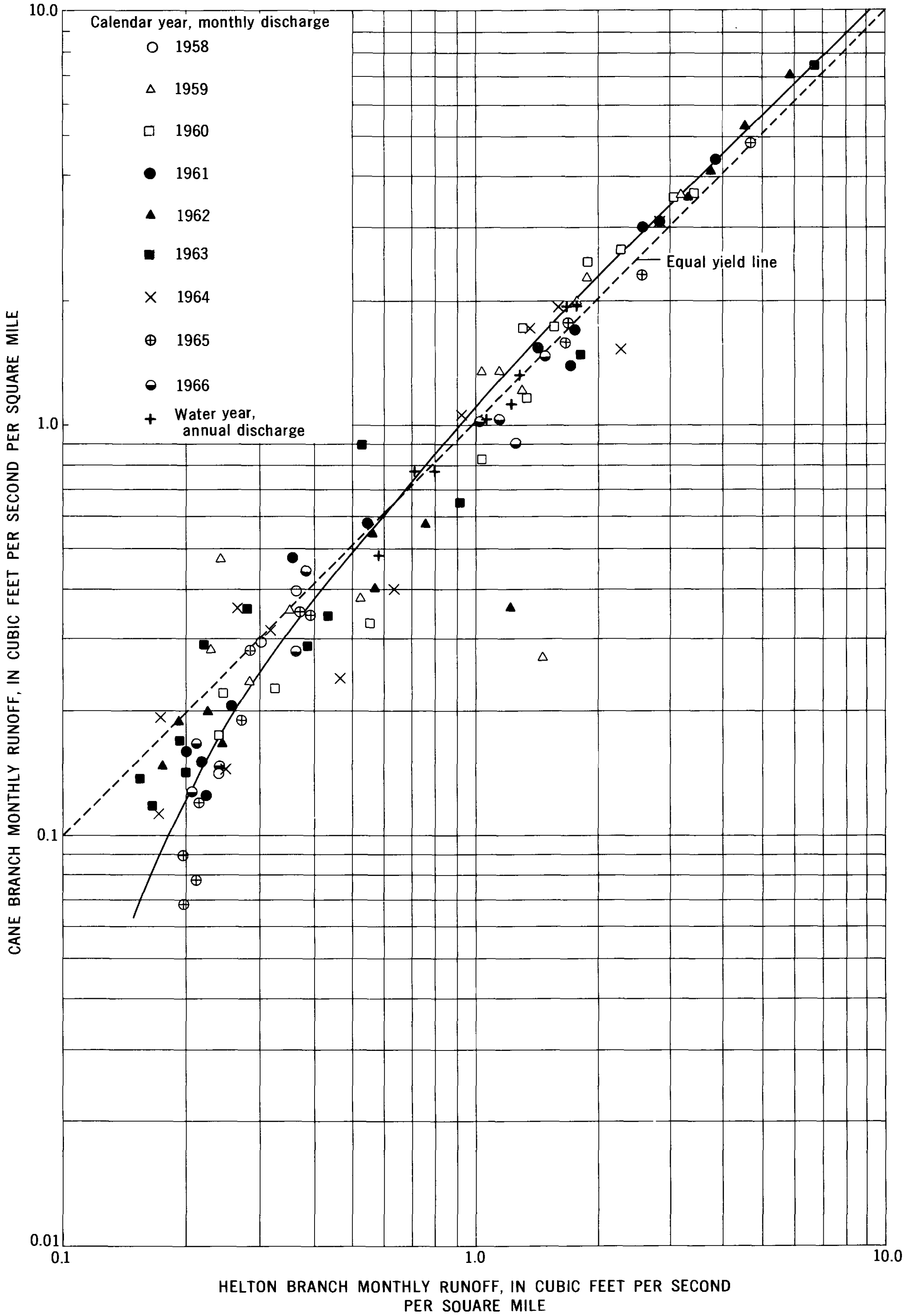

FIGURE 4.—Comparison of concurrent monthly runoffs, Cane and Helton Branches, October 1958 to September 1966.

from tables 22, 23, and 24. Changes in base-flow storage were chosen from figure 10 in Collier and others (1964) using the daily discharge on the last day of the indicated water year. Thomas developed this relationship between base-flow discharge and storage on the basis of records for the period January 1956 to September 1958. Additional records collected for water years 1959–66 showed no change in the relationship.

Except for the period March to September 1956, the change in storage for each water year is minor. This is to be expected, as the water year ends during the low-water season.

Evapotranspiration was computed from precipitation, runoff, and change in storage. For each basin, runoff is approximately 40 percent of the precipitation, and evapotranspiration is approximately 60 percent of the precipitation. There was slightly more precipitation, runoff, and evapotranspiration for Cane Branch than for Helton Branch.

TABLE 1.—*Summary of annual precipitation, runoff, change in ground-water storage contributing to base flow, and evapotranspiration*

[All values are in inches]

Water year	Cane Branch basin				Helton Branch basin			
	Precipitation	Runoff	Change in storage [1]	Evapotranspiration	Precipitation	Runoff	Change in storage [1]	Evapotranspiration
1956 [2]	27.98	10.11	−0.41	18.28	27.18	9.16	−0.77	18.79
1957	56.19	21.57	+ .04	34.58	55.75	20.61	+ .09	35.05
1958	52.00	23.04	0	28.96	51.92	22.57	+ .01	29.34
1959	41.85	10.40	− .05	31.50	38.83	10.85	− .02	28.00
1960	55.18	25.76	0	29.42	52.33	22.67	− .02	29.68
1961	43.14	18.03	− .02	25.13	39.38	17.75	+ .02	21.61
1962	56.43	25.80	+ .02	30.61	54.44	24.40	− .06	30.10
1963	44.73	14.76	0	29.97	38.81	14.59	0	24.22
1964	37.02	10.54	+ .08	26.40	37.48	9.64	+ .35	27.49
1965	45.76	15.86	− .10	30.00	40.94	17.60	− .33	23.67
1966	39.54	6.71	+ .16	32.67	34.25	7.87	+ .12	26.26
Total	499.82	182.58	−.28	317.52	471.31	177.71	− .61	294.21

[1] Change in ground-water storage contributing to base flow.
[2] Period March to September.

CONCLUSIONS

A hydrologic analysis of precipitation and streamflow records for Cane Branch and Helton Branch basins for water years 1956–66 indicated measurable differences in runoff characteristics between the two basins, despite the fact that similar percentages of annual precipitation go to runoff and evapotranspiration in each basin. Application of both flow-duration and annual-flood methods to analysis of stream hydrographs indicated that Cane Branch has greater peak flows per square mile of drainage area and more rapid changes in discharge, but Helton Branch has greater base flows. However, an examination of the hydrologic data for progressive change in runoff characteristics of Cane Branch that could be related to the history of mining in the area failed to indicate any such change.

GROUND WATER

By H. T. Hopkins and D. S. Mull, U.S. Geological Survey

METHODS OF STUDY

Investigation of ground water in the southwest spoil bank and the adjacent bedrock ridge was begun in 1958. The purpose of the investigation was to determine the effects of mining on the occurrence, movement, and quality of ground water in the Cane Branch study area. Ground water in the essentially unmined West Fork Cane Branch study area was also investigated to provide a basis for comparison. Results of the investigations during the period 1958–59 were reported by William E. Price, Jr., (in Collier and others, 1964, p. B19–B24).

During the period November 1959 through September 1966, water-level measurements were continued in the Cane Branch and West Fork Cane Branch study areas. In the Cane Branch study area, the observation sites included one water well and one coal-test hole in the bedrock and 14 auger holes in the southwest spoil bank. In the West Fork Cane Branch area, five coal-test holes in the bedrock served as observation sites. Water samples were collected periodically at most of these sites for chemical analysis. The observation sites are numbered consecutively from 1 to 21; their locations are shown on plate 1.

Continuous water-level recorders were operated in the Cane Branch area on water well 12, coal-test hole 16, and auger hole 5. All other observation sites were measured monthly by hand tape. Staff gages were installed and read monthly in pools 3, 9, and 11 on the southwest spoil bank. After May 1963, measurements were discontinued at the five coal-test holes in the West Fork Cane Branch area and at auger holes 13 to 15 and pools 9 and 11 in the Cane Branch area. Thus, with one exception, observations were continued through September 1966 at auger holes 1 to 11 and pool 3 on the southwest spoil bank, at coal-test hole 16 on the nearby ridge, and at water well 12. The exception is auger hole 1 which was destroyed in January 1966. Intermittent observations were made on discharge from the spoil bank.

To ascertain the reliability of the hydrologic data, sensitivity tests were conducted in auger holes 1 to 10 in June 1963. Water levels were lowered by withdrawing approximately 20 ounces of water from each well. At auger hole 5, a 6-inch diameter hole, approximately 0.5 gallon was withdrawn. The following table lists the auger holes and the corresponding period of time required for water levels to return to static level.

Auger hole	*Time, in minutes, for water level to return to static level*
1	17
2	1,300+ (0.9 days)
3	92
4	7,000+ (4.8 days)
5	17
6	175
7	226
8	350
9	180
10	150

The above data show that only two observation points, auger holes 2 and 4, have a poor hydraulic connection with spoil at the base of the pile, where most of the horizontal movement of water in the spoil bank takes place.

GROUND-WATER HYDROLOGY

No strip mining occurred on the southwest side of Cane Branch during the period 1958–66, and, therefore, the conditions observed were of the change in the ground-water environment following earlier strip mining. Little overall change from the 1958–59 conditions was observed during the 1959–66 period. Apparently, ground water in the spoil bank attained equilibrium with its environment prior to the beginning of the investigation in 1958.

In bedrock areas, the shallow ground water is recharged by precipitation and moves from topographically high areas to streams. Ground water in the southwest spoil bank also is recharged from precipitation, both by direct infiltration and by seepage after collection in pools along the western and southern margins of the spoil bank. A small amount of the recharge is indirect recharge moving from the bedrock of the ridge to the adjacent pools and then into the spoil bank. Pools 3 to 5 (plate 1) are essentially hydrologic links between the spoil bank and the adjacent ridge. These pools receive continuous ground-water runoff from the ridge, as well as overland runoff following precipitation. Ground water moves from the pools toward the center of the spoil pile (see fig. 8) and discharges to the southeast into tributaries draining the spoil-bank area.

Seasonal variations in recharge were recorded by fluctuations in the water levels in all observation wells. The seasonal trends during 1959–66 generally continued the trends recorded during the early part of the investigation. The hydrograph of the water level in auger hole 5, shown in figure 5, is typical of the hydrographs of most of the wells, although the range in fluctuation of the water level in the spoil bank is much less than the 5- to 29-foot range in the coal-test holes on the ridges. The greater range in fluctuation of the water table in the bedrock ridges is probably due to a combination of (1) more rapid recharge by direct infiltration, as a result of the much higher permeability of the unsaturated jointed bedrock as compared with spoil, and (2) transpiration by heavy forest growth, which contrasts with the widely scattered small pine trees that have become established on the spoil bank in the vicinity of the observation wells.

The generally lower elevation of the water level in auger hole 5 during the period 1963–66 as compared with that during the period 1959–62 reflects (1) the lesser amount of precipitation that fell during the later period, as shown on a water year basis in the following table, and (2) possible deepenof gullies in the spoil bank and increased transpiration by vegetation as a result of limited natural reforestation in the vicinity of the well. Loss of

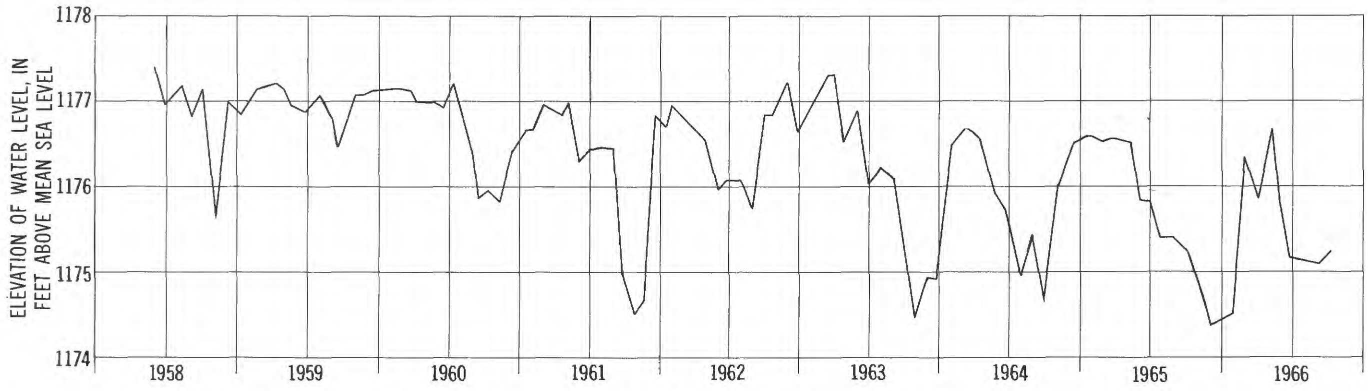

FIGURE 5.—Variations in water level in auger hole 5 on the southwest spoil bank, calendar years 1958–66.

ground-water storage as a result of this slight lowering of the water table was small.

Precipitation at gage 2, Cane Branch study area, water years 1959–66

Water Year	*Precipitation, in inches*
1959	41.03
1960	55.34
1961	43.08
1962	55.37
1963	44.28
1964	36.65
1965	45.16
1966	39.15

When compared in detail with the record of precipitation, the pattern of fluctuation shows that water levels respond to precipitation on the spoil bank within 24 hours, as shown in figures 6 and 7. The response is equally rapid in the coal-test holes in the bedrock ridges.

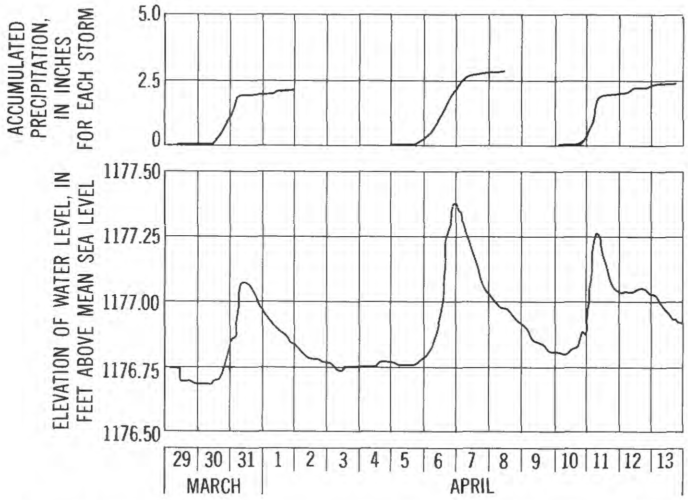

FIGURE 6.—Accumulated precipitation and variations in water level in auger hole 5, Cane Branch study area, March 29 to April 13, 1962.

The two different patterns of water-level fluctu ation in auger hole 5 that are shown in figures 6 and

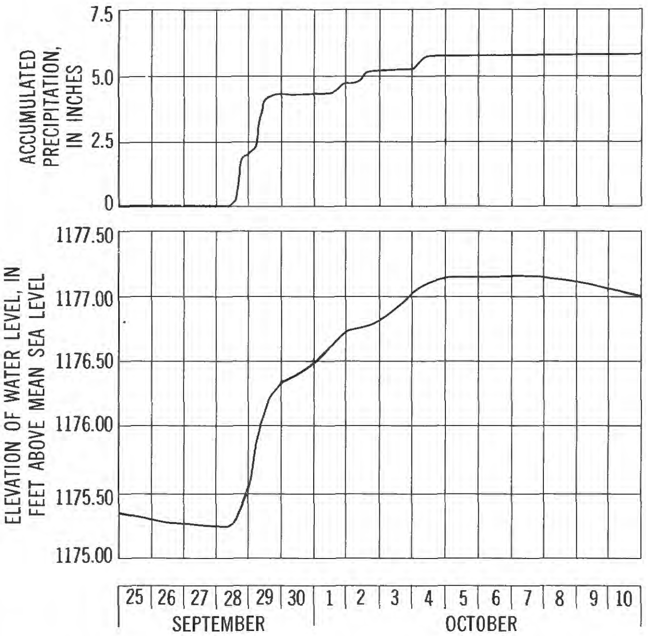

FIGURE 7.—Accumulated precipitation and variations in water level in auger hole 5, Cane Branch study area, September 25 to October 10, 1964.

7 are the result of seasonal differences in the relative amounts of recharge derived from the two major sources of recharge to ground water in the spoil bank. During the winter-spring wet season, variations in recharge (reflected by the three peaks on the graphs in figure 6) are primarily due to direct infiltration of precipitation. Ground-water levels, pool stages, and soil moisture are high at this time of year. The addition of increments of water from precipitation causes rapid rises in ground-water levels but has little effect on pool levels because they are near or at levels of overflow, and their contribution to recharge is fairly constant. The water level in auger hole 5 rises sharply and declines rapidly to near pre-storm levels (fig. 6) because it reflects only

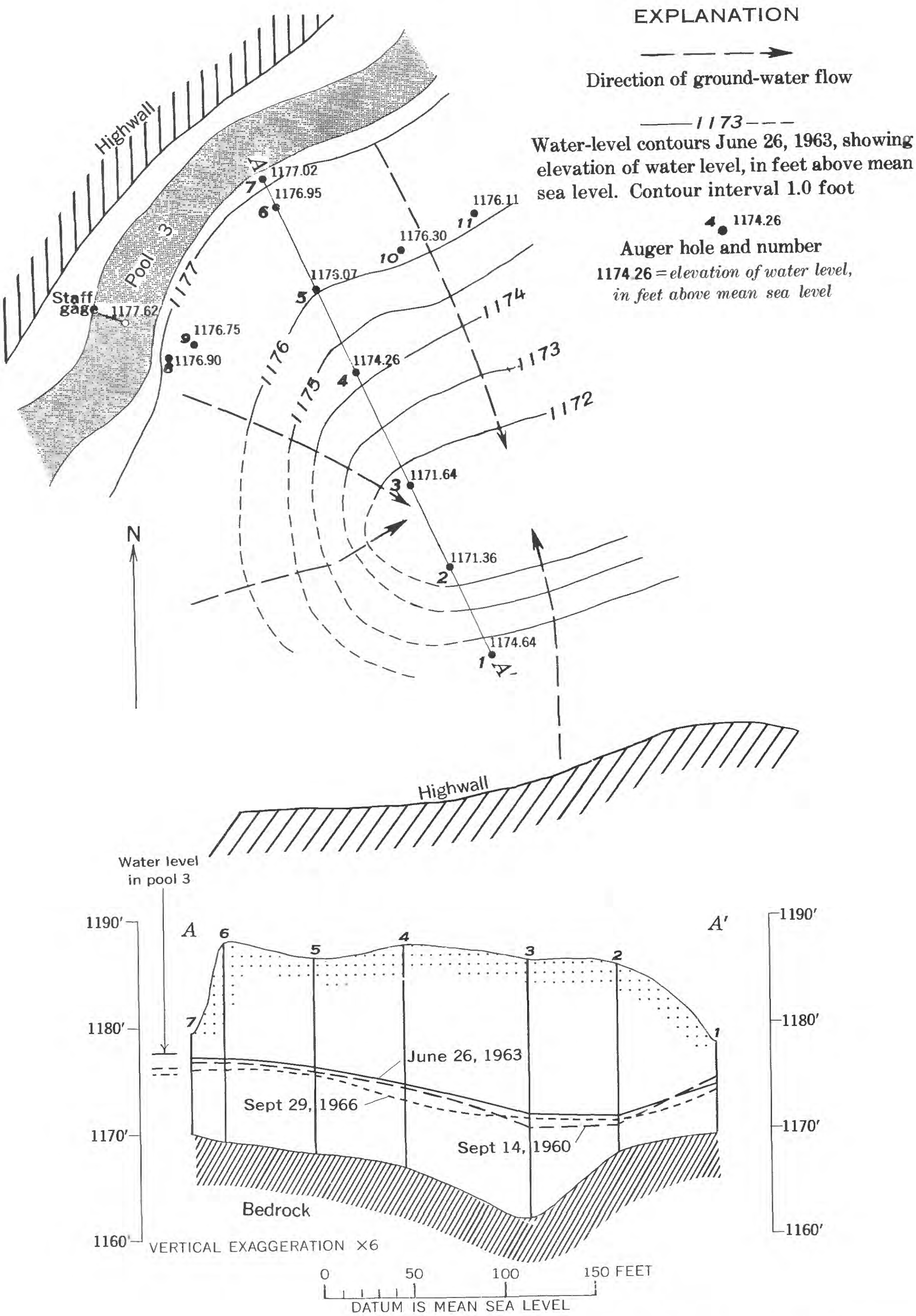

FIGURE 8.—Water-level contours, direction of water flow, and water-level profiles in the southwest spoil bank.

direct infiltration of precipitation, which ceases soon after precipitation stops.

In contrast, in the drier season of the year, the water level in auger hole 5 rises rapidly during the period of precipitation (fig. 7), then continues to rise more slowly owing to increased recharge from pool 3, whose water level has been raised by surface runoff. The water level in auger hole 5 then declines slowly as the water level in pool 3 declines, and recharge from the pool gradually decreases.

Figures 6 and 7 show that recharge from pools exerts a greater control on variations in water levels in the spoil bank during the dry season than during the wet season. In contrast to flow of water from pools into the spoil bank during the dry season, there is probably flow of ground water from the spoil bank into the pools immediately after winter or spring rains, when the water table in the spoil bank is higher than the level of water in the adjacent pools.

Profiles of the water table across the spoil bank, shown in figure 8, suggest that there has been no significant change in the configuration of the profile since observations began in the spring of 1958. The water table roughly conforms to the inferred surface of the bedrock. Thus, the lows at wells 3 and 2 and the gentle slope between wells 6 and 4 reflect corresponding elevations of the bedrock surface and the eastward slope of the bedrock channel.

The slope of the water table and the direction of movement of ground water in the southwest spoil bank also are shown in figure 8. The contours were drawn from readings taken on June 26, 1963. The probable flow pattern is shown by the dashed arrows crossing the water-level contours at right angles and converging in the trough between wells 3 and 2. The main ground-water discharge is along this trough, in a general eastward direction. This flow pattern and ground-water discharge system in the spoil pile had developed prior to the start of water-level studies in the area.

The general shape of the water table in the southwest spoil bank results principally from the local topographic situation and the location of the area of discharge or drainage. The spoil and perimeter pools occupy and fill the U-shaped upper end of a tributary valley. The spoil and pools receive recharge from the bedrock on the north, west, and south sides of the valley in addition to the precipitation directly on the pile. The water moving through this area is discharged at the lower end of the valley near the base of the southeastern part of the spoil. The water surface slopes from all areas of recharge to the area of discharge, giving rise to the U-shaped pattern shown in figure 8.

Transmissibilities of the spoil, determined by the bailer method of Skibitzke (1958) at three of the auger holes on the southwest spoil bank, ranged from 28 gpd per ft (gallons per day per foot) at auger hole 1 to 64 gpd per ft at auger hole 5. The two wells with the best hydraulic connection with the water in the spoil bank had the highest and the lowest transmissibilities measured. Extremely small transmissibilities, such as those determined at the auger holes, are believed to be representative of most of the southwest spoil bank; exceptions occur where sandy material is present in the spoil or where massive blocks of wallrock were deposited as part of the spoil material in such a way that large voids between the blocks were preserved.

In spite of the small transmissibility of the spoil, water seeping from the spoil bank continuously provides highly mineralized water to Cane Branch. This contribution is particularly significant during periods of low flow, when it constitutes a major part of the flow of Cane Branch and provides the bulk of the dissolved solids and acid loads of that stream. (See "Geochemistry of Water.")

Several seeps occur at relatively high points along the south fork of the surface drainageway that leads into the tributary on which supplemental sampling site M is located (plate 1). Another seep occurs in the north fork of the drainageway in the vicinity of pool 3. These seeps discharge only as long as ground-water storage is available above the points of seepage and, therefore, are not perennial. All perennial drainage is from near the base of the spoil immediately above the surface of the bedrock into tributaries draining the spoil bank area.

CONCLUSIONS

There has been no significant change in the occurrence and movement of ground water in the vicinity of the southwest spoil bank since the beginning of observations in the spring of 1958. Shallow ground water in bedrock is recharged by precipitation and moves from topographically high areas to streams. Ground water in the southwest spoil bank is recharged by direct infiltration of precipitation and seepage from adjacent pools, and it discharges mostly eastward into tributaries draining the spoil bank area.

Fluctuations of the water table in the spoil bank are largely controlled by direct infiltration of precipitation during the winter-spring season, but they are strongly influenced by seepage from pools adjacent to the spoil bank during the summer-autumn season. Recharge from the pools varies with water levels in the pools during the summer-autumn season, but it is fairly constant during the winter-spring season, when the pools are full most of the time.

The shape and slope of the water table in the spoil bank have not changed significantly since observations began in 1958. Although the amount of ground water in storage in bedrock areas and in the southwest spoil bank changes seasonally, there was little overall change for the period of record. However, there was indication of a small overall loss in storage for the study period, mostly the result of deficient precipitation in 1963, 1964, and 1966, but possibly due in part to deepening of gullies in the spoil bank and increased transpiration by vegetation.

GEOCHEMISTRY OF WATER

By J. J. MUSSER and R. J. PICKERING, U.S. Geological Survey

BACKGROUND AND SCOPE

One of the environmental factors most obviously influenced by strip mining in the Cane Branch basin is the chemical composition of the water. Cane Branch became an acid stream because of strip mining in the Cane Branch study area. This section of the report describes and evaluates (1) changes in the chemical composition of water in the Cane Branch study area, (2) the chemical composition of water in nearby study areas unaffect-

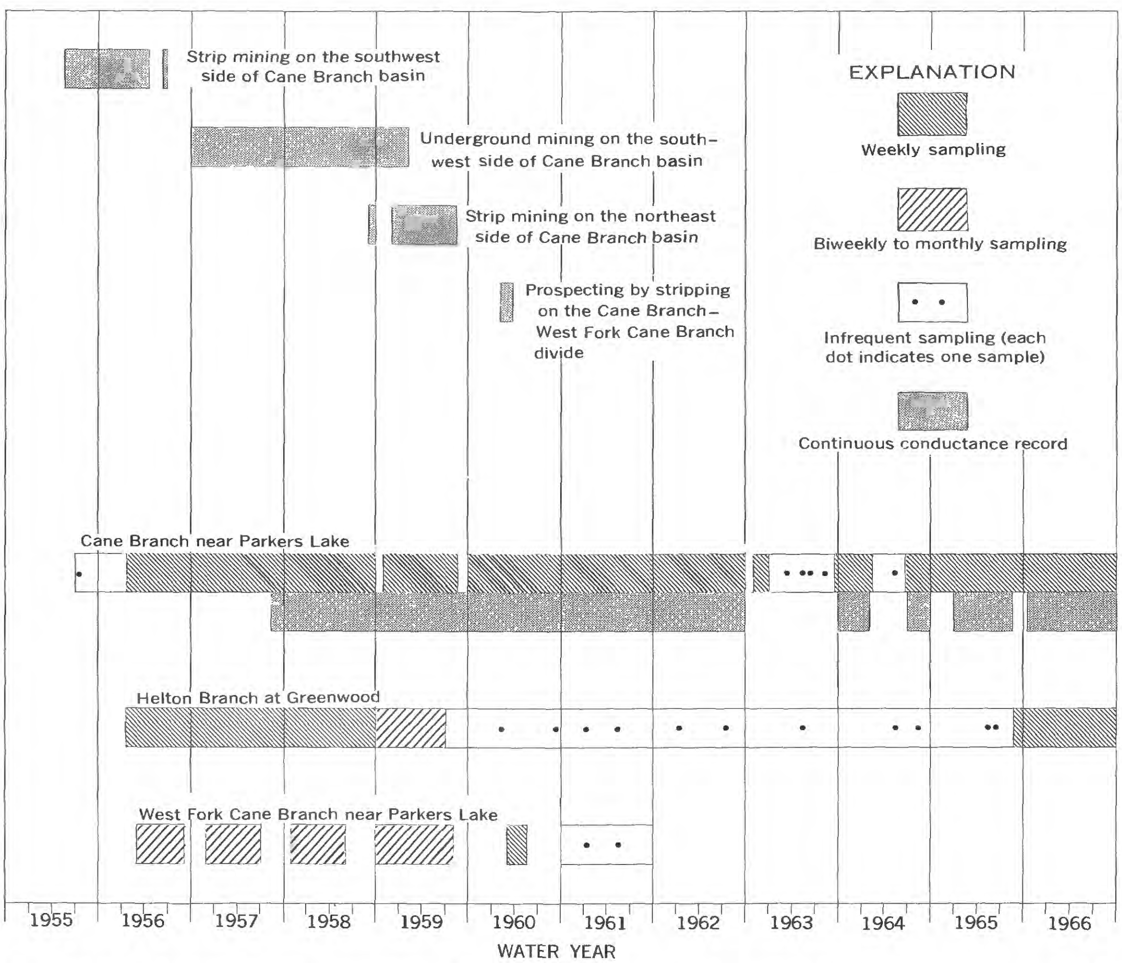

FIGURE 9.—Periods of mining activities, periods of chemical-quality records, and sampling frequencies, water years 1955–66.

ed by mining, and (3) the general persistence of acid water downstream from the Cane Branch mining area. Although the results of studies conducted during water years 1959–66 are emphasized in this report, the conclusions at the end of this section are based on the period 1955–66 in order to provide a comprehensive picture of the entire 11-year period of investigation. Results obtained during the period 1955–59 were described by John J. Musser and George W. Whetstone (in Collier and others, 1964, p. 25–48) and will be reviewed only as needed to relate earlier conditions to those existing during the period 1959–66.

The periods of record and the sampling frequencies at the three established gaging stations are shown in figure 9. An additional 190 water samples were collected from 40 other sites. The locations of many of these sampling sites are shown on plates 1 and 2 and in figures 14 and 17. Basic data on the chemical quality of water at scheduled stations during the period 1959–63 were published by the U.S. Geological Survey (1959–63) in its Water-Supply Paper series. Basic data for water years 1964–66 were published in the U.S. Geological Survey's series of annual State reports (U.S. Geological Survey, 1964–66). Only selected data for scheduled stations and data for unscheduled sampling points are included in this report.

Because the waters of Helton Branch and West Fork Cane Branch were not affected by mining, they are described first to illustrate the natural chemical quality of water in the upper Beaver Creek basin.

HELTON BRANCH

Concentrations of dissolved constituents in water in Helton Branch remained at low levels during the period 1959–65. The similarity in water quality to that in preceding years of the study reflected the constancy of the environment of the Helton Branch study area over a period of many years and is representative of the 'natural' rate of weathering; that is, the rate not greatly affected by man's activities.

The water in Helton Branch is a dilute calcium bicarbonate type in which the sulfate ion is also significant. During the period 1959–65, the dissolved-solids concentration ranged from about 15 ppm to about 50 ppm. The pH of the water ranged from 5.8 to 7.5. The dissolved-solids content included about 25 percent silica by weight, 50 percent calcium and bicarbonate, and 15 percent sulfate; other cations and anions comprised the remaining 10 percent. The water is weakly buffered; consequently, the pH is readily changed by the addition of small amounts of acidic or basic substances. Selected chemical analyses of samples collected from Helton Branch at the gaging station are given in table 2.

TABLE 2.—*Chemical analyses of selected samples from Helton Branch at Greenwood, 1958–65*

[Results in parts per million, except as indicated]

Date of collection	Instantaneous discharge (cfs)	Silica (SiO_2)	Aluminum (Al)	Iron [1] (Fe)	Manganese [1] (Mn)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Dissolved solids (residue at 180° C.)	Hardness (divalent cations as $CaCO_3$)	Specific conductance (micromhos at 25° C.)	pH
Oct. 14, 1958	0.18	---	---	---	---	9	1.4	--	--	7	20	6.6
Jan. 2, 1959	1.06	---	---	---	---	--	13	--	--	26	68	5.8
June 2	9.9	---	---	---	---	8	7.6	--	--	13	36	6.5
Feb. 9, 1960	.92	---	---	---	---	10	7.2	1.0	31	14	41	6.6
Sept. 12	.20	---	---	---	---	10	5.0	.5	--	8	22	7.2
Jan. 17, 1961	1.18	5.0	0.1	---	---	10	6.8	2.0	20	15	39	6.4
May 22	.40	---	---	---	---	11	6.2	--	26	12	29	6.8
Jan. 30, 1962	2.1	4.0	---	0.05	0.05	7	7.8	2.5	25	12	39	6.3
July 17	.14	6.1	---	.26	.02	10	1.6	1.0	22	8	28	6.8
May 26, 1963	.30	5.1	---	.08	.13	9	2.6	.5	22	8	28	6.5
May 25, 1964	.14	6.0	.1	---	---	12	2.8	1.0	20	8	24	6.9
Aug. 5	.13	---	.1	---	---	10	.4	--	--	9	19	6.6
June 22, 1965	.16	---	---	.15	.05	16	5.6	2.0	33	15	42	6.6
Sept. 26	.12	---	---	---	---	8	1.6	--	26	7	19	6.1

[1] In solution when collected.

The estimated annual total yields of dissolved solids from the Helton Branch study area during the period 1959–62 ranged from about 25 tons per square mile in drier years to nearly 60 tons per square mile in wetter years. Measured annual yields for water years 1957–58 were within the same range. On the basis of rainfall and runoff, it can be assumed that the annual yields during the

1963–65 period were in the lower part of the range for the 1959–62 period. The annual total dissolved-solids yields of the Helton Branch area, which is unaffected by mining, are ¼ to ⅛ those of the Cane Branch study area, where yields increased as a result of mining.

In August and September 1965, construction began on a highway relocation near Greenwood in the upper part of the Helton Branch basin. Extensive cut-and-fill operations in the headwaters of Helton Branch resulted not only in disturbance of the shale and sandstone bedrock and overlying soil at the relocation site, but also in the introduction of many tons of limestone fill. This construction altered the chemical and physical characteristics of water in Helton Branch to the extent that data for water year 1966 do not have relevance to this study and therefore are not included in table 2.

WEST FORK CANE BRANCH

The water of West Fork Cane Branch is a dilute magnesium and calcium sulfate and bicarbonate type with a mean dissolved-solids concentration of about 20 ppm. It is similar to that of Helton Branch in its low concentration of dissolved constituents. Selected chemical analyses of samples collected from West Fork Cane Branch are given in table 3.

TABLE 3.—*Chemical analyses of selected samples from West Fork Cane Branch near Parkers Lake, 1957–61*

[Results in parts per million, except as indicated]

Date of collection	Instantaneous discharge (cfs)	Aluminum (Al)	Iron [1] (Fe)	Manganese [1] (Mn)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Dissolved-solids (residue at 180° C.)	Hardness (divalent cations as $CaCO_3$)	Specific conductance (micromhos at 25° C.)	pH
June 6, 1957	---	---	---	---	8	5.4	--	10	33	7.0
Nov. 15, 1958	0.02	---	---	---	9	6.0	--	13	43	5.3
Mar. 26, 1959	.70	---	---	---	4	4.8	--	6	22	6.1
June 5	---	---	---	---	2	5.4	--	5	22	5.0
July 19	.32	---	---	---	3	4.0	--	3	16	5.9
Mar. 1, 1960	.70	---	0.15	0.14	4	13	--	5	23	6.1
Mar. 22	1.86	---	---	---	--	5.6	12	5	18	6.7
Mar. 29	1.02	---	---	---	--	6.8	20	5	19	6.0
Apr. 5	.54	0.1	.21	.05	8	4.4	16	5	23	6.8
Apr. 12	.16	---	---	---	--	5.6	13	6	22	7.6
Apr. 19	.16	---	---	---	--	5.6	19	6	26	6.8
May 3	.25	.1	.12	.08	8	6.8	34	6	23	6.8
Jan. 18, 1961	.34	---	---	---	3	4.8	10	7	20	6.1
May 23	.03	---	---	---	6	7.0	28	15	21	6.6

[1] In solution when collected.

During February 1960, a few coal prospect trenches were dug in the West Fork Cane Branch study area by a mining operator, and small quantities of pyrite were exposed to weathering. However, the water in West Fork Cane Branch was not affected by this activity, as shown by a lack of any significant changes in sulfate concentration during the period 1956–61. Such changes are excellent indicators of pyritic weathering products in mine drainage. The median sulfate concentration of West Fork Cane Branch was 5 ppm during the period.

The acidity of West Fork Cane Branch decreased slightly during 1960–61, as shown by a shift in the pH range from 5.0–7.0 in 1956–59 to 6.0–7.6 in 1960–61. Also, the number of samples with pH above 6.5 totaled nine in the 1960–61 period, as compared with two in the more heavily sampled 1956–59 period. Washing into the stream of limestone gravel from a road near the eastern divide of the West Fork study area may have contributed to this slight decrease in acidity, but available data are insufficient to confirm this effect.

CANE BRANCH STUDY AREA

Since the spring of 1956, the water in Cane Branch has been acid. This acid water is the result of coal mining in parts of the Cane Branch basin. During strip mining, which took place in 1955–56 and again in 1958–59, large quantities of iron disulfide minerals associated with the Barren Fork coal seam and adjacent rocks were exposed to oxidation and leaching. Surface water running over, and ground water moving through, the spoil banks and highwalls react chemically with these iron disulfide minerals and their oxidized products. Several of these reactions result in the production of acid. Because the surface water and ground water have little neutralizing capacity to counteract the effect of the acid-producing minerals, leaching results in pools and streams of highly mineralized, acid water. Water in the strip pits, in the spoil banks, in the Cane Branch tributaries draining the spoil banks, and in Cane Branch itself is affected by this acid mine drainage.

The chemical reactions believed to be involved in the formation of acid mine drainage have been discussed by many authors in recent years, including Temple and Koehler (1954), Hem (1960), Barnes and Clarke (1964), and Clark (1966). The reader is referred to these publications for detailed discussions of the subject.

POOLS NEAR SPOIL BANKS

Following the completion of mining in the Cane Branch study area, pools of water formed in the abandoned strip pits between the highwalls and spoil banks. Most of these pools now contain acid water. In the winter and spring, the pools overflow into the tributaries of Cane Branch. The water in the pools also slowly infiltrates the adjacent spoil banks. Pool locations are shown on plate 1, and chemical analyses of samples collected during the period 1960–66 are given in table 29.

Pools 1 to 11 are in the area on the southwest side of Cane Branch that was strip mined in 1955–56. With the exception of pool 10, these waters are of the calcium magnesium sulfate type, have significant quantities of aluminum, iron, and manganese, and contain free acid. In 1956–59, sulfate concentrations ranged from 52 to 3,080 ppm; in 1960–66, the range had changed to 21 to 469 ppm. For these same periods, the pH range changed from 2.50–4.10 to 2.95–4.45. Thus, the analyses for 1960–66 indicate a general decrease in the concentrations of dissolved constituents in the pools.

Pools 2, 3, and 9 show definite decreases in mineralization since the end of mining in 1956. After relatively rapid initial decreases, mineralization decreased more slowly, and since 1961 or 1962, little additional decrease has been observed. This is illustrated in figure 10, in which have been plotted the maximum measured conductances for each water year. Slumping of the overlying weathered soil and bedrock into the strip pits since their abandonment has resulted in the restriction of air and water circulation to the sulfide-bearing rocks exposed in the highwall and has probably contributed to the decrease in mineralization of water in the pools.

Pool 10 is south of the area mined during 1956, is surrounded by well-weathered rocks, receives no acid mine drainage, and therefore contains the type of water that would be present if pyrite had not

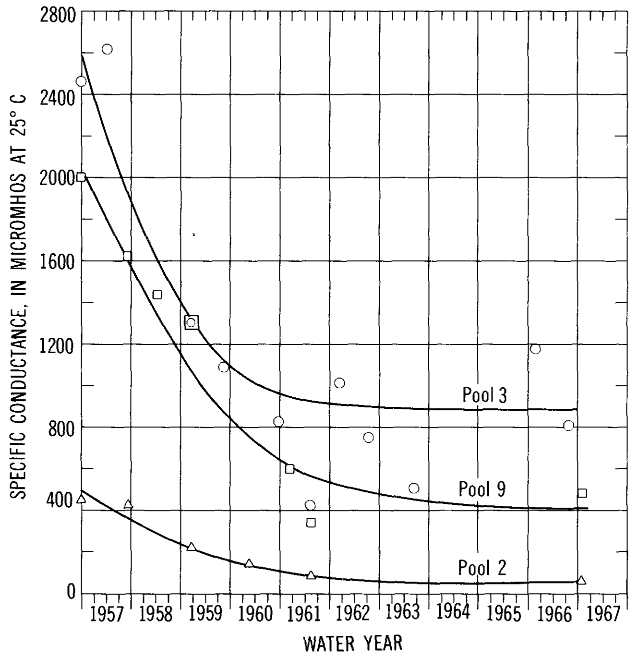

FIGURE 10.—Decrease with time in specific conductance of water in selected pools on the southwest spoil bank.

been exposed by mining. In May 1961, this pool contained dilute calcium sulfate water with a pH of 5.3. It is dry during periods of little rainfall.

Low silica concentrations in pools on the southwest spoil bank during the summer and autumn months may be due to the extraction of silica from the water by diatoms. Several of the pools contained less than 1 ppm silica in October 1966.

Pools 12 and 13 are in a small mined area on the northeast side of the Cane Branch basin. After mining, which took place in 1958, the water in pool 12 had a pH of 4.2 and contained free acid. Since early 1960, however, the pH has been about 5 and the sulfate content has decreased. Pool 13, which never was acid, apparently is not in contact with spoil containing abundant iron sulfide minerals.

Pools 14 to 19 on the northeast side of Cane Branch resulted from strip mining during 1959. The water in pools 14 to 18 became acid during and immediately following the 1959 mining. The water is of the calcium magnesium sulfate type and contains significant quantities of aluminum, iron, and manganese. Chemical analyses of samples collected in 1966 indicated little change from earlier conditions. The observed range in sulfate content during the period 1960–66 was 290–1,260 ppm, and the observed range in pH was 2.9–5.1.

Pool 19 did not increase in mineralization or become acid immediately after mining was completed in 1959, as did other nearby pools. Musser and Whetstone (in Collier and others, 1964, p.32) suggested that "the sulfide-bearing rocks are buried in a part of the spoil bank where the ground water has difficulty in flowing to pool 19," and that "soluble products from the spoil bank may eventually reach the pool and make the water in it acid." Data collected since 1959 have confirmed this prediction. Water in pool 19 became acid in early 1961, and has remained acid since that time. In addition, there has been a progressive increase in the mineralization of the pool water since 1961, as shown in table 29.

Pool 20 formed in a prospect pit on the southwest side of Cane Branch in March 1960. This pool, which contains acid water, contributes overflow to Cane Branch.

GROUND WATER

The chemical quality of ground water in the southwest spoil bank has changed little from that recorded during the earlier part of the investigation. Variations in solute concentrations are due primarily to changes in the relative amounts of recharge from three sources—direct infiltration of precipitation, pools formed between the spoil bank and the highwall, and ground water in the bedrock of adjacent ridges. Ground water in the spoil bank is more highly mineralized than either the water in the adjacent pools or the water in the bedrock. Compared with bedrock water, spoil-bank water is relatively high in sulfate, silica, aluminum, iron, manganese, calcium, and magnesium (table 30).

The concentrations of chemical constituents in ground water in the spoil bank vary from point to point. Minimum concentrations are found in the water from auger holes adjacent to the pools and along the low point in the water table between auger holes 2 and 3. (See fig. 8.) Maximum concentrations are found in the vicinity of auger hole 5.

Figure 11 shows monthly changes in the specific conductance of water in the spoil bank (auger hole 5, pl. 1), in an adjacent pool (pool 3, pl. 1), and in ground water in the bedrock of an adjacent ridge (coal-test hole 16, pl. 1), for a period of nearly 2 years. Although total precipitation for the 2-year period was exceptionally light, the conductance of water in the pool and water in the spoil bank varied in a characteristic manner.

The conductance of the water in pool 3 exhibits the effect of dilution by precipitation. Pool 3 reaches its lowest conductance during the winter-spring period, when direct runoff dilutes the highly mineralized water; the pool reaches its highest conductance during the summer-autumn period, when little direct runoff is available for dilution, and evaporation causes an increase in concentration of dissolved constituents.

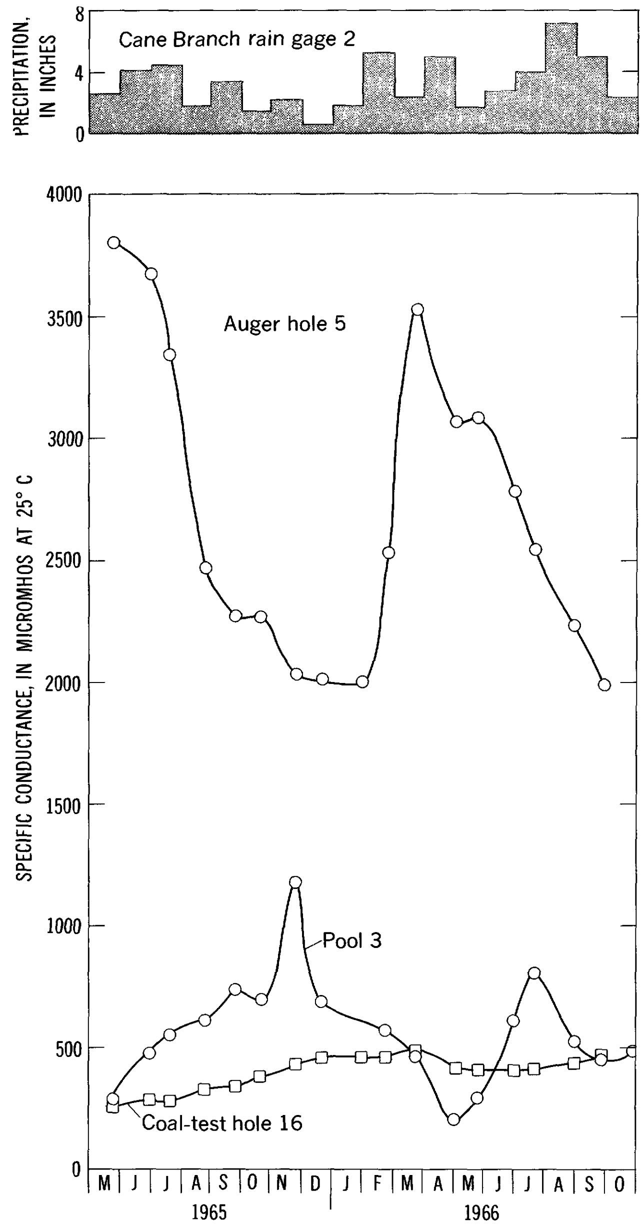

FIGURE 11.—Monthly variations in rainfall and in specific conductance of water in pool 3, auger hole 5, and coal-test hole 16, May 1965 to October 1966.

The conductance of ground water in auger hole 5 shows an opposite pattern of variation. Conductance declined during the summer and autumn, then increased during the winter. This pattern of variation can be explained on the basis of changes in the source of recharge to ground water in the spoil bank and changes in the elevation of the water table.

During the winter-spring period, direct infiltration of precipitation constitutes a significant part of the recharge to the spoil bank. In moving from the surface into the spoil material, this oxygenated water leaches highly soluble iron sulfate minerals formed through oxidation of pyrite in the zone of aeration during the previous summer and autumn and it also contributes to further oxidation of pyrite in the spoil material. In addition, the winter rise of the water table brings the main body of ground water into contact with previously aerated spoil and its content of iron sulfate minerals, resulting in some leaching below the water table.

During the period of high evaporation in the summer and autumn, the water table declines, and recharge of ground water in the spoil bank is largely by infiltration of water from the adjacent pool 3 and by movement of ground water from the nearby ridge into the spoil bank. Both sources of recharge are much less highly mineralized than the ground water in the spoil bank. Furthermore, this poorly oxygenated recharge water, flowing through less oxidized parts of the spoil bank below the water table, picks up less soluble material than does infiltrating precipitation. The net result is less highly mineralized ground water in the spoil bank during the summer and autumn than during the winter and spring.

The preceding observations indicate that the greatest additions to the chemical content of ground water in the spoil bank are derived from the zone of aeration. Nevertheless, the somewhat more dilute summer-autum recharge water becomes highly mineralized as it passes through the spoil bank, and serves to increase the dry-weather drainage from the spoil and the total contribution of acid water to Cane Branch.

The quality of ground water in coal-test hole 16, which was drilled in bedrock of the adjacent ridge, followed the pattern normally found under natural conditions during most of the study period. It was most dilute (least mineralized and had lowest conductance) during the winter-spring period, when recharge is greatest, and most mineralized during the summer-autumn period, when recharge is slight and evapotranspiration is high. However, the unusually light rainfall in the early part of 1966 caused the mineralization to remain at a higher level than would be expected during a more normal year. Figure 11 shows that the conductance rose progressively during the period May to December 1965, then remained near the November level throughout the succeeding year. Low water levels measured in coal-test hole 16 throughout water year 1966 indicate a general lack of recharge by dilute surface water, thus explaining the abnormally high conductance shown in figure 11.

The reason for the generally higher levels of sulfate and conductance in coal-test hole 16 than in coal-test holes 17, 19, 20, and 21 (fig. 12), in the nearby West Fork Cane Branch basin (pl. 1), is not known. Perhaps the rocks penetrated by hole 16 contain much more iron sulfide than do those in the West Fork basin. If this is true, then it is possible that oxidation of iron sulfide minerals occurs along the uncased walls of hole 16 during periods when low water levels expose the walls to the atmosphere, and that dissolution of the resulting sulfate minerals, as a result of water level fluctuations in the well, adds to the sulfate content and increases the mineralization of the water.

Well 12, which is just beyond the toe of the southwest spoil bank and penetrates the underlying bedrock, predates the beginning of mining in the basin. Musser and Whetstone (in Collier and others, 1964, p. 36) concluded that, as of June 1959, the quality of water in the underlying bedrock, as observed at well 12, had been only slightly affected by downward movement of mineralized ground water from the spoil bank.

Since 1959, there has been an increase in the mineralization of the bedrock water at well 12. (See table 30.) The increase is relatively minor, however, and is apparent only in the sulfate content of the well water (fig. 13). The relationship between the sulfate content and the level of water in the well is similar to that exhibited in the spoil bank at auger hole 5, thus adding support to the conclusion that increases in the sulfate content of the bedrock water are due to infiltration of water from the spoil bank.

TRIBUTARIES OF CANE BRANCH

Tributary streams carry the soluble products of chemical weathering into Cane Branch. Some of these tributaries contain only slightly mineralized water that comes from parts of the Cane Branch area not affected by mining. Other tributaries contain acid mine drainage that comes from pools and spoil banks in the mined areas. Supplemental sampling sites on tributaries to Cane Branch are shown on plate 1. Analyses of these waters are given in table 31.

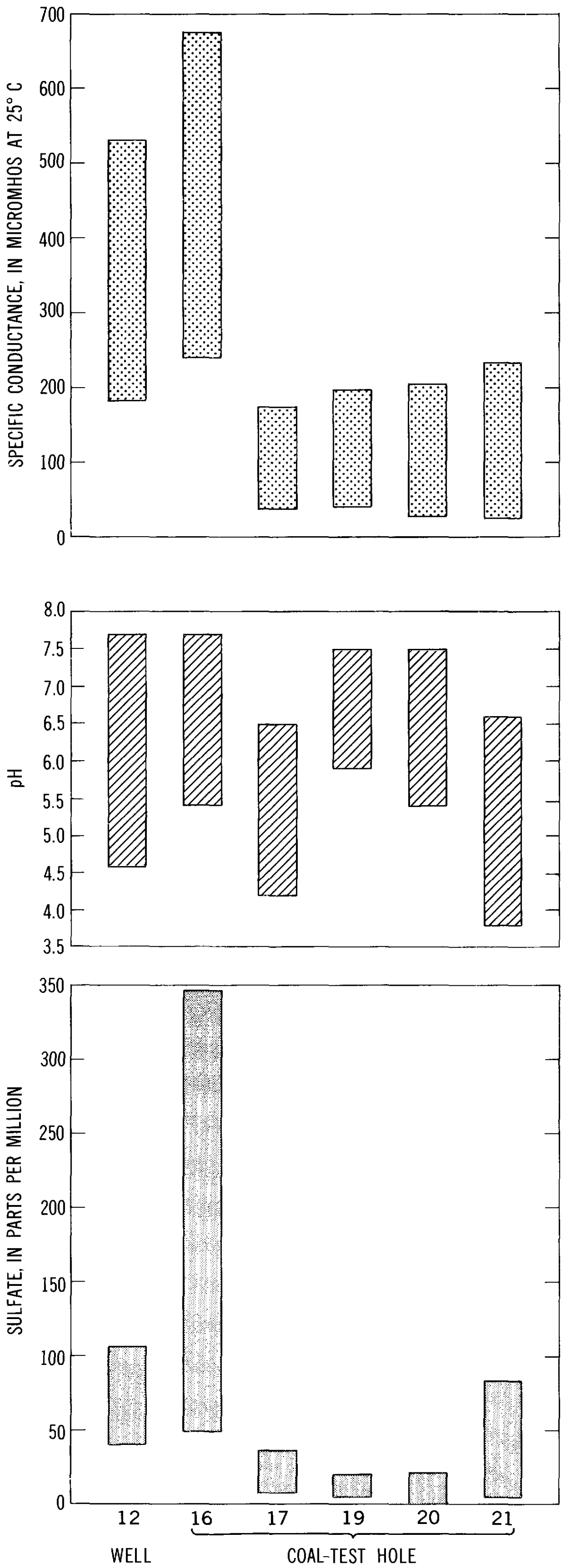

FIGURE 12.—Sulfate content, pH, and specific conductance of water in well 12 and coal-test holes 16, 17, 19, 20, and 21, water years 1958–66.

The water in the two major tributaries in the southern part of the study area is not influenced by mine drainage. At sites B and C (pl. 1), the dilute waters of the two tributaries vary from calcium bicarbonate to calcium sulfate types. The observed dissolved-solids content ranged from 16 to 34 ppm, the pH ranged from 5.8 to 7.6, and bicarbonate alkalinity was present at all times. Sulfate concentrations did not exceed 13 ppm.

Downstream from sites B and C, acid mine drainage from the southwest spoil bank enters Cane Branch, and, because the receiving water has little buffering capacity, Cane Branch becomes acid. Many seeps from the southwest spoil bank add small quantities of acid water to Cane Branch, but the tributaries at sites P, M, and G contribute the largest quantities.

Sites P, M, and G are in streams which receive acid surface and ground water directly from the southwest spoil bank. During periods of high runoff, pools behind the spoil bank overflow into these three streams. During periods of no rainfall, ground water seeps out of the spoil bank to sustain the flow of the streams. During the period 1959–66, the principal dissolved constituents of the water at these sites were calcium, magnesium, sulfate, silica, aluminum, iron, and manganese. The pH at sites P and M ranged from 2.50 to 3.10. Concentrations of dissolved constituents remained high from 1959 to 1966, and these tributaries continued to transport acid water to Cane Branch. Although the water at site G is somewhat less acid and less mineralized than that at sites M and P, it showed no im-

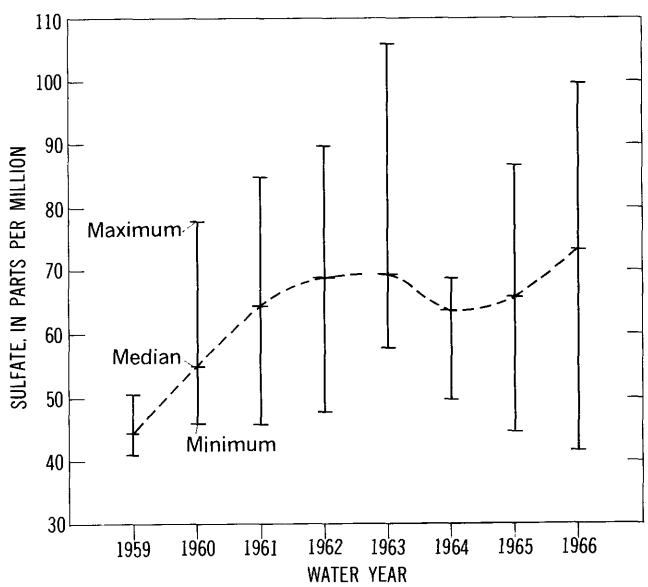

FIGURE 13.—Changes in the sulfate content of water in well 12, water years 1959–66.

provement during the period 1959–66 and continued to contribute to the acidity and dissolved-solids content of water in Cane Branch.

Site O is on a tributary that receives part of its drainage from the small area on the northeast side of Cane Branch mined during 1958. The water passing site O has never contained free acid, even though sources of acid are present on a small spoil bank upstream. Apparently, all acid water entering the drainage system above site O is effectively neutralized by water from other parts of the subbasin. The waters from this and other nearby tributaries of similar chemical quality dilute and partly neutralize the acid waters of Cane Branch.

Until 1966, the water at site O was a calcium sulfate and bicarbonate type with a pH range of about 6 to 7. The maximum observed sulfate concentration during 1959–66 was 40 ppm on October 27, 1966. The dissolved-solids content on that date was the highest observed at site O and may indicate an increasing influence of drainage from pools 12 and 13 on the general quality of water in the tributary.

The drainage area upstream from site N includes much of the area on the northeast side of Cane Branch that was strip mined during 1959. The overflow from pools 15 to 18 passes site N in traveling to Cane Branch. Before the 1959 mining, the water passing the sampling site was a calcium bicarbonate type, was only slightly mineralized, and had a pH near 7 (Collier and others, 1964, p. B38). During mining, the mineralization of the water increased, the type changed to calcium sulfate, and the pH slowly decreased. From the completion of mining through 1961, water passing site N had a pH range of from 2.25 to 3.60, and a range of sulfate concentrations from 350 to 538 ppm. In October 1966, the streamflow at site N consisted principally of drainage from pools 17 and 18 and had chemical characteristics very similar to those present in 1959–61. The water in the tributary continued to transport significant quantities of acid mine drainage to Cane Branch from 1961 to 1966.

The chemical composition of water in the tributary draining the northeast spoil bank in the vicinity of pool 19 showed little evidence of the presence of acid mine drainage prior to 1961. In October 1966, however, water in this tributary at site H (fig. 14) had a considerably higher sulfate content and lower pH than had been observed previously. The increase in mineralization probably began in 1961 as a consequence of the change of pool 19 into an acid pool during that year.

Figure 14 illustrates the relationship between the pH of Cane Branch water and the pH of water in its tributary streams and in the pools on the spoil piles in October 1966. Conductance and pH values listed in the figure were measured in the field on October 27, 1966.

CANE BRANCH

The effect of acid mine drainage upon the chemical quality of water in Cane Branch is measured at the Cane Branch gaging station, just downstream from the mined areas. Selected chemical analyses of Cane Branch water are presented in table 4 to show the general chemical quality of the stream. As a rule, samples with maximum, minimum, and intermediate conductances for each year have been chosen for tabulation. A more complete tabulation was published by the U.S. Geological Survey in its basic data publication series (U.S. Geological Survey, 1956–66).

The original dilute calcium and magnesium bicarbonate water of Cane Branch changed during early 1956 to a highly mineralized, acid, calcium and magnesium sulfate water as a result of strip mining of coal on the southwest side of the basin (Collier and others, 1964, fig. 27 and p. B38–B39), and it remained this type of water throughout the study period, which ended in October 1966. Silica, aluminum, iron, and manganese also were predominant among the constituents dissolved in the water.

An examination of the chemical composition of water in Cane Branch during the years subsequent to the initial mining shows that the mean concentrations of chemical constituents increased in 1959 owing to a resumption of mining, then decreased during the period 1960–65. From 1960 to 1966, no additional mining occurred in the Cane Branch study area. Limited prospecting near pool 20 resulted in the addition of a small amount of acid water to Cane Branch, but the effect of this addition was not measurable.

From June 1956 to September 1965, the pH of water in Cane Branch ranged from 2.55 to 4.35. At no time did the water contain bicarbonate ions. In contrast, water in Helton Branch, which was not influenced by mining, had a pH range of 5.7 to

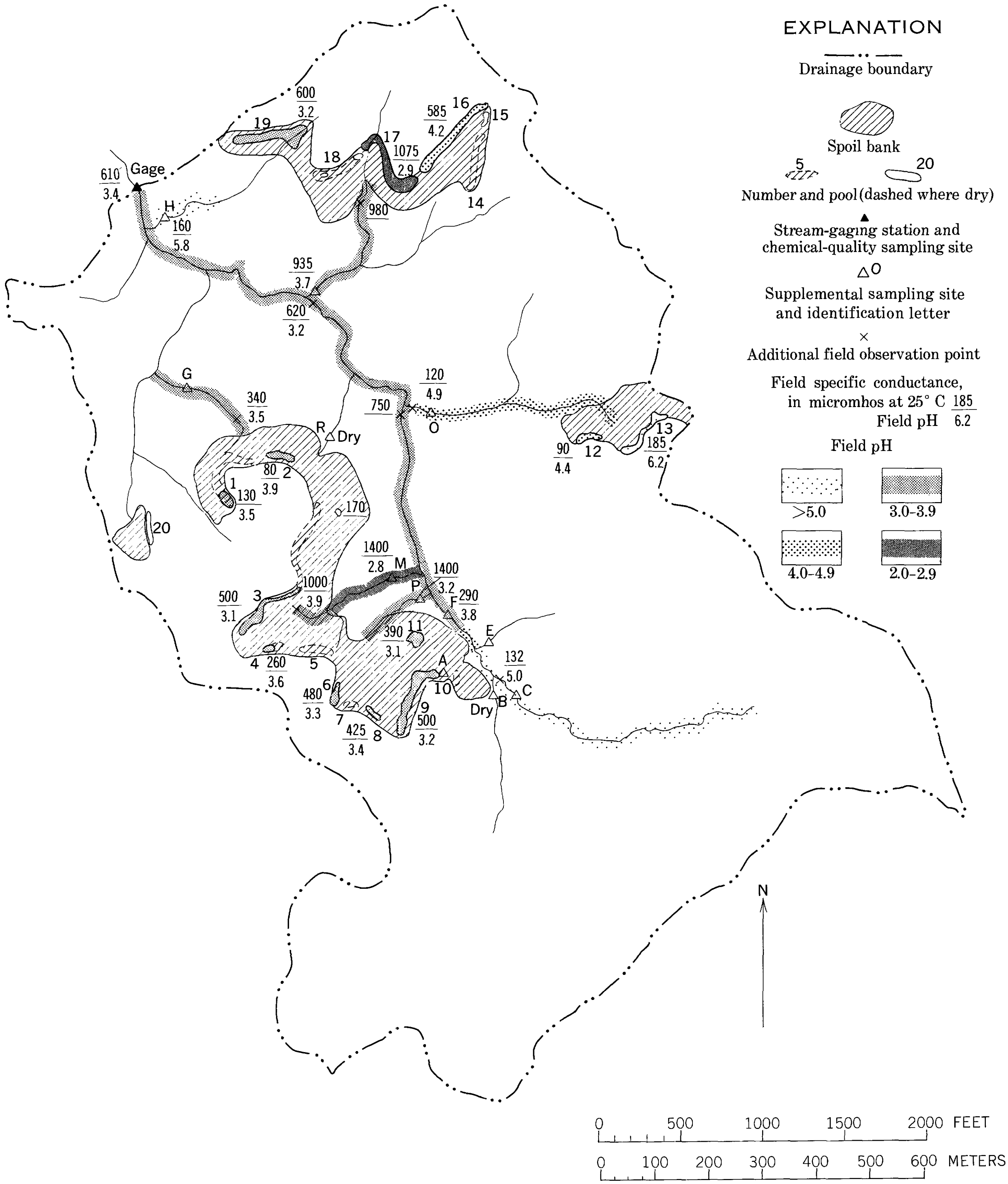

FIGURE 14.—Specific conductance and pH of water in pools, tributaries, and main stem of Cane Branch on October 27, 1966.

TABLE 4.—*Chemical analyses of selected samples from Cane Branch near Parkers Lake, 1955–66*

[Results in parts per million, except as indicated]

Date of collection	Instantaneous discharge (cfs)	Aluminum (Al)	Iron[1] (Fe)	Manganese[1] (Mn)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Dissolved solids (residue at 180° C.)	Hardness (divalent cations as $CaCO_3$)	Acidity to pH7 (H^+)	Specific conductance (micromhos at 25° C.)	pH
Sept. 1, 1955	---	---	---	---	10	16	----	18	---	61	6.7
Jan. 18, 1956	---	0.3	0.24	0.05	17	3	31	16	---	44	6.8
May 29	0.09	5.4	1.8	5.3	0	123	195	88	---	296	4.0
Aug. 14	.56	---	---	---	0	1,220	----	440	---	2,220	2.6
Apr. 9, 1957	3.9	1.8	1.9	.07	0	46	76	34	0.4	151	3.8
July 16	.065	85	---	---	0	1,050	1,420	242	14	2,010	2.6
Aug. 15	.065	5.4	1.4	7.7	0	175	298	100	1.6	534	3.2
May 6, 1958	11.8	---	---	---	0	46	----	31	.3	138	4.2
Sept. 10	.026	3.4	3.0	6.4	0	144	----	81	1.1	493	3.2
Sept. 17	1.19	---	---	---	0	1,150	----	234	16	2,060	2.6
Feb. 10, 1959	5.3	---	---	---	0	77	----	53	.6	222	3.8
May 28	.13	8.8	9.3	14	0	282	----	120	2.6	900	2.9
Aug. 17	1.73	86	15	16	0	970	1,380	170	13	1,940	2.7
Oct. 20	.10	---	---	---	0	359	515	---	3.8	986	3.0
Feb. 2, 1960	.39	6.4	7.3	8.5	0	199	268	143	1.5	551	3.4
Mar. 29	3.0	---	---	---	0	67	108	---	.5	215	3.8
May 2, 1961	5.4	1.1	2.6	1.9	0	47	72	36	.4	145	4.0
June 6	.2	6.0	14	12	0	281	408	360	1.9	778	3.2
Sept. 12	.1	---	---	---	0	586	926	---	7.2	1,270	3.0
Feb. 27, 1962	52	---	---	---	0	43	87	---	.4	134	3.9
May 1	.4	5.1	.36	9.3	0	207	305	153	1.2	549	3.2
Sept. 4	.1	---	---	---	0	416	----	---	---	955	3.3
Dec. 21	1.2	---	---	---	0	234	----	---	---	696	2.9
Mar. 1, 1963	1.7	---	---	---	0	144	----	---	---	406	3.3
May 26	.3	5.3	4.4	10	0	186	287	135	1.6	557	3.3
Jan. 21, 1964	.87	---	---	---	0	104	----	---	---	322	3.6
July 14	.06	6.8	6.3	12	0	248	385	---	---	736	3.2
Sept. 8	.06	---	3.1	9.4	0	156	261	118	1.0	479	3.4
Nov. 10	.08	---	---	---	0	245	348	166	1.8	681	3.3
Dec. 30	.70	5.6	4.1	5.3	0	123	199	86	1.3	378	3.6
Mar. 27, 1965	3.8	---	---	---	0	57	95	42	.5	80	4.1
Feb. 8, 1966	.64	17	7.6	13	0	317	458	191	2.9	802	3.3
Apr. 10	.14	5.4	.07	7.7	0	166	278	111	1.3	478	3.4
May 1	4.4	---	---	---	0	55	94	36	.5	187	3.8
Oct. 27	.08	6.0	15	11	0	249	400	172	1.8	710	3.6

[1] In solution when collected.

7.5 during the same period and always contained bicarbonate ions.

An assessment of the change in water quality with time at a specific point on a stream, such as at the Cane Branch gaging station, requires an intensive sampling program consisting of (1) continued measurement of an important chemical parameter of the stream quality, and (2) regular sampling and comprehensive analysis of the stream water as a means of relating other constituents in the water to the constituent measured continuously. Probably the most useful parameter to monitor is specific conductance, which reflects the content of ionic solute in the water. Relationships between specific conductance and the content of major constituents in the water can be determined from analyses of the regularly collected samples. With this information, representative concentrations of the major constituents can be calculated for selected time periods; and by combining these concentrations with a continuous record of runoff, loads of chemical constituents transported by the stream past the sampling point can be determined. Assessment of the gross geochemical characteristics of the Cane Branch study area was based on this approach.

Infiltration and storage of precipitation in geologic materials vary with the porosity and permeability of the materials. The nature of the spoil in the Cane Branch basin allows entry of precipitation into the spoil. As a result, the spoil becomes a reservoir for ground-water storage and a contributor to base flow of the stream, even during periods of little or no precipitation. In addition, the high content of iron sulfide minerals and their highly soluble weathering products in the spoil provides a continued supply of soluble material to the percolating ground water. Thus, drainage of water from the spoil banks contributes the bulk of the dissolved chemical load passing the Cane Branch gaging station during periods of base flow in the stream. Even direct storm runoff from the spoil banks becomes highly mineralized through dissolution of soluble minerals near the surface of the spoil and through flush-out of pools adjacent to the spoil bank.

Monthly loads of equivalent sulfuric acid, sulfate, and total dissolved solids passing Cane Branch gaging station are listed in table 32 for water years 1959–66. Data for water years 1957 and 1958 were reported by Musser and Whetstone (in Collier and others, 1964, p. B47). The monthly load depends both on the amount of water passing the gaging station and the concentration of the chemical constituent of interest in that water. In an attempt to examine the record of monthly loads transported by Cane Branch for significant changes during the period 1956–66, a cumulative plot of runoff and dissolved-solids load was prepared (fig. 15). The slopes of the lines in figure 15 represent average concentrations of dissolved solids in the water; an increase or decrease in slope means that the average dissolved-solids concentration for that period increased or decreased, respectively, with time. Pronounced differences in concentration between winter-spring (high-flow) and summer-autumn (low-flow) months, represented by the stair-step-like nature of the lineation of points which define the line representing all months, and the lack of data for certain months during water years 1963–65 made it necessary to plot high-flow months ($>$ 15 cfs-days) and low-flow months ($<$ 15 cfs-days) separately in order to clarify long-term trends. The dashed part of the line for all months is based on an interpolation of these trends. The scale of the drawing does not permit all points on the line for low-flow months to be shown.

The bulk of the dissolved constituents in Cane Branch is contributed by direct runoff and seepage from the spoil banks. Changes in slope of the lines in figure 15 thus represent changes in the quantity of dissolved constituents contributed by these spoil-bank waters to Cane Branch. The average concentration of the dissolved solids during a period of time is defined by the slope of the line drawn through all points for that period. The slope of the line for water years 1956–58 is representative of the period following cessation of strip mining in the southwestern part of the study area. Steepening of the slope during water years 1959 and 1960 is the result of mining activity in the northeastern part of the study area, which caused a substantial increase in the rate of chemical weathering in the mined area and a twofold increase in the effective concentration of dissolved constituents in the stream. The decrease in slope during water year 1961 reflects the lack of further disturbance in the northeastern area following cessation of mining there. However, the slope of the line is greater than that for the period prior to 1959 because of the added increment of dissolved solids contributed to the stream by drainage from spoil banks in the northeastern mined area. Continued decrease of loads contributed by both mined areas during water year 1962 resulted in an average concentration of dissolved solids approaching that observed prior to mining in the northeastern area, as shown by the slope of the curve for all months. Curves for equivalent sulfuric acid and sulfate (not shown) are nearly identical with the curves for dissolved solids shown in figure 15.

Because of the limited amount of direct runoff from both mined and unmined areas during the summer and autumn months, little dilution of ground water entering Cane Branch from the spoil banks takes place, and concentrations of dissolved solids are high, as shown by the slope of the line representing low-flow months. In spite of the concentrations of dissolved constituents, the contribution to the total annual load during these months is much less than during the high-flow months, when concentrations are less as a result of dilution, but the increased volume of water for leaching results in higher loads.

In figure 15, the upturns at the upper ends of the curve for high-flow months and the curve for all months represent increases in average concentration and are the result of exceptionally light precipitation and decreased direct runoff during the

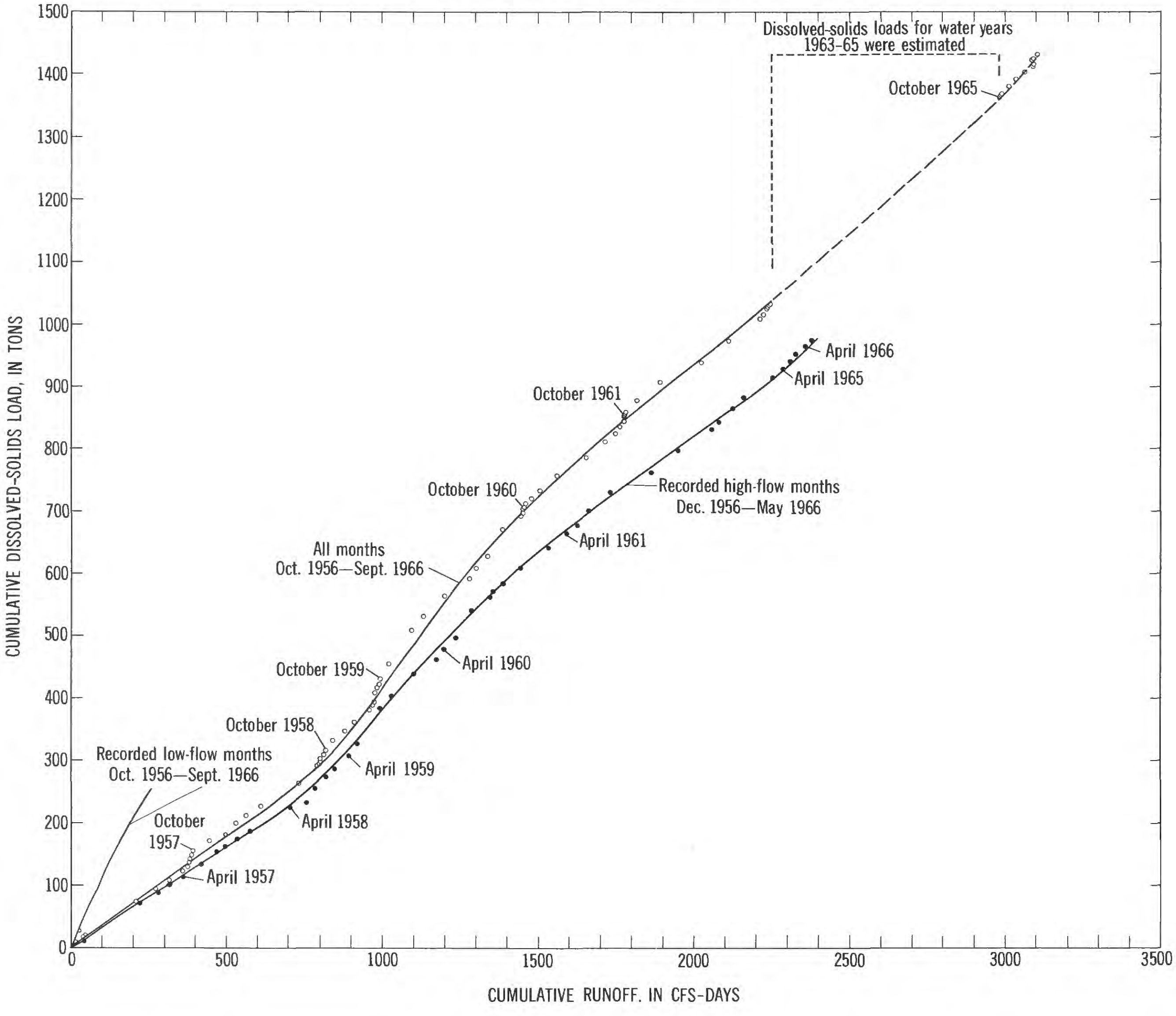

FIGURE 15.—Changes in relation of cumulative dissolved-solids load to cumulative runoff, Cane Branch gaging station, water years 1957–66.

winter and spring months of water year 1966. Normally, the bulk of the annual runoff in the Cane Branch basin occurs during the period November to May, when there is little uptake by vegetation, and the ratio of runoff to precipitation is fairly high. In 1966, 40 percent of the precipitation occured during July, August, and September, when evapotranspiration was at a maximum. Consequently, runoff was low over much of the basin during most of the water year. On the spoil banks, however, sparseness of vegetation and the spoil's moderate infiltration capacity resulted in a large contribution of spoil-bank runoff to the total runoff of the basin. This higher proportion of spoil-bank runoff in the basin and the smaller amount of less mineralized direct runoff during the winter-spring months resulted in higher average monthly concentrations during the winter-spring months and a higher mean annual concentration for the entire water year.

Analysis of hydrologic data on a water-year basis is commonly useful as a means of eliminating seasonal effects, such as gross differences in chemical loads transported during low-flow months as compared with loads transported during high-flow months (table 32 and fig. 15). For Cane Branch, annual loads and annual mean concentrations of dissolved solids, sulfate, and equivalent sulfuric acid, calculated from runoff and load data shown in table 32, are listed in table 5 for water years 1957–66. Partial load data for water years 1964 and 1965 were used to calculate an estimated total load for the 2 years, and this total load was appor-

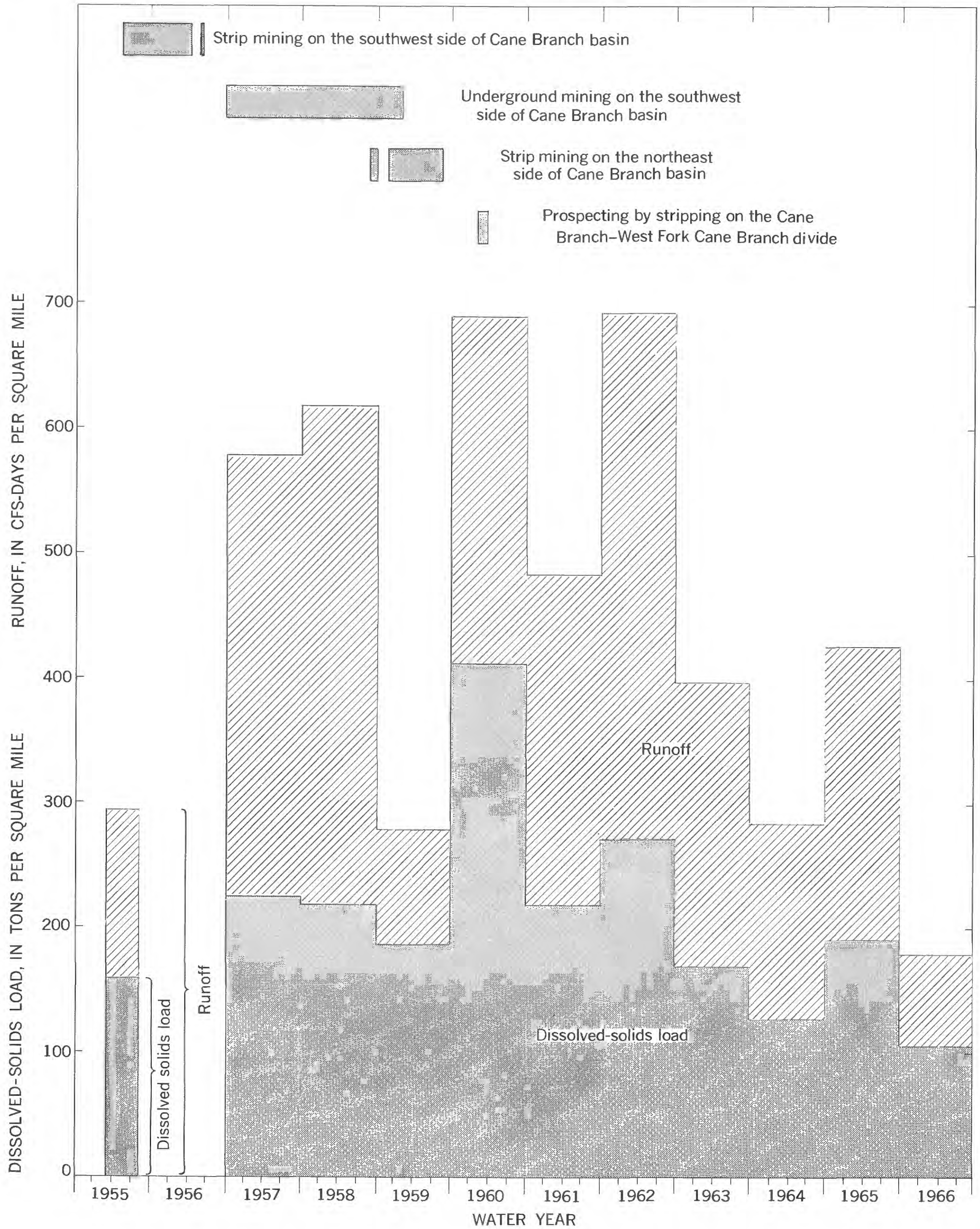

FIGURE 16.—Periods of mining activity, annual runoff, and annual loads of dissolved solids in Cane Branch basin, water years 1955–66.

tioned between the 2 years on the basis of annual runoff. The estimated load for water year 1963 was based on annual runoff for 1963 and the dissolved solids load–runoff ratios for 1962 and 1964. The high annual mean concentrations for water year 1966 were the result of the small amount and unusual distribution of rainfall during the year, as described in the preceding paragraph.

TABLE 5.—*Annual runoff, and gross annual loads, and annual mean concentrations of key chemical constituents, at gaging station Cane Branch near Parkers Lake, water years 1957–66*

[e, estimated]

Water years	Runoff (cfs-days per sq mi)	Load discharged (tons per sq mi)			Annual mean concentration [1] (parts per million)		
		Dissolved solids	Sulfate	Acidity (equivalent H_2SO_4)	Dissolved solids	Sulfate	Acidity (equivalent H_2SO_4)
1957	580	227	147	55	145	94	35
1958	619	219	140	51	131	84	31
1959	280	189	121	61	250	160	81
1960	691	414	275	115	222	147	62
1961	485	221	153	62	169	117	47
1962	694	274	178	60	146	95	32
1963	398	[2] e 168	---	---	e 156	---	--
1964	284	[3] e 172	---	---	[4] e 166	---	--
1965	427	[3] e 191	---	---	[4] e 166	---	--
1966	180	106	64	26	218	132	53

[1] Calculated from annual runoff and annual load.
[2] Load based on annual runoff for 1963 and dissolved-solids load: runoff ratios for water years 1962 and 1964.
[3] Partial load data for water years 1964 and 1965 used to calculate an estimated total load for the 2 years. Proportioning of the total load between the 2 years was based on annual runoff for the 2 years.
[4] The identical estimated annual mean concentrations for water years 1964 and 1965 are the result of the method by which the annual loads for those 2 years were estimated.

Annual loads per square mile of dissolved constituents transported by Cane Branch are plotted in figure 16, along with data on annual runoff and mining activities. The absence of a direct relationship between annual loads and annual mean concentrations is illustrated by the data for water year 1966. Although the annual mean concentration was the highest calculated for any year since water year 1960, the annual load was the least for any year during the entire 10-year period of record.

Figures 15 and 16 illustrate the difficulty of separating natural changes from man-induced changes in environmental studies. Grouping of data on an annual basis can be used to mute seasonal variations and expression of the leaching of soluble materials in terms of concentration can be used to mask the effect of year-to-year changes in precipitation and runoff; but these analytical manipulations do not completely eliminate the effect of natural variations in the hydrologic cycle.

In spite of these difficulties, the general picture obtained from the two illustrations is the same. An increased rate of chemical weathering in Cane Branch basin resulted from strip mining of coal in the southwestern part of the study area in 1955 and 1956. This rate was further increased by additional strip mining in the northeastern part of the study area in 1959. Following cessation of mining in the northeastern area, the rate of chemical weathering gradually decreased until water year 1966 when it was slightly less than that observed in 1957 following the initial mining in the study basin. Nevertheless, it remained much higher than the rate of chemical weathering prior to the initial disruption of bedrock in the basin in 1955.

COMPARISON OF CHEMICAL EROSION IN CANE BRANCH AND HELTON BRANCH STUDY AREAS

The Helton Branch basin was studied because its hydrologic characteristics were believed to be similar to those of the Cane Branch basin prior to coal-mining activities. It has been assumed that any gross differences between the two basins observed during the study period could be attributed to mining of coal in the Cane Branch basin.

During the study period, a distinct difference was observed between the load of dissolved solids transported by Helton Branch and the load transported by Cane Branch. On a yearly basis, the dissolved-solids loads removed from the Cane Branch study area are four to eight times greater than those removed from the Helton Branch study area, but this difference does not give a correct indication of the relative rates of chemical erosion in the mined Cane Branch area and chemical erosion in the natural Helton Branch area. A better quantitative comparison of rates can be made by considering not only how much dissolved material leaves each area, but also how much dissolved material is received by each area in precipitation.

The dissolved-solids load transported from each area minus the dissolved-solids load received in precipitation equals the net dissolved-solids load removed due to chemical degradation. Data on these three different dissolved-solids loads for the Cane and Helton Branch study areas for the period 1957 to 1962 are given in table 6. The dissolved-solids loads in precipitation were computed by using the annual precipitation records for each area and a mean concentration of 8 ppm dissolved solids, which had been determined by chemical analysis of precipitation samples. In both study areas, the dissolved solids loads in precipitation are about the same per unit area for corresponding years because there was little difference in the amounts and chemical composition of precipitation received by the two areas. Total dissolved-solids yields for Helton Branch

TABLE 6.—*Rates of chemical degradation and runoff in the Cane and Helton Branch study areas, water years 1957–62*

Water year	Runoff at gaging station (cfs-days per sq mi)	Dissolved solids (tons per sq mi per yr)		
		Total discharge at gaging station	In precipitation	Net from degradation of area
Cane Branch				
1957 ----	580	227	33	194
1958 ----	619	219	30	189
1959 ----	280	189	24	165
1960 ----	691	414	32	382
1961 ----	485	221	25	196
1962 ----	694	274	33	241
Helton Branch				
1957 ----	554	46	32	13
1958 ----	607	56	30	26
1959 ----	292	[1]e 25	22	3
1960 ----	610	[1]e 54	30	24
1961 ----	478	[1]e 42	23	19
1962 ----	656	[1]e 58	32	26

[1] Dissolved-solids loads for water years 1959–62 are based on annual runoff and assumed constancy of the runoff-concentration relationship during the period 1957–62.

for water years 1957 and 1958 are based on weekly to monthly chemical analyses; yields for 1959–62 are estimated and are based on infrequent analyses and on the similarity of the runoff-concentration relationship during the two periods.

During the water years 1957–62, Cane Branch transported a net dissolved-solids load of about 1,370 tons per square mile of drainage area and Helton Branch transported a net load of about 111 tons per square mile of drainage area. Thus, the rate of chemical degradation for the Cane Branch area was about 12 times greater than that for the Helton Branch area during the 6-year period. The more rapid rate of chemical degradation in the Cane Branch area was largely due to strip mining of coal in 1955–56 and again in 1959, which exposed significant quantities of pyrite and other unweathered minerals to agents of weathering and erosion.

A rough estimate of the rate of chemical degradation from the spoil bank areas alone, as compared with that for the total basin, can be obtained if it is assumed that the dissolved-solids load derived from unmined parts of Cane Branch basin is equal to that observed in the unaffected Helton Branch basin. Calculations based on this assumption indicate a net dissolved-solids load of approximately 14,000 tons per square mile of drainage area for the spoil bank areas for the 6-year period, or a rate of chemical degradation for the spoil banks that is 126 times the rate for the unmined Helton Branch area.

UPPER BEAVER CREEK BASIN

As the acid water from the Cane Branch study area moves downstream in the Beaver Creek basin, streams with bicarbonate alkalinity mix with, dilute, and neutralize the acid water. By the time the water from Cane Branch reaches Beaver Creek, most of the acid load has been neutralized. Beaver Creek is only slightly acid. Table 7 lists chemical analyses of streams in the upper Beaver Creek basin; sampling sites are indicated in table 8 and in figure 17.

TABLE 7.—*Chemical analyses of major streams in the upper Beaver Creek basin*

[Results in parts per million, except as indicated]

Date of collection	Sampling site [1]	Instantaneous discharge (cfs)	Aluminum (Al)	Iron [2] (Fe)	Manganese [2] (Mn)	Sodium (Na)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Dissolved solids (residue on evaporation at 180° C.)	Hardness (divalent cations as $CaCO_3$)	Acidity to pH7 (H^+)	Specific conductance (micromhos at 25° C.)	pH
1957													
June 6 ----------	1	--------	--------	--------	--------	--------	8	6.8	--------	10	.0	33	6.9
	5	--------	--------	--------	--------	--------	4	12	--------	14	.0	43	6.4
1958													
June 2 ----------	1	--------	--------	--------	--------	--------	11	7.4	--------	12	.0	40	6.5
	4	--------	--------	--------	--------	--------	0	139	--------	79	.9	376	3.6
1959													
November 2 ----------	1	--------	--------	--------	--------	--------	11	6.4	--------	13	--------	36	7.0
November 3 ----------	2	0.14	10	18	14	--------	0	318	457	158	--------	907	3.0
November 2 ----------	3	--------	--------	--------	--------	--------	0	174	--------	91	--------	528	3.3
	4	--------	--------	--------	--------	--------	0	158	--------	103	--------	472	3.4
	5	--------	--------	--------	--------	--------	2	40	--------	33	--------	116	4.7
November 3 ----------	7	--------	--------	--------	--------	--------	0	38	--------	32	--------	103	4.6
	8	--------	--------	--------	--------	--------	10	13	--------	19	--------	52	6.5
November 2 ----------	9	--------	--------	--------	--------	--------	2	34	--------	29	--------	99	4.8
November 3 ----------	12	--------	--------	--------	--------	--------	16	7.6	--------	18	--------	45	6.9
	13	--------	--------	--------	--------	--------	6	24	--------	24	--------	68	6.1
1964													
August 4 ----------	1	.13	--------	.70	.05	1.2	12	3.6	26	13	--------	33	7.0
August 3 ----------	2	.03	--------	3.5	3.4	1.5	0	200	298	144	1.2	624	3.2
August 4 ----------	6	.28	--------	.84	4.2	1.8	6	10	36	12	.1	40	6.0
	7	.16	--------	--------	--------	--------	1	20	40	20	.1	70	5.5
August 5 ----------	10	.1	--------	.68	.71	1.9	22	4.8	--------	21	--------	48	7.0
	11	.13	.1	--------	--------	.6	10	.4	--------	9	.0	19	6.6
	12	.76	--------	.54	.02	.6	12	2.4	20	11	.0	28	6.7

[1] See figure 17.
[2] In solution when collected.

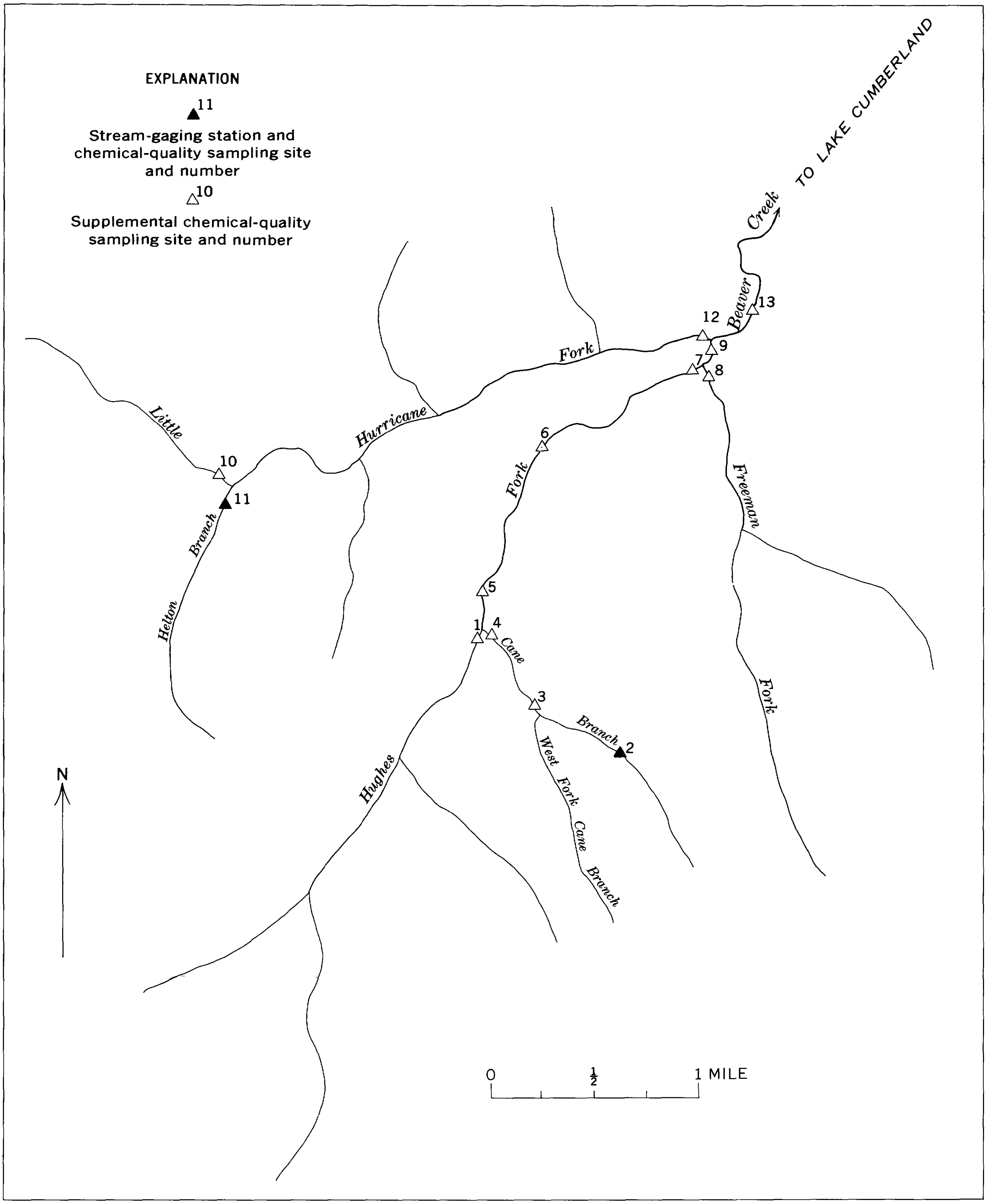

FIGURE 17.—Locations of chemical-quality sampling sites on the major streams of the upper Beaver Creek basin.

TABLE 8.—*Chemical-quality sampling sites on major streams in the upper Beaver Creek basin*

Sampling site	Location
1	Hughes Fork above Cane Branch.
2	Cane Branch at gaging station.
3	Cane Branch below West Fork Cane Branch.
4	Cane Branch at mouth.
5	Hughes Fork below Cane Branch.
6	Hughes Fork 1 mile above mouth.
7	Hughes Fork at mouth.
8	Freeman Fork at mouth.
9	Beaver Creek above Little Hurricane Fork.
10	Little Hurricane Fork above Helton Branch.
11	Helton Branch at gaging station.
12	Little Hurricane Fork at mouth.
13	Beaver Creek below Little Hurricane Fork.

As it travels downstream from the Cane Branch gaging station, water in Cane Branch receives relatively unmineralized water containing bicarbonate alkalinity from West Fork Cane Branch. This water neutralizes a small part of the acidity of Cane Branch, but the stream remains acid to its mouth at Hughes Fork.

Hughes Fork above Cane Branch is a relatively unmineralized stream with some bicarbonate alkalinity. During periods of high flow, Hughes Fork effectively dilutes the dissolved constituents and neutralizes the acid it receives from Cane Branch; but during medium and low-flow periods, the water in Hughes Fork does not contain enough alkalinity to neutralize all the acidity from Cane Branch. During these periods, Hughes Fork contains a small amount of acidity and generally some bicarbonate alkalinity at the mouth (sampling site 7, fig. 17).

Beaver Creek begins at the confluence of Hughes Fork and Freeman Fork. A few hundred feet below this confluence, Little Hurricane Fork enters Beaver Creek. In 1959, both Freeman[1] and Little Hurricane Forks had relatively unmineralized water with bicarbonate alkalinity and a near-neutral pH. The two streams completed the neutralization of the acid carried by Hughes Fork, and Beaver Creek below the mouth of Little Hurricane Fork had water of good chemical quality and a pH near that of streams unaffected by mans activities. Only sulfate concentrations and hardness values slightly higher than those found in nearby more dilute streams remained as evidence of the acid mine drainage contributed from the Cane Branch mining area.

[1] An additional field inspection on May 23, 1961, indicated that Freeman Fork remained largely unaffected by strip mining of coal in the upper part of its basin in 1958; the measured conductance of Freeman Fork water was 100 micromhos at 25° C, and the pH was 7.3.

CONCLUSIONS

Cane Branch became a highly mineralized, acid stream during 1956 as a result of strip mining of coal in the basin during the period May 1955 to April 1956. This high level of mineralization and acidity, which prevailed through 1958, increased in 1959 as a result of additional strip mining from December 1958 to August 1959. Exposure of fresh rock during this later period of mining resulted in a renewal of rapid chemical weathering and erosion. Concentrations of dissolved solids, sulfate, and acidity in the water of Cane Branch increased significantly after the mining. These concentrations began to decrease in 1960, and by 1962 had reached the 1957 level. Although fluctuations of annual mean concentrations due to climatic variations have made it difficult to identify a definite trend during the period 1962–66, it appears that there was little change in the rate of chemical weathering or in the chemical composition of the water in Cane Branch during the last 5 years of the study.

During the period 1957–62, Cane Branch transported a net dissolved-solids load of about 1,370 tons per square mile compared with about 111 tons per square mile transported by Helton Branch, which was not affected by mining. Thus, the rate of chemical degradition in the Cane Branch study area was about 12 times faster than that in the Helton Branch study area. During the same period, the spoil banks alone contributed a net dissolved-solids load of approximately 14,000 tons per square mile of drainage area on the spoil banks. This represented a rate of chemical degradition of the spoil banks about 126 times the rate for the unmined Helton Branch area.

As the acid mine drainage from the Cane Branch area moves downstream, it is diluted and neutralized by inflow from streams containing bicarbonate alkalinity. The effects of the mine drainage are almost undetectable at the point where water from Little Hurrican Fork enters Beaver Creek, and Beaver Creek below this point has a slightly acid pH like that of neighboring streams unaffected by acid mine drainage.

EROSION AND SEDIMENTATION

By C. R. Collier, U.S. Geological Survey

BACKGROUND AND SCOPE

Spoil banks, which result from contour strip mining in mountainous regions, consist of vast quantitites of disturbed rock and soil. This material, without the protection of a vegetal cover, is subject to rapid erosion and transportation into the local stream system. In the investigation of the hydrologic environment of parts of the Beaver Creek basin, Musser (1963) described the physical environment and mining history of the study areas, and Collier and Musser (in Collier and others, 1964, p. B48–B64) defined the sedimentation characteristics of the unmined Helton Branch basin and of the small unmined subbasins of the Cane Branch basin. The effects of mining on the sedimentation characteristics of the Cane Branch basin from 1956 through September 1959 were described in considerable detail. The purpose of this paper is to describe and evaluate additional effects of strip ming on the rates of erosion, transportation, and deposition of sediment in the Cane Branch basin. Changes in these rates since the beginning of strip mining in 1955 are discussed with emphasis given to changes from 1959 to 1966.

Since 1959, investigations of sedimentation in the Cane Branch study area have included measurement of sediment discharges at the Cane Branch gaging station, measurements of gullying in and erosion from parts of the southwest spoil bank, and mapping of sediment deposits in a selected reach of the channel of Cane Branch. Methods used in these studies were, in general, the same as those described by Collier and Musser (in Collier and others, 1964, p. B48–B49).

SHEET EROSION IN THE STUDY AREAS

Sheet erosion, the removal of sediment particles by overland runoff from precipitation with the formation of channels, is strongly influenced by land use and by the type and density of the vegetal cover. John W. Roehl and A. S. Johnson reported (in Collier and others, 1964, p. B65–B66) that in the Helton and West Fork Cane Branch study areas the estimated rate of sheet erosion was less than 1 ton per acre per year. In contrast, in the Cane Branch study area, a rate of 7.82 tons per acre per year was estimated for 1959.

In the West Fork Cane Branch study area, 82.8 percent of the sediment removed by sheet erosion during 1959 was derived from areas disturbed by prospecting for coal; in the Cane Branch study area, 98.1 percent of such sediment was derived from strip-mined land.

John W. Roehl, U.S. Soil Conservation Service, described (written commun., March 9, 1966) the changes in vegetal cover and rates of sheet erosion in the study areas during the period 1959–64 as follows:

> The relative importance of several sources of sediment in terms of sheet erosion in the three watersheds under study apparently has not changed significantly during the period 1959–64 when compared with the period 1955–59. In general, field observations indicate that the major land use has remained the same but that the protective ground cover has improved to some degree.
>
> In Helton Branch, the small amount of cultivated land has continued in a rotation of corn and meadow. It is true that during the years corn is grown this cropland is subject to active sheet erosion. However, the average soil loss over the period 1959–64 is of the same magnitude experienced during the previous period. The quality of the erosion-resistant cover of the woodland and idle land has improved but not to the degree that would indicate any great decrease in the amount of sheet erosion to be expected on these areas. The same is true for the pasture lands in this watershed.
>
> In West Fork Cane Branch there also has been an improvement in the ground cover that would indicate a slight decrease in sheet erosion from woodland and idle land areas. The main locale of sheet erosion, however, remains on the old prospect areas in the West Fork.
>
> In Cane Branch, the situation is much the same as described for the other two watersheds. There has been no change in the major land uses but the cover conditions have improved to the extent that sheet erosion losses on the woodland and idle land areas are somewhat less for the 1959–64 period than for the 1955–59 period. The areas previously laid bare by the strip-mining activities apparently have not yet gained enough vegetative cover to decrease their effect as a source of sediment by the sheet erosion processes.
>
> The strip-mined areas of Cane Branch remain as the predominant source of sediment derived from sheet erosion in this watershed, still accounting for about 98 percent of the total. While the improvement of the cover on those lands not affected by the mining operations has decreased the erosion on them, this decrease is not of sufficient magnitude to change the relative importance of these various areas as far as sheet erosion is concerned.

The heterogeneous mixture of sandstone, siltstone, claystone, and soil which forms most of the spoil banks in the Cane Branch study area (Musser, 1963, p. A11) is not resistant to weathering. The fresh, unweathered rock fragments were sharp and angular. The particles on and near the surface of the spoil banks were exposed to the agents of chemical weathering described by Musser and Whetstone and to physical weathering described by Collier and Musser (in Collier and others, 1964, p. B27, B49). After the spoil bank was leveled in 1956, the general surface texture was coarse. Weathering soon softened, rounded, and disintegrated the material, and the general surface texture of the spoil banks became finer grained and smoother. (See fig. 22.) The most noticeable change in texture occurred during the first year or so after the spoil bank was leveled. The finer particles were easily removed from the spoil bank by sheet and gully erosion, and new particles were then exposed. This process of weathering and erosion will continue at a rapid rate until the spoil banks are protected by a vegetal cover.

Natural vegetation on the southwest spoil bank in the Cane Branch study area has changed very little since 1959, according to Robert Tobiaski, U.S. Forest Service. In areas close to seed sources where natural revegetation had begun prior to 1959, growth was still good and seedlings are becoming established. However, vegetal growth remains poor or nonexistent on about 95 percent of the spoil area. Natural revegetation is not sufficient to cause a visible decrease in the rates of weathering and erosion on the spoil banks.

EROSION FROM A COAL HAUL ROAD

Access roads to the strip mines are areas where accelerated weathering and severe erosion may occur. These roads were cut through the forests, were unsurfaced, and received only minimum maintenance during the period of active mining when they were used by trucks for hauling the coal. After mining, the roads were abandoned and, in total, comprise an appreciable area without vegetal cover and subject to accelerated weathering and erosion.

A small area near the north end of the southwest spoil bank included 0.15 acre of coal haul road and 0.65 acre of woodland and drained onto the spoil bank. From April 26, 1959 to February 17, 1960, all the runoff from this small drainage basin was trapped in a small pool on top of the spoil bank (area 13 on pl. 1). The amount of sediment eroded from the drainage basin and deposited in the pool was computed from detailed plane table surveys of the pool bottom.

Precipitation measured at rain gage 2 (see pl. 1 for location) on the spoil bank and near area 13 equaled 42.60 inches during the period April 26, 1959, to February 17, 1960. Thirty-two storms in this period provided more than 0.5 inch of precipitation per storm, nine of these had more than 1.0 inch per day, and one had more than 2 inches per day.

During the nearly 10-month period, 262 cubic feet of sediment was deposited in the pool. With a measured specific weight of 86.4 pounds per cubic foot, this sediment weighed 11.3 tons. Nearly all this material eroded from the road. Roehl and Johnson (in Collier and other, 1964, p. B66) reported an average annual rate of sheet erosion from wooded areas of 0.14 ton per acre in the Cane Branch study area. Deducting the amount of sheet erosion from the woodland area, the average rate of erosion from the road was computed at 90 tons per acre per year, or 57,600 tons per square mile per year.

A sediment yield of this magnitude is more than twice the yield of 27,000 tons per square mile per year from the spoil bank area reported on page C40 of this report. However, a high sediment yield was expected from this section of road because the road was steep and the runoff gathered into channels and caused gullying. This yield should not be considered as representative of all coal haul roads in the study area or in other areas being strip mined. It does show that erosion from roads may be significant in some places and warrants consideration in the planning and construction of road systems so that other resources will not be adversely affected.

EROSION FROM THE SOUTHWEST SPOIL BANK

Selected areas and gullies on the southwest spoil bank in the Cane Branch area were mapped periodically to determine changes due to erosion and to ascertain the principles of spoil-bank erosion. Detailed maps were made of two small drainage areas on the outer edge of the southwest spoil bank in 1958, 1962, and 1966. Also, longitudinal profiles of four gullies were surveyed in 1959, 1962, and 1966. The locations of these areas and gullies are shown on plate 1.

The stripping operations left a very rugged and irregular surface on the southwest spoil bank. In June 1955, the bank was leveled by bulldozers. The general topography resulting from this leveling was the primary control on the development of the drainage network on the spoil bank. The surface runoff and accompanying erosion of spoil material formed a drainage network of rills and channels on the top of the spoil bank which drain into gullies at the outer edge of the bank. (See figs. 19, 20.)

The magnitude of gully development in the spoil bank is directly related to the drainage area of the gully and to the amount of runoff passing through it. In general, the larger the drainage area, the larger the gully. Storm runoff causes significant and rapid changes in the size and shape of the large gullies. Conversely, rills and small gullies have small drainage areas and consequently carry only small quantities of storm runoff. Rills that have almost no drainage area on top of the spoil bank have shown little change during the study.

The gullies, numbered 14 to 17 on plate 1, were well incised into the spoil bank at the time of the first survey in August 1959. Subsequent surveys and observations revealed the changes and erosional processes that lead to enlargement of the gullies. Water flowing in a slightly sinuous gully erodes the channel both vertically and laterally, thereby undercutting the gully walls. Portions of these undercut walls slump into the channel, and some of the slumps are large enough to cause shifting of the channel. (See fig. 23.) The loose and fragmental material that slumped into the channel is transported downslope during subsequent storm events. This sequence of vertical and lateral cutting followed by sediment transport causes the gully to increase in both depth and width.

As the gully widens and deepens, it also increases in length through headward cutting into the top of the spoil bank. The gullies studied now extend more than 60 feet into the spoil bank. Because the difference in elevation between the top and bottom of the spoil bank at a given site remains nearly unchanged, the lengthening of the gully causes a gradual reduction in the channel gradient. The channel gradient of the gullies surveyed in August 1959, August 1962, and October 1966, are given in the following list:

Average gradient	Gully number 14	15	16	17
August 1959	0.389	0.251	0.344	0.367
August 1962	.382	.246	.342	.336
October 1966	.368	.240	.313	.302

The gradient of each of these gullies has decreased with time.

The shapes of the longitudinal profiles of the gullies also changed significantly. In the early stage of development, their profiles approximated the profile of the outer edge of the spoil bank. As widening and downcutting progressed, the profiles tended to become concave upward. This is apparent in the profile of gully 14, shown in figure 18. This tendency to reach a concave profile is evident in each of the four gullies surveyed and is in agreement with the characteristic concave channel profile of natural rivers (Leopold and others, 1964). As more spoil material is eroded from the bottoms and sides of the gullies, the profiles are expected to become more and more concave.

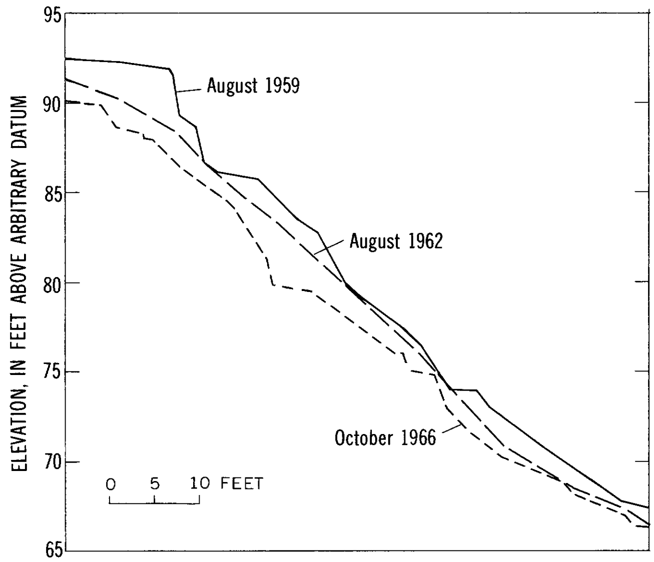

FIGURE 18.—Profiles of the floor of gully 14, showing erosion from August 1959 to October 1966.

In gully 14 and in the others surveyed, there was a general downcutting of the channel throughout the length of the gully. Downcutting occurred where a gentle channel slope was followed by a steep channel slope. In almost all gullies, such riffles and waterfalls either disappeared into a smooth profile or receded during the periods between surveys. At the base of the small waterfalls, where the channel slope became more gentle, temporary deposition often occurred. The greatest downcutting occurred at the outer edge of the top of the spoil bank.

The following tabulation shows the average degradation, in feet, in the surveyed reach of each gully:

Degradation	Gully 14	15	16	17
1959–62, average	1.17	1.51	1.88	1.48
Per year	.39	.50	.63	.49
1962–66, average	1.12	2.32	1.02	1.86
Per year	.28	.58	.26	.46

In gullies 14 and 16, the annual rate of downcutting was appreciably less during 1962–66 than during 1959–62. In gullies 15 and 17, the annual rate of downcutting was much the same during the two periods. These differences in rates of degradation may result from differences in the spoil material in the gully and in the size of the gullies drainage areas on the spoil bank, which were not defined in this study. Differences in the number and intensity of storms and amount of precipitation between the periods also would have affected the rate of gully development. For the period between the 1962 and 1966 surveys, which nearly coincided with the 1963–66 water years, precipitation and runoff were generally below normal and considerably less than that which occurred between the 1959 and 1962 surveys. (See "Precipitation and Runoff.")

Selected areas of the southwest spoil bank were surveyed in detail to obtain a measure of the erosion and to record changes in the channels and gullies. Each area was comprised of one or more small drainage basins. Elevation contour maps made in 1958 of two of these areas are shown in figures 19

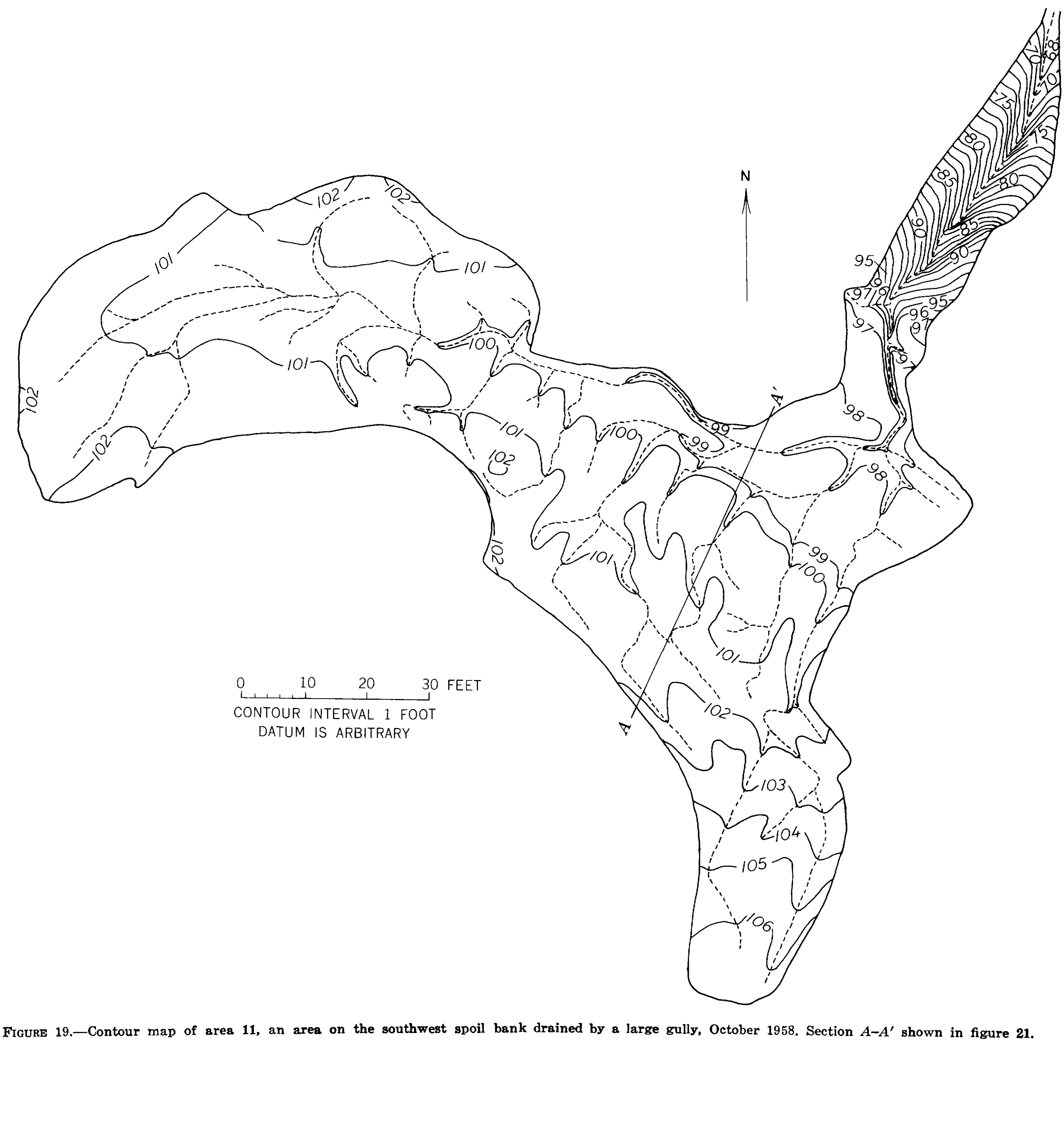

FIGURE 19.—Contour map of area 11, an area on the southwest spoil bank drained by a large gully, October 1958. Section A–A′ shown in figure 21.

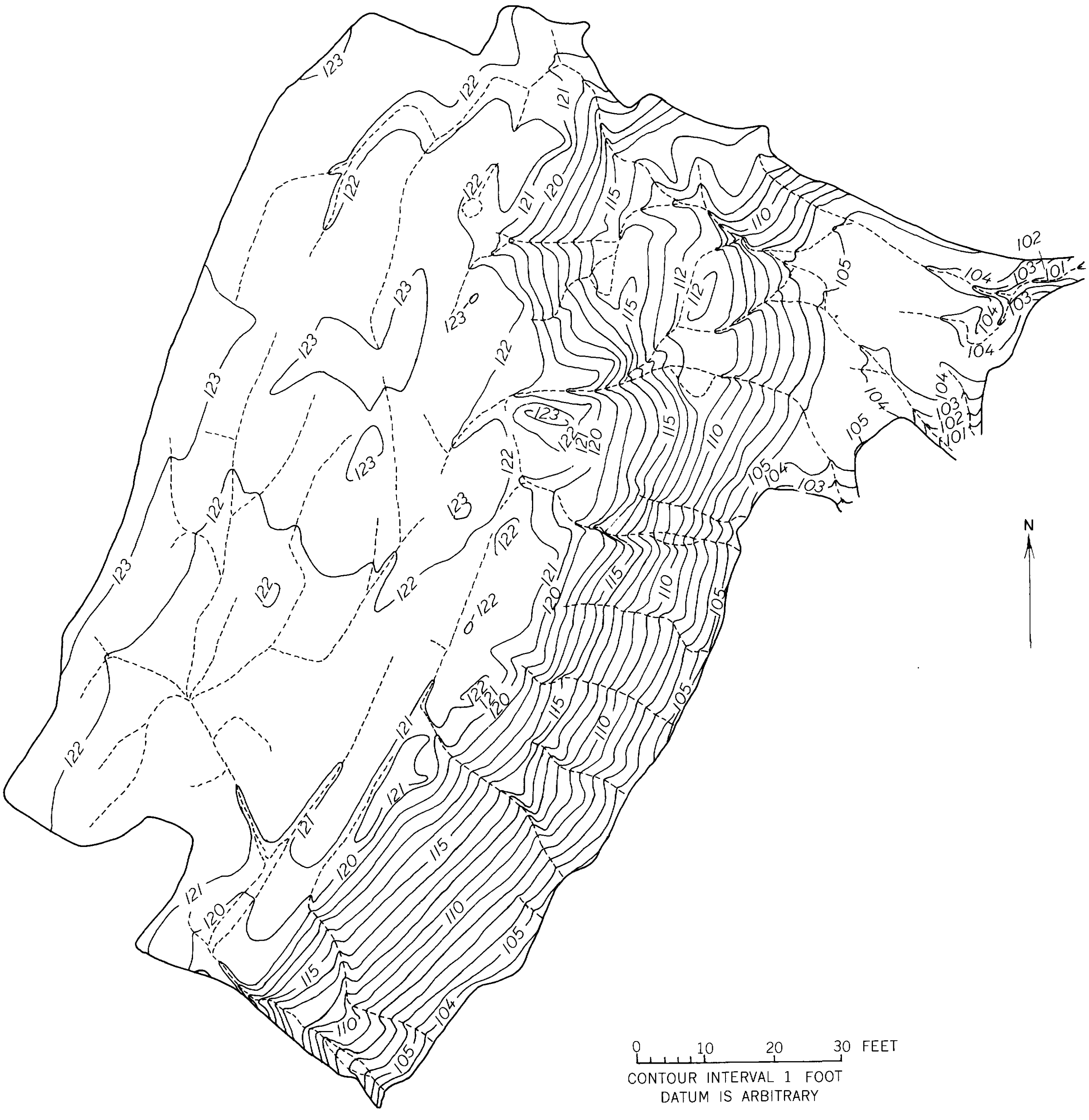

FIGURE 20.—Contour map of area 12, a rilled and terraced part of the southwest spoil bank, October 1958.

and 20; the areas are located on plate 1. Figure 19, a map of area 11, shows a small drainage basin on the spoil bank in which a major gully has developed. In area 12, figure 20, the spoil bank is partly terraced, and although the steep slope has a number of well-defined rills, no major gully has formed.

Most of the headwater channels on top of the spoil bank are nothing more than slight linear depressions. These depressions are sometimes obliterated by sheet erosion, and then new depressions form a few feet away. As the rills deepen and become better defined on the gently sloping top of the bank, stream piracy is common. Significant changes in the drainage area of some rills were noted as they both gained and lost sizable areas to other channels. The drainage patterns are still developing and are becoming more stable each year.

On the top of the spoil bank, the divides between the mapped areas and adjoining small drainage basins were very poorly established, and some shifting of the divides was noticed. This shifting of divides resulted in areas being both lost and gained by the mapped basins. Between the surveys of October 1958 and September 1962, for example, net increases of 3 percent in the size of area 11 and 0.7 percent in the size of area 12 were measured. Along the sides of the gully in area 11, drainage area was gained as the gully walls slumped and captured adjoining rills on the steep slope of the bank.

The southwest spoil bank was leveled by a bulldozer and patrol grader in June 1956 (Musser, 1963, p. A23), so more than 2 years elapsed between the leveling of the bank and the first survey of areas 11 and 12. The spoil bank was compacted by the equipment used in the leveling operations, and further settling may have occurred during the following years. It is believed, however, that settling has been insignificant since 1958. Abrupt changes in contours were not observed on top of the spoil bank in areas 11 and 12, and bench marks established on the spoil bank have remained stable.

In area 11, erosion was most noticeable along the main gully, but the gently sloping top of the bank eroded to a significant degree also. The profiles shown in figure 21 illustrate the amount of material removed from the upper surface of the bank in area 11. From 1958 to 1962, the top of the spoil bank

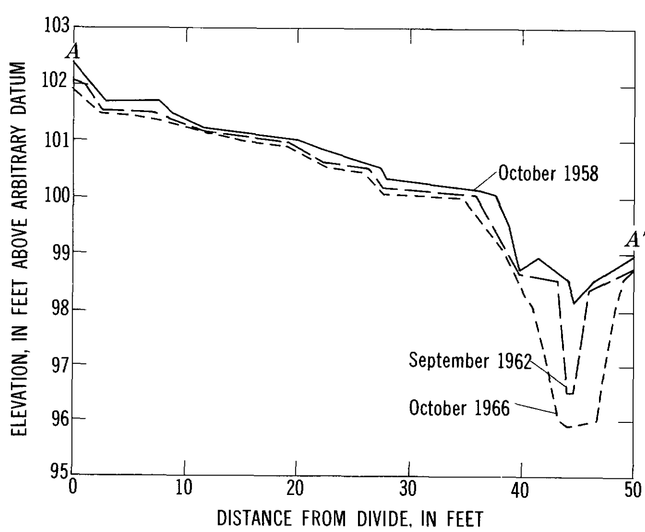

FIGURE 21.—Profiles of upper surface of spoil bank, area 11, section *A–A′*, showing erosion from October 1958 to October 1966. Trace of section shown in figure 19.

was lowered by sheet erosion an average of about 0.2 foot. From 1962 to 1966, loss by sheet erosion averaged only about 0.1 foot for the same period of time. The right side of the profile cuts across the area's main gully, which has advanced into the top of the spoil bank. The gully widened noticeably and downcut about 1.7 feet from 1958 to 1962. From 1962 to 1966, the gully grew even more. It widened from 3 feet to nearly 10 feet and downcut an additional 0.6 foot.

Runoff causes sheet erosion on the top of the bank as particles of spoil material are washed into minor channels for transport to the main gully. As the runoff is collected by the minor channels, the channels are deepened and widened. This concentration of flow causes removal of material by downcutting of the channel beds, undercutting of the channel walls, and slumping of the sides of the channel; and a gully is formed.

Channel development on the spoil bank in area 11 is shown in the photographs in figure 22. The well-defined channel, which is the upstream part of the main gully in the area, appears more incised in 1962 (middle picture) than it was in 1958, but the minor channels have undergone little change. By 1966 (lower picture), the gully has deepened and widened, and the tributary channels have become well established. (The pipes at left center and upper right of each picture are in auger holes 13 and 14, respectively. The cross section shown in figure 21 crosses the area shown in the pictures.)

Changes that took place in the lower part of the gully in area 11 can be seen in the three photographs in figure 23, which were taken from the top of the spoil bank. The gully has deepened considerably as shown by the increased exposure in the more recent pictures of the tree stump standing vertically near the center of the gully. The gully has also widened by slumping of the walls. Notice in the upper photograph the large mass of spoil material that had recently slumped from the right side of the gully wall. By 1962 (middle picture) the slump has been rounded by weathering and erosion. The lower picture (October 1966) shows only a small hump in the gully side as evidence of this slump.

The rate of erosion from area 11, which contains a major gully, is significantly greater than from the rilled and partly terraced part of the spoil bank in area 12. Area 11, which contained 0.1743 acre, lost 88.0 cubic yards of material from 1958 to 1962 and 132 cubic yards from 1962 to 1966. This is equal to 126 and 192 cubic yards per acre per year, respectively, or an average annual loss of 159 cubic

FIGURE 22.—Comparative photographs of upper surface of spoil bank, area 11, showing channel development and surface texture. Upper photograph, December 10, 1958; middle, September 30, 1962; lower, October 20, 1966.

yards per acre. Area 12 contained 0.2649 acre and lost only 19.8 and 9.8 cubic yards of spoil during each of the 4-year periods, with an average annual loss of 14.8 cubic yards per acre. The drainage area as originally mapped in 1958 was used as the base area for the computations of spoil loss; base elevations were 68 feet for area 11 and 105 feet for area 12.

In "Precipitation and Runoff," McCabe shows that lesser amounts of precipitation and runoff occurred during 1962–66 than in the preceding 4 years. In table 25, he reports 15 storms with precipitation in excess of 2 inches from October 1958 to September 1962, and only nine storms for the period October 1962 to October 1966. Total precipitation for these storms at rain gage 2, which is close to areas 11 and 12, was 38.12 inches for the earlier period and 21.30 inches for the later period. Most erosion and transport of material from the spoil banks probably occurs during intense storms.

The amount of material lost by sheet erosion from areas 11 and 12 has decreased with time. In both areas less material was removed by sheet erosion during the period 1962–66 than during the previous 4 years, as evidenced by the change in the elevation of the top of the spoil bank. (See fig. 21.) This decrease in sheet erosion may be attributed to fewer intense storms and less precipitation and runoff during the later period.

Although sheet erosion decreased during the period 1962–66 in comparison with that during the preceding 4 years, the loss of material by gully erosion increased greatly with time. Although there were fewer storms and less runoff in the 1962–66 period, erosion from area 11, which is drained by a major gully, increased by about 50 percent from the erosion during 1958–62. The removal of material along the major gully accounted for most of this increase.

The data on erosion in areas 11 and 12 illustrate the effect of topography and channel development on rates of erosion. For a unit area, much more material is eroded and transported from the spoil bank from areas drained by major gullies than is removed from rilled or terraced areas. In gullies, large quantities of surface runoff are gathered into a single main channel, where the turbulence and velocities of the water are sufficient to transport large volumes of material from the spoil bank. Also, large quantities of loose material are made available for transport by slumping of the gully walls. In the rilled and terraced sections of the bank runoff is not gathered into one main channel. Mat-

FIGURE 23.—Comparative photographs illustrating slumping of spoil and deepening of the gully in area 11. Upper photograph, December 10, 1958; middle, September 30, 1962; lower, October 20, 1966.

erial that is eroded during a given storm may be transported only a short distance, or to the next terrace, where it is temporarily deposited. Thus, lesser volumes of material are completely removed from the spoil bank.

SEDIMENT TRANSPORT

Material that is eroded from the spoil bank during a storm may be carried directly into Cane Branch or it may be deposited on the forest floor and in the channels of the tributaries. The deposited sediment is commonly eroded by runoff from succeeding storms and transported further downstream. Even material that reaches Cane Branch immediately after erosion from the spoil bank may pass through numerous cycles of erosion, transportation, and deposition before reaching the gaging station where it is measured. The sediment discharge measured at the gaging station defines the amount of material removed from the study area and is not a measure of the total erosion taking place within the area. The following sections describe the sediment concentration in runoff from mined and forested areas, changes in the rate of sediment discharge, and storage of sediment in the channel of Cane Branch by deposition.

COMPARISON OF SEDIMENT TRANSPORT IN MINED AREAS WITH SEDIMENT TRANSPORT IN FORESTED AREAS

The same processes of weathering, erosion, and sediment transport are active in both the mined and unmined areas, but the quantities of sediment involved are much less in unmined and forested areas. The soil in unmined areas is protected from erosion by vegetation, and there are no large areas of loose material available for transport.

Storm runoff from strip-mined areas has a much higher sediment concentration than does runoff from forested areas. The sediment concentration of Cane Branch exceeded 30,000 ppm during 37 storm events in the more than 8 years of sediment record between February 1956 and September 1966, and has exceeded 20,000 ppm 68 times during that period. For comparison, the maximum sediment concentration measured in the forested Helton Branch basin during the $2\frac{1}{2}$ years of record, February 1956 to September 1958, was only 553 ppm.

The higher sediment concentrations and loads carried in storm runoff from strip-mined areas are further illustrated in figure 24, which shows hydrographs of the May 7, 1960, storm. The rainfall accumulation during the storm was about 2.7 inches

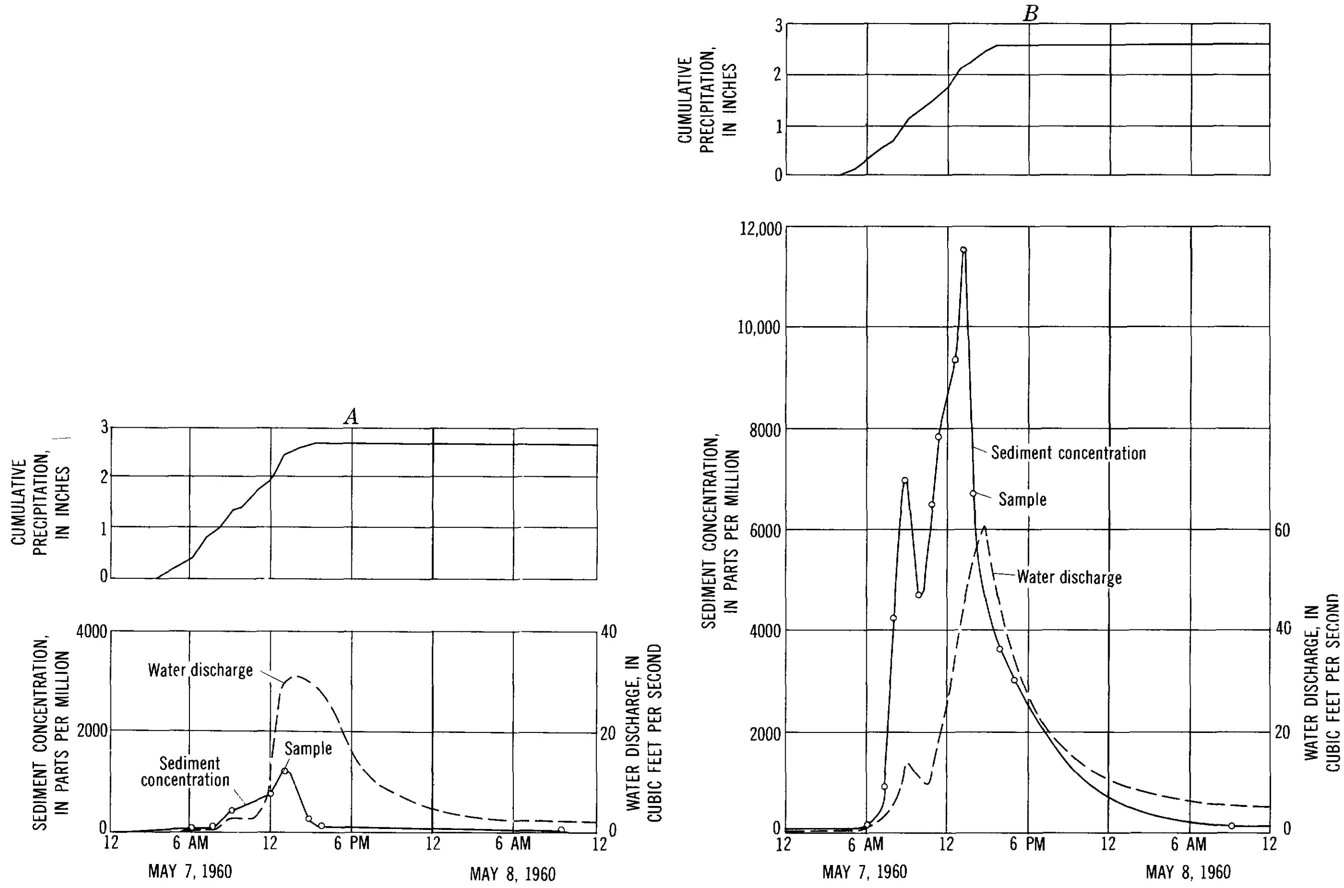

FIGURE 24.—Comparative hydrographs and sediment concentrations for the storm of May 7, 1960. *A*, West Fork Cane Branch gaging station; *B*, Cane Branch gaging station.

in each study area, and the rainfall intensities during the 12 hours of precipitation were similar. The basin of West Fork Cane Branch is forested, except for 1.3 acres which were disturbed by prospecting for coal and by construction of an access road to the gaging stations. In the Cane Branch basin, 44.6 acres were disturbed by strip mining. Runoff from the storm on May 7 caused a peak sediment concentration of 1,210 ppm in West Fork Cane Branch (fig. 24*A*) and produced a sediment load of 9.6 tons for the drainage basin, or 36.9 tons per square mile. In Cane Branch, the sediment concentration reached 11,500 ppm (fig. 24*B*), and 217 tons of sediment, equal to 324 tons per square mile, was discharged from the basin.

SEDIMENT TRANSPORT AT CANE BRANCH GAGING STATION

The annual sediment yield from unmined parts of the study areas is probably in the range of 20 to 30 tons per square mile. A yield of this magnitude was established by Collier and Musser (in Collier and others, 1964, p. B53) from measurement of the sediment discharge of Helton Branch and from the similarity of sediment concentrations measured at Helton Branch and at reconnaissance sites in unmined subbasins of Cane Branch. Prior to mining, the Cane Branch basin, which had a hydrologic environment similar to that of Helton Branch (Musser, 1963), probably had a sediment yield of about 25 tons per square mile. During two periods 1955–56 and 1958–59, strip mining disturbed a total of 10.4 percent (44.6 acres) of the Cane Branch basin and provided large quantities of loose material, unprotected by vegetation, for erosion and transport by surface runoff.

Since the 1956 mining, the annual sediment yield of Cane Branch has ranged from 617 to 3,010 tons per square mile (table 9). The highest weighted mean concentration, 1,640 ppm, occurred during the 1959 water year and was due partly to active strip mining on the northeastern side of the basin.

TABLE 9.—*Summary of sediment discharge by water years, Cane Branch near Parkers Lake*

Water year	Water discharge (cfs-days)	Sediment concentration (ppm)[1]	Sediment discharge (tons)	Sediment yield (tons per sq mi)
1956 (part)[2]	333.032	437	393.64	588
1957	388.698	537	562.74	840
1958	414.882	1,160	1,294.65	1,930
1959	187.711	1,640	830.84	1,240
1960	464.119	1,380	1,731.00	2,580
1961	324.726	689	603.89	901
1962	464.928	1,600	2,018.42	3,010
1963	265.95	--	--	--
1964	190.38	--	--	--
1964 (part)[3]	28.28	2,510	191.66	286
1965	285.80	1,550	1,199.76	1,790
1966	120.88	1,270	413.07	617

[1] Weighted with water discharge.
[2] February to September only.
[3] October to January and July to September only.

The average sediment yield from the Cane Branch study area for 4 water years, 1959–62, was 1,934 tons per square mile. If an average annual sediment yield of 25 tons per square mile is assumed for unmined parts of the Cane Branch study area (Collier and others, 1964, p. B53), the sediment yield from the mined areas was calculated and found to average more than 27,000 tons per square mile per year. The sediment yield computed for the mined area for the 1962 water year exceeded 42,700 tons per square mile.

In table 9, there is no correlation between annual water discharge and annual sediment discharge. The 1960 and 1962 water years, for example, had nearly identical water discharges, but about 288 more tons of sediment was discharged in 1962 than in 1960. The increase in sediment discharged in 1961 as compared with 1957, a year of similar water discharge, is as expected because an additional 17.1 acres of the study area was strip mined in 1958–59 and provided additional loose and unprotected material for erosion and transport by runoff.

Lower sediment yields during the 1965 and 1966 water years resulted from a deficiency in precipitation and runoff and are not indicative of a decrease in the potential erosion of the mined area. The annual sediment yield was lowest during the 1966 water year, the year having lowest streamflow. The high amounts of precipitation and runoff during the summer of 1966 resulted in a proportionately higher weighted mean concentration for those months. The Cane Branch basin averaged 7.34 inches of rainfall in August 1966 (see table 24), and the sediment discharge of Cane Branch was 145 tons (see table 33), more than one-third of the sediment discharge for the year.

Few storms occurred during the period of record in the 1964 water year also, as shown by the extremely low total water discharge for the period. The weighted mean sediment concentration for that period of record was high, however, because 176 of the 192 tons was discharged during three storms in August and September, months when storm runoff causes relatively high sediment concentrations in Cane Branch.

An inspection of the summary of the monthly sediment discharge of Cane Branch, shown in table 33, reveals that during the warm months the weighted mean sediment concentration was highest and was frequently greater than 2,000 ppm. In other words, for a given amount of runoff, considerably more sediment was transported during the warm months than during cold months when the spoil material was frozen and more resistant to erosion. Also, high intensity rainstorms, which generally occur in the warm months, loosen material by the impact of raindrops and produce high rates of runoff to transport the sediment.

The monthly data for the period February 1956 to September 1959 were given by Collier and others (1964, p. B56). The daily sediment discharges, daily mean concentrations, and particle-size analyses for water years 1956–63 were published annually by the U. S. Geological Survey (1956–63) in its Water-Supply Paper series. The data for the 1964–66 water years were released in the series of annual State reports of the U.S. Geological Survey (1964–66).

CHANGES IN SEDIMENT YIELD OF CANE BRANCH STUDY AREA

Although no records of sediment discharge for Cane Branch were obtained previous to mining, Collier and Musser (in Collier and others, 1964, p. B52–B58) showed that the sediment yields of the Helton Branch and Cane Branch basins were probably similar. Therefore, substantial changes in the relationship of sediment discharge to water discharge in Cane Branch must be attributed to mining and associated activities in the Cane Branch basin because these were the only activities that altered the hydrologic environment of the basin.

Changes in the relation between water discharge and sediment discharge of Cane Branch from 1956 to 1959 were described by Collier and Musser (in Collier and others, 1964, p. B60–B61). This relation is extended in figure 25 by including the data for storm runoff during the 1960–62, parts of 1964, and the 1965–66 water years. As in the earlier analysis, only the water and sediment discharged by direct

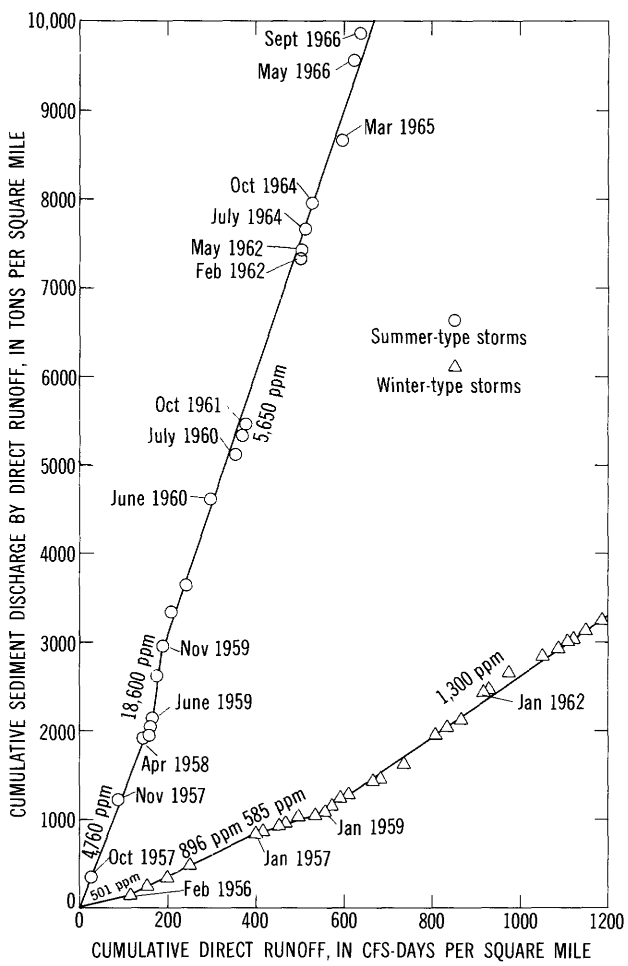

FIGURE 25.—Changes in relation of cumulative sediment discharge to cumulative direct runoff, Cane Branch gaging station.

runoff from storms that produced more than 1 cfs per sq mi (cubic feet per second per square mile) were used in the analysis of the period 1960–66. The curves that were developed, therefore, represent 40.8 percent of the total water discharge and 95.6 percent of the total sediment discharge. One curve is for the intense summer-type storms and the other curve is for the longer duration winter-type storms. The points shown are plots of the cumulative totals for each month; if several storms occurred in a given month, they are shown as one point. McCabe (see "Precipitation and Runoff") found no progressive change in runoff characteristics of Cane Branch during the 11-year period of study; changes in the slope of the curves result from a change in the water-sediment relationship.

Each change in slope of the curves can be related to events or changes that took place in the strip-mining activity in the study area. Mining started on the southwest side of Cane Branch in 1955 and was nearly completed when the sediment record was begun in February 1956. The sediment discharge of Cane Branch probably began to increase shortly after the beginning of mining. The discharge-weighted mean sediment concentration in storm runoff averaged 501 ppm in February 1956. The quantity of sediment transported by winter storms continued to increase during 1956; the weighted mean concentration of the direct runoff averaged 896 ppm from February 1956 until January 1957. During the succeeding two winters, it averaged slightly less, 585 ppm. Few winter storms occurred from February 1957 to January 1959 (see Collier and others, 1964, p. B6, and table 5), and the runoff and sediment concentrations were both less than in the previous years.

The effects of the new mining started on the northeast side of Cane Branch during late 1958 caused an increase in the weighted mean concentration in winter storms. Since January 1959 it has averaged 1,300 ppm, a greater concentration than during any previous period. This new mining caused an even greater increase in the amount of sediment transported by summer-type storms; from 1956 to June 1959, the mean concentration was 4,760 ppm. It increased to 18,600 ppm during the summer of 1959. By the summer of 1960, the immediately available loose material from the northeast spoil bank apparently had been transported past the gaging station and the weighted mean concentration decreased. It remained at an average of 5,650 ppm through September 1966. A comparable decrease was not noted for the winter-type storms.

As vegetation becomes established on the spoil banks, the spoil will gradually become more protected from weathering, erosion will decrease, and the mean concentration of sediment transported by Cane Branch will no doubt decrease. Later extensions of the curves in figure 21 would have a lesser slope. This reduction in sediment transport, however, has not yet occurred in the Cane Branch study area. The heterogeneous material of the spoil banks continues to erode at an excessive rate and may do so until a vegetal cover provides stability for the rocks and soil.

CHANGES IN PARTICLE-SIZE DISTRIBUTION OF FLUVIAL SEDIMENT IN CANE BRANCH

Sediment concentration increases and the particle-size distribution of the sediment becomes coarser as the water discharge increases in Cane Branch. Collier and Musser (in Collier and others, 1964, p. B61–B62) showed that at low concentrations the material in transport was predominantely clay. At higher concentrations, which resulted from increased direct runoff with greater turbulence and higher velocities, larger particles were picked up by the water, and the percentage of coarser material increased.

The average particle size for a given range in concentration has become coarser since 1959. This is illustrated in figure 26, which shows the average

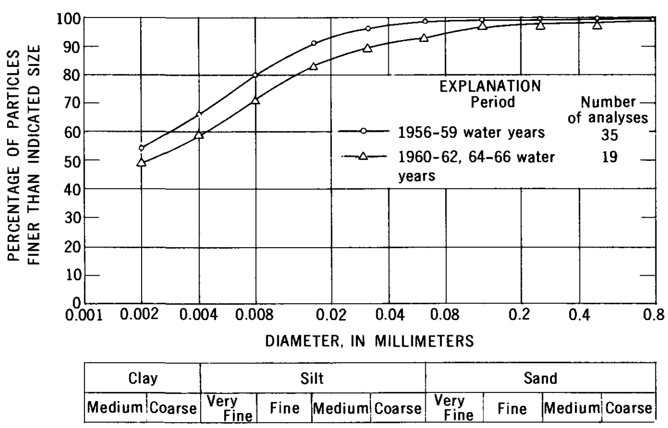

FIGURE 26.—Particle-size distribution of suspended sediment in the 1,040- to 7,790-ppm concentration range, Cane Branch gaging station.

particle-size distribution from analyses of samples with concentrations ranging from 1,040–7,790 ppm for the period 1956–59, and also for the combined periods of 1960–62 and 1964–66. At this concentration range, the average percentage of clay decreased from 67 percent during the earlier period to 59 percent during the later period; silt increased from 32 percent to 34 percent, and sand increased from 1 percent to 7 percent.

This increase in particle size is the result of several factors. The 1959 mining, which was done on the northeast side of the Cane Branch basin, provided a source of loose material closer to the gaging station than the earlier mining; the coarser material, therefore, had a shorter distance to migrate to the gage and reached it relatively soon after erosion. Also, after initial erosion of finer material, the coarser silts and sands from the southwest spoil bank may have had enough time to migrate to the gage in quantities sufficient to contribute to the change in particle-size distribution.

An increase in the particle size also was noted in the sediment deposits along the channel of Cane Branch in area 1, a short distance upstream from the Cane Branch gaging station. In the early years of this investigation, the deposits consisted of mucky, unconsolidated, fine material, through which it was difficult to walk. These deposits became coarser during the period 1960–61 and after a severe storm in February 1962. The deposits are now firm and contain a higher percentage of sand. They are discussed further in the following section.

SEDIMENT DEPOSITION IN CANE BRANCH

Large quantities of sediment were deposited in the channels of the streams affected by strip mining in the Cane Branch basin. Along Cane Branch, many pools in the stream were almost completely filled with sediment, and additional deposition occurred on the flood plains along the channel. This deposition is, in many places, temporary and ever changing; the material is alternately eroded, transported, and redeposited as it migrates downstream during storm events.

Selected reaches of the Cane Branch channel and flood plain were mapped repeatedly to define erosional and depositional changes. The locations of these areas are shown on plate 1.

In April 1958, the rather straight reach of channel in area 1, located a short distance upstream from the Cane Branch gaging station, consisted of a shallow pool containing clay and silt with some sand particles (fig. 27). At the downstream end of area 1, just behind a log and brush dam, there was a large hole more than 1 foot deep in the channel bed.

In March 1960, area 1 was essentially the same as in 1958 except that several inches of sediment had been deposited on the bed of the shallow pool. The log and brush dam had moved 3 feet downstream, but the hole was still present behind the dam.

A severe storm in February 1962 resulted in the highest runoff in Cane Branch for the period of record and caused many of the deposits in the Cane Branch channel from the spoil bank to the gaging station to be flushed downstream. During this storm, extensive scouring along the channel in area 1 removed much of the material that had been deposited on the streambed and on some parts of the channel banks.

By May 1962, the pool in area 1 had again become partly filled with sediment, but in July 1962, entirely new conditions were noted along the channel. The long shallow pool was almost completely filled with sediment, and the stream had a braided pattern through the reach rather than the single

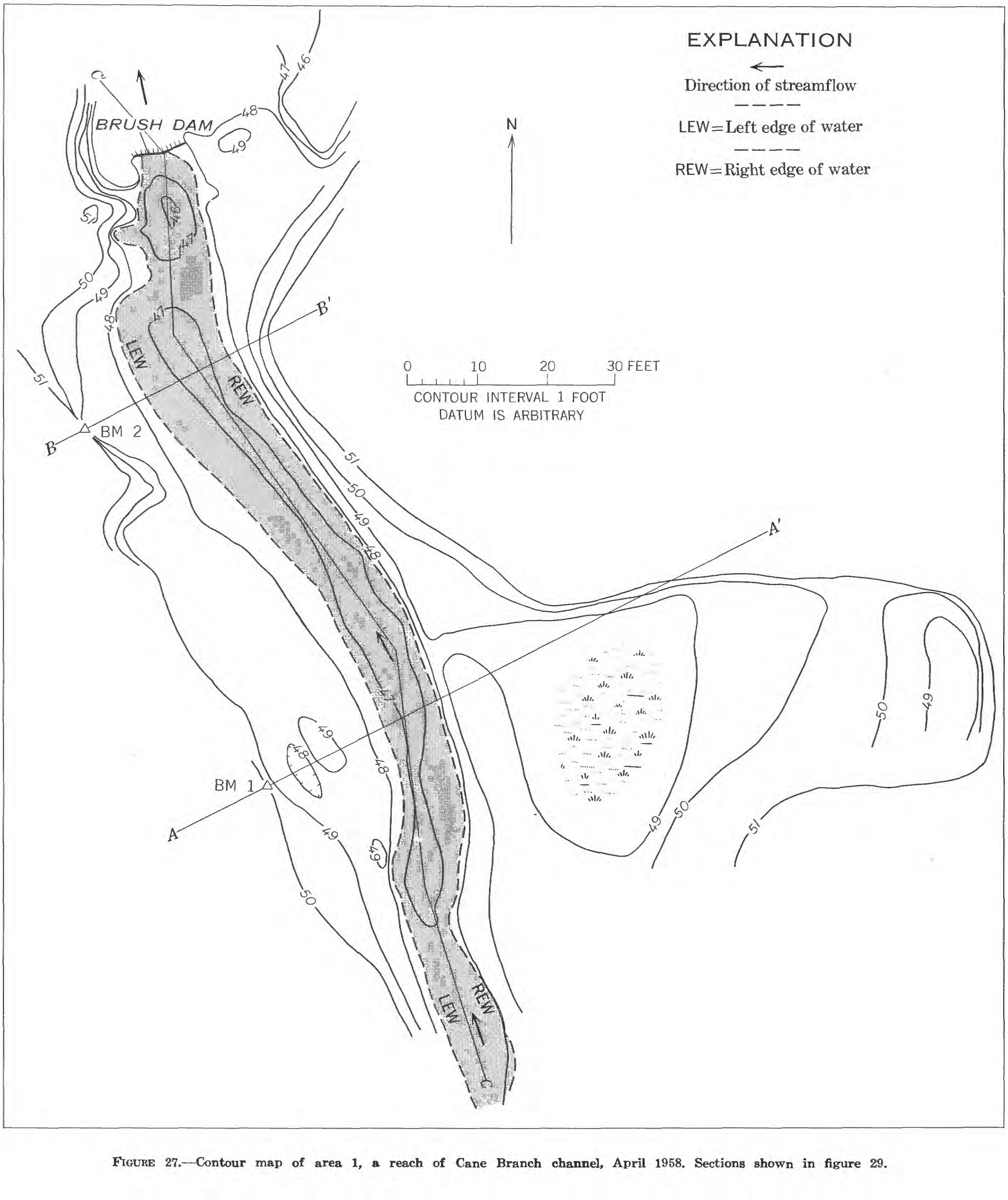

FIGURE 27.—Contour map of area 1, a reach of Cane Branch channel, April 1958. Sections shown in figure 29.

channel and pool as before. The sediment deposits contained more sand, whereas clay and silt had predominated in 1958–59. A small tributary draining part of the northeast spoil bank and entering Cane Branch in area 1 had built a delta of about 30 square feet along the side of the channel. This

FIGURE 28.—Comparative photographs of the Cane Branch channel in area 1, showing sediment deposits and changes in the channel. Upper photograph, April 20, 1958; lower, October 26, 1966.

delta was not present during previous observations. Sandbars filled the holes in the stream bed behind the brush dam. Thus, within only 6 months after the February storm, the channel had become refilled with sediment. By October 1966, additional deposition was evident. The delta was still present, but it had enlarged to about 50 square feet, and the pool was nearly filled with sediment.

Changes in the appearance of the channel in area 1 are evident in the comparative photographs in figure 28. Water discharges at the times of these photographs were 0.53 cfs on April 20, 1958, and 0.11 cfs on October 26, 1966. In April 1958 (upper picture), the channel was well defined, although recent deposits of dark gray sediment covered the flood plain along the left bank and partly filled the pool. In October 1966 (lower picture), the channel was nearly filled with sediment. The elevation of the flood plain along the left bank was less than 1 foot above the water surface in the 1966 picture compared with about 2 feet above in 1958.

The longitudinal profile and cross sections of area 1, shown in figure 29, illustrate the amount and location of sediment deposition in the channel. The longitudinal profile, section *C–C′*, through the deepest part of the channel (see fig. 27 for location) shows that from 1958 to 1962 net sediment deposition varied from 0.1 foot in the upstream end of the pool to as much as 1.7 feet near the brush dam and averaged about 0.6 foot. From 1962 to 1966, additional deposition averaged about 0.8 foot and extended nearly 30 feet further upstream, with the sediment being more evenly distributed throughout the length of the pool.

Sediment deposition in the channel and on the flood plains in area 1 is shown best in sections *A–A′* and *B–B′* in figure 29. Prior to strip mining in the Cane Branch basin, an overflow channel apparently existed along the west flood plain in the upstream part of the area. In 1958, this channel was nearly filled with sediment, and only shallow depressions remained. From 1958 to 1962, the overflow channel was completely filled with sediment, as shown in section *A–A′*. The maximum thickness of this new deposit was 2.2 feet.

The total thickness of sediments deposited on the west flood plain since the 1956 mining activity ranges from about 0.5 to 2.8 feet, as determined by probing. A considerable amount of deposition also occurred in the swampy area on the east flood plain. (See fig. 29, stations 30–56, section *A–A′*.

During the period 1956–1959, the flood-plain deposits consisted of about 40 percent sand and 60 percent silt and clay. The sediment deposited since 1959 contains about 60 percent sand. The larger particle sizes in the flood-plain and channel deposits since 1959 resulted from the increased size of sediment transported by Cane Branch.

Considerable change occurred in the downstream part of area 1. From 1958 to 1962, the brush dam just downstream from section *B–B′* was forced downstream approximately 15 feet. During this period, deposition was greater near the dam than in the upstream end of the pool. The deep hole in the channel just above the dam was almost completely filled with 1.8 feet of newly deposited sediment by 1962. Along the east side of the channel (stations 20–25), between the main channel and

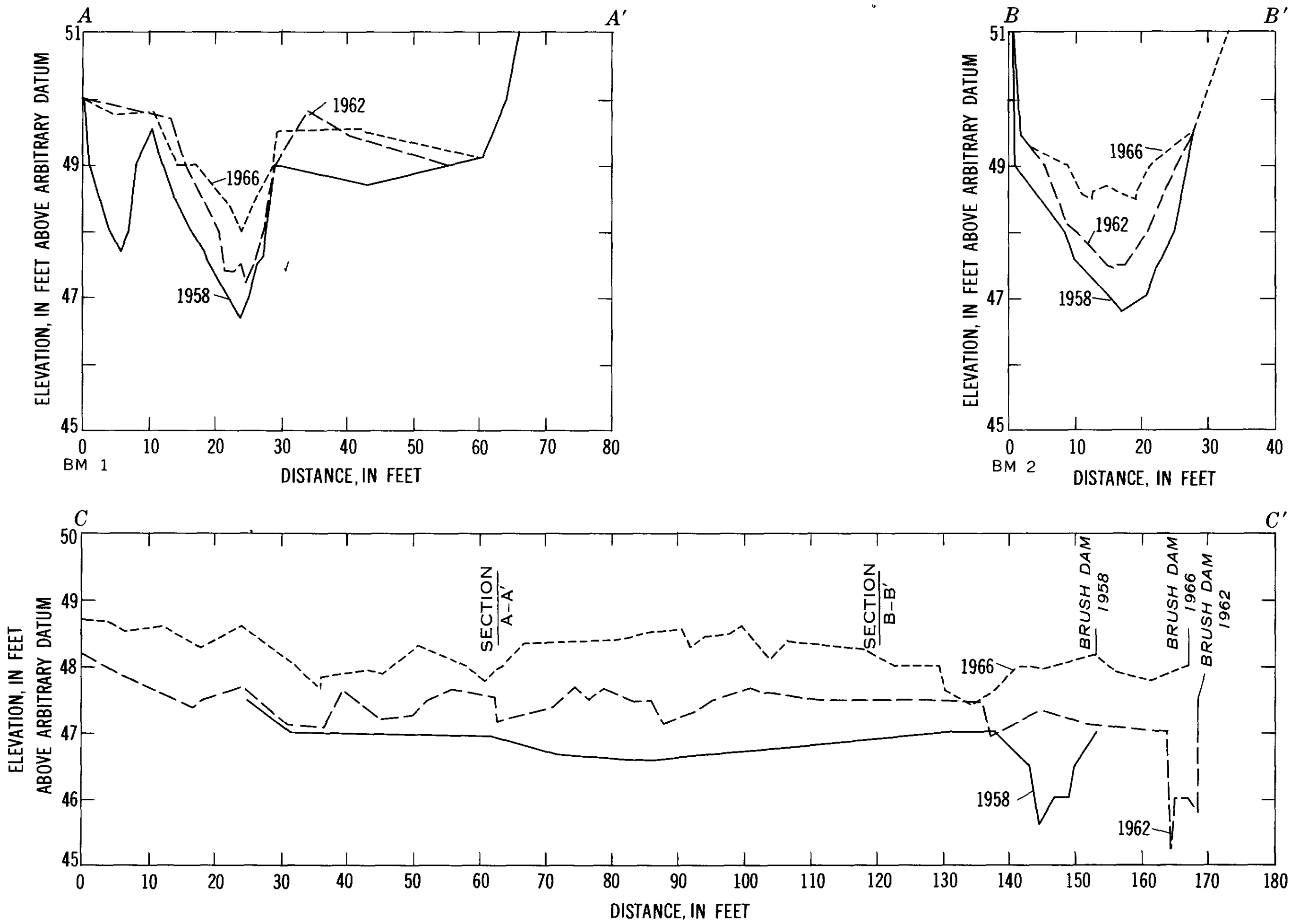

FIGURE 29.—Longitudinal and cross-section profiles of Cane Branch channel in area 1. Vertical exaggeration 10:1.

an overflow channel, rhododendron and other brush trapped nearly a foot of sediment. From 1962 to 1966, the brush dam remained stable, but the overflow channel to the east of the dam was enlarged.

In 1958, the overflow channel at the downstream end of the pool was blocked by roots and debris. In succeeding years, these obstructions were undercut, and by 1966 the overflow channel had eroded headward about 10 feet nearer to the pool in the main channel. If the brush dam continues to block the main channel, the stream will in time move to the present overflow channel.

Sediment deposits similar to those in area 1 are apparent in the other pools in Cane Branch downstream from the strip mine. Deposition in Hughes Fork was reported to extend 4,000 feet downstream from the mouth of Cane Branch in November 1959 (Collier and others, 1964, p. B64). These deposits were also observed in August 1964 and will probably continue to exist as long as the spoil banks in the Cane Branch basin contribute large volumes of sediment to the stream system.

CONCLUSIONS

The sediment characteristics of Cane Branch were greatly affected by strip mining in the headwaters of the stream. The sediment yield from unmined areas averaged about 25 tons per square mile per year, whereas from 1959 to 1962, erosion of the spoil banks in the Cane Branch basin resulted in an average yield of more than 27,000 tons per square mile of spoil bank per year.

Sheet erosion on the gently sloping top of the spoil bank decreased appreciably during the latter part of this study period, whereas loss of material by gully erosion increased with time. The gullies have become well incised into the spoil bank and enlarged by downcutting and slumping of the gully walls.

Erosion of abandoned coal haul roads in the Cane Branch basin was severe in places where the roads had steep grades. Measurements of sediment loss from one short length of steep road indicated an annual sediment yield of 90 tons per acre of road. This is equivalent to an erosion loss of 57,600 tons per square mile.

Since the fall of 1959, when mining ended on the northeast side of Cane Branch, there has been no overall reduction in the amount of sediment discharged by Cane Branch. However, the particle size of the sediment in transport and in the channel and flood-plain deposits of Cane Branch has become coarser since the 1959 mining. Many of the pools in Cane Branch have been nearly filled with sediment deposited since strip mining in the study area. Deposits of fine material were observed in Hughes Fork at the mouth of Cane Branch in August 1964 and were noticeable for several thousand feet downstream from the confluence.

STREAM BOTTOM FAUNA

By J. P. HENLEY, Kentucky Department of Fish and Wildlife Resources

Strip mining of coal in the Cane Branch basin of Beaver Creek affected the invertebrate bottom fauna of both Cane Branch and its reeciving stream, Hughes Fork. Effects on the two streams during the period 1956–58 were reported by Bernard T. Carter (in Collier and others, 1964, p. B77–B80). This report summarizes, for the years 1959–65, (1) the changes in the invertebrate bottom fauna composition of Cane Branch and Hughes Fork, (2) the invertebrate bottom fauna composition of the two control streams, Helton Branch and Little Hurricane Fork, and (3) the benthic repopulation of Hughes Fork. However, reported conclusions are based on the entire period of study, 1955–65.

METHODS

Bottom fauna collections were taken during the month of June in 1959, 1960, 1961, 1962, and 1965, and in August 1964. During each collection period, sampling was done at sites throughout the entire length of each stream, with the exception of Little Hurricane Fork in 1964. Sampling stations were established on each stream, and bottom fauna collections were taken at these same stations each year when water conditions permitted. Only Cane Branch and Helton Branch were sampled in 1965.

Bottom samples were collected from the riffle areas at each station with a Surber square foot sampler. The large bottom material was washed and sorted for macrobenthos, and the remaining benthic organisms and detritus were preserved in alcohol for later identification. The data are presented on a square-foot basis so the bottom fauna from each stream can be compared directly.

RESULTS

Data for Cane Branch, which is immediately affected by strip-mine drainage, and Helton Branch, which is similar in respect to bottom types and morphology but is unaffected by mining activities, are presented in table 10. On the basis of the six samplings during the period 1959–65, Helton Branch supported a mean of 178 benthic organisms per square foot. In this same 7-year period, Cane Branch supported a mean of 30 benthic organisms per square foot, strongly indicating that adverse environmental factors were still present. Variations in annual production of benthic organisms per square foot of stream bed in Cane and Helton Branches are shown in figure 30.

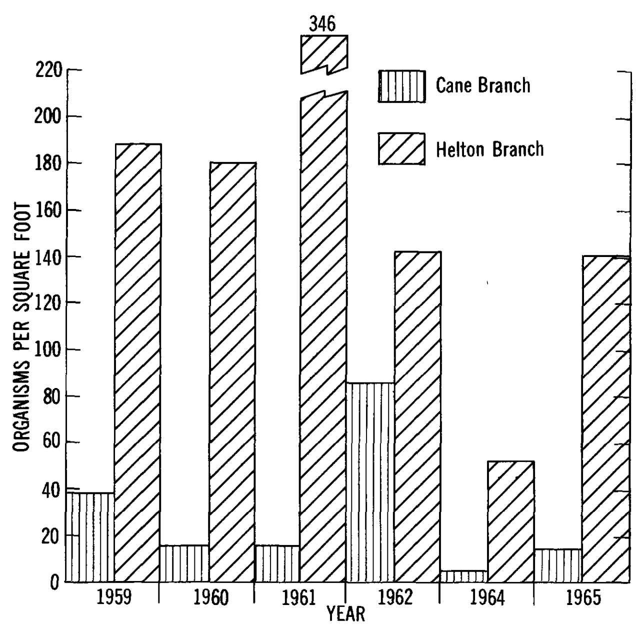

FIGURE 30.—Variations in annual production of bottom fauna in Cane Branch and Helton Branch, June 1959, 1960, 1961, 1962, and 1965, and August 1964.

TABLE 10.—*Average number of bottom fauna per square foot in riffles, Cane Branch and Helton Branch, June 1959, 1960, 1961, 1962, and 1965, and August 1964*

[Tr., trace]

Organisms	Cane Branch						Helton Branch					
	1959	1960	1961	1962	1964	1965	1959	1960	1961	1962	1964	1965
Ephemeroptera	Tr.	0	0	0	0	0	45	28	86	20	3	22
Plecoptera	2	0	0	0	0	0	48	44	62	18	16	17
Trichoptera	0	0	0	0	0	0	46	6	18	16	2	15
Megaloptera	1	1	0	3	4	2	2	2	0	Tr.	0	1
Coleoptera	Tr.	1	Tr.	0	0	0	6	7	26	6	8	7
Diptera	36	17	18	85	2	10	39	91	150	82	11	82
Odonata	Tr.	0	0	0	0	0	4	1	4	2	9	1
Oligochaeta	0	0	0	0	0	0	0	1	Tr.	0	0	0
Crustacea	0	0	0	0	0	0	0	0	0	0	6	2
Amphipoda	0	0	0	0	0	0	0	2	Tr.	2	0	0
Totals	39	19	18	88	6	12	190	190	346	146	55	147

Mayflies (*Ephemeroptera*) and caddis flies (*Trichoptera*), insect orders which form the bulk of the diet of most small stream fishes, were almost entirely lacking from Cane Branch. In Helton Branch, these two orders comprised 28 percent of the total samples collected during the 7-year period.

Cane Branch supported six insect orders in 1959, three orders in 1960, and two orders in 1961, 1962, 1964, and 1965. Helton Branch, on the other hand, supported a total of seven insect orders in 1959, 1961, 1962, and 1964, and eight orders in 1960 and 1965.

The paucity of bottom fauna in Cane Branch and Helton Branch in 1964 was due not only to strip-mine drainage but also to low streamflow and to sampling later in the year. Low water conditions, which prevailed in both streams in August, made sampling of suitable areas very difficult. Also, samples were taken in August after the emergence of the two-winged midges (*Diptera*). In previous samplings, the *Diptera* group represented 92 percent of the combined total numbers of benthic organisms in Cane Branch and 41 percent in Helton Branch. In 1964, the relative abundance of this group decreased to only 33 percent of the total number in Cane Branch and 20 percent of the total number in Helton Branch.

An analysis of data collected from Hughes Fork below the confluence of Cane Branch and from Little Hurricane Fork, the control stream, further illustrates the adverse effect of Cane Branch effluent on bottom fauna (table 11). Hughes Fork, during the 6-year sampling period, supported a mean of 48 benthic organisms per square foot. In the same 6-year period, Little Hurricane Fork supported a mean of 211 benthic organisms per square foot.

The 6-year trend in bottom fauna production in Hughes Fork did not show a definite upward or downward pattern (fig. 31), indicating that Hughes Fork remained relatively constant in bottom fauna production with only minor year-to-year variations. The stream substrate in Hughes Fork has become very unstable following prolonged acid water drainage. The aquatic vegetation in the stream channel, once a stabilizing factor, has been killed, leaving the stream substrate to shift and be

TABLE 11.—*Average number of bottom fauna per square foot in riffles, Hughes Fork and Little Hurricane Fork, June 1959, 1961, and 1962, and August 1964*

[Tr., trace]

Organisms	Hughes Fork					Little Hurricane Fork				
	1959	1960	1961	1962	1964	1959	1960	1961	1962	1964
Ephemeroptera	Tr.	Tr.	Tr.	Tr.	1	44	102	117	21	20
Plecoptera	63	24	24	18	36	41	70	100	11	25
Trichoptera	Tr.	Tr.	6	2	4	10	42	53	16	15
Megaloptera	2	3	2	2	3	2	2	3	2	1
Coleoptera	Tr.	Tr.	1	Tr.	1	6	48	55	12	8
Diptera	3	5	26	7	6	10	103	58	14	19
Odonata	Tr.	0	Tr.	0	1	2	6	5	3	1
Hemiptera	0	0	0	0	0	0	Tr.	0	0	1
Oligochaeta	1	Tr.	Tr.	0	0	0	1	0	Tr.	1
Crustacea	Tr.	0	0	0	0	4	Tr.	Tr.	1	Tr.
Amphipoda	0	0	Tr.	0	0	Tr.	Tr.	0	Tr.	0
Totals	69	32	58	29	54	119	374	391	80	91

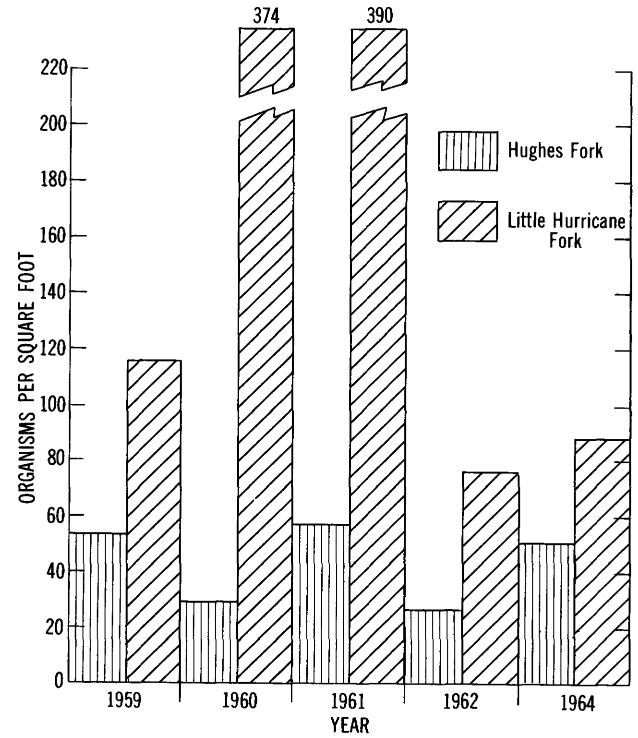

FIGURE 31.—Variations in annual production of bottom fauna in Hughes Fork and Little Hurricane Fork, June 1959, 1960, 1961, and 1962, and August 1964.

washed out during periods of high water. Because of this unstable condition, the benthic organisms are periodically washed out of the study areas by storm runoff.

Bottom fauna production in Little Hurricane Fork increased from 1959 through 1961, dropped to a low in 1962, and then experienced a slight recovery in 1964. In spite of these variations, it is evident from the data collected that Little Hurricane Fork, which has clear flowing water and a stable substrate, consistently supported a faunal complex greater than that observed in Hughes Fork.

Evidence of an increase in aquatic vegetation in Hughes Fork was noted in 1964. Algal growth on the substrate was noticeably greater than that observed during the period 1959–62, and *Dianthra,* a higher form of aquatic vegetation, was beginning to recur along the shoreline.

Selected water-quality data for the above streams at the time of sample collection for benthic organisms in August 1964 are presented in table 12. It is evident from the data that Cane Branch was still receiving a relatively large amount of acid mine drainage in 1964, as shown by the high concentration of sulfate and the low pH in the stream. The pH of 3.2 in Cane Branch on August 4–5, 1964, is well below the tolerance level for most benthic organisms. However, during the same period, Hughes Fork had a pH of 6.0, only slightly below the low range found in many eastern Kentucky streams not affected by acid mine drainage and well within the tolerance range for most benthic organisms.

TABLE 12.—*Stream water temperatures, water discharge, alkalinity, sulfate, and pH for Cane Branch, Helton Branch, Hughes Fork, and Little Hurricane Fork, August 4–5, 1964* [1]

Stream	Temperature (° F)	Water discharge (cfs)	Alkalinity (ppm)	Sulfate (ppm)	pH
Cane Branch	69	0.06	0	242	3.2
Helton Branch	67	.13	10	.4	6.6
Hughes Fork	74	.28	6	10	6.0
Little Hurricane Fork	70	.76	12	2.4	6.7

[1] Chemical analyses by U.S. Geological Survey.

The mayfly nymph, *Ephemeroptera,* caddis fly larva, *Trichoptera,* and beetle larva, *Coleoptera,* are important insect groups and are indicative of clean natural streams in eastern Kentucky, as observed in Helton Branch and Little Hurricane Fork. These three orders were used as indicator species (fig. 32) to test for improvement in stream habitat in Hughes Fork.

No significant increase in abundance occurred in the order *Ephemeroptera* in Hughes Fork during the 6-year sampling period. A very minor increase in abundance occurred in 1964, but this increase was not great enough to be considered a positive indication of improved conditions. A noticeable increase occurred in the order *Trichoptera* in Hughes Fork in 1961, 1962, and 1964; however, the

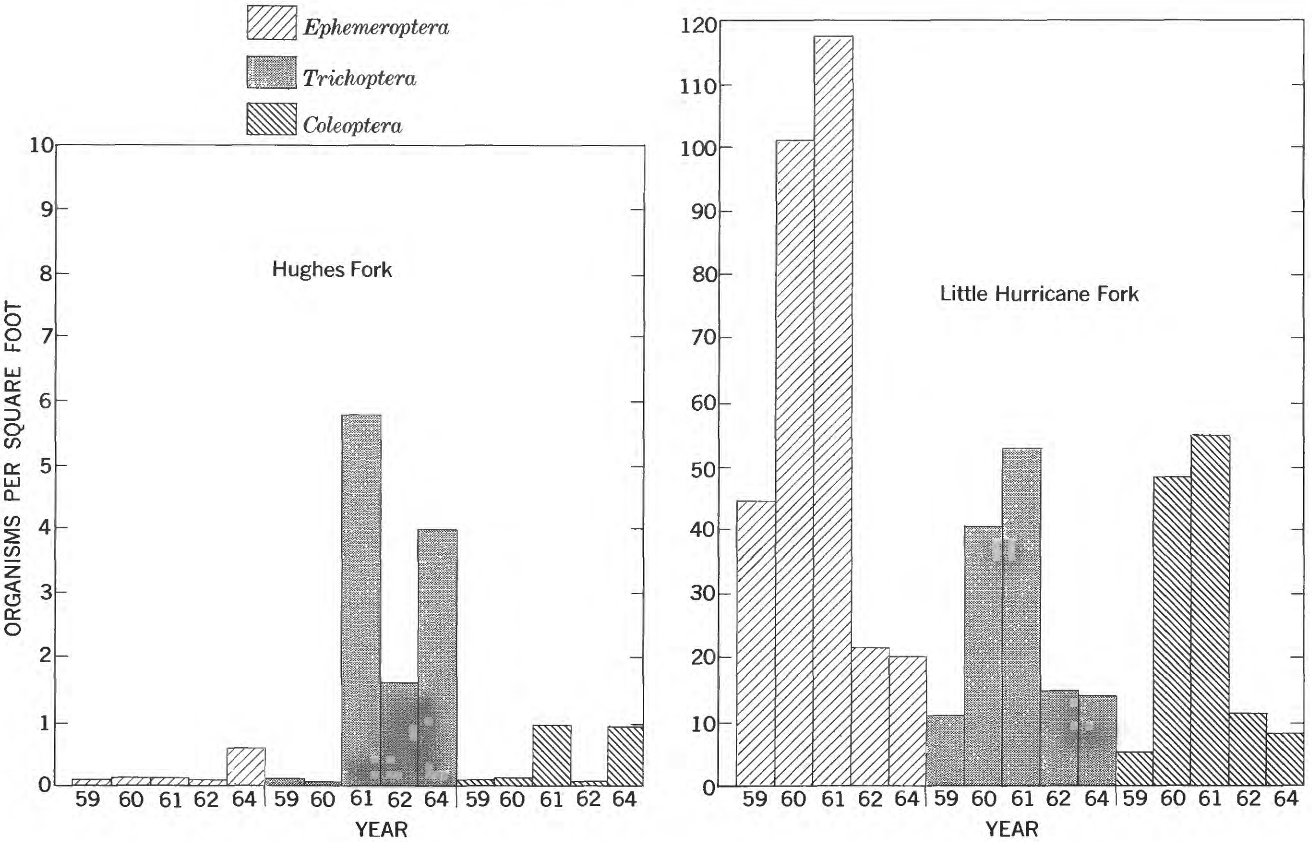

FIGURE 32.—Variations in annual production of *Ephemeroptera*, *Trichoptera*, and *Coleoptera* in Hughes Fork and Little Hurricane Fork, June 1959, 1960, 1961, and 1962, and August 1964.

abundance per square foot was still well below those values recorded in Little Hurricane Fork. The order *Coleoptera* did not increase in any significant numbers in Hughes Fork during the 6-year period. In 1961 and again in 1964, only one specimen was taken per square foot.

The above data indicate that a limited amount of repopulation of benthic organisms has occurred in Hughes Fork. If the stream had not been severely affected by extensive silt and sand deposition, repopulation probably would have occurred much faster. The stream channel must become stabilized again and the benthic habitat reestablished before normal repopulation will occur.

CONCLUSIONS

These and previous data show conclusively that strip mining of coal and the resulting acid water and sediment that were subsequently transported to the stream from the strip-mined areas have resulted in a loss of invertebrate bottom fauna in Cane Branch and Hughes Fork. In spite of a limited repopulation of benthic fauna observed in Hughes Fork in 1964, this loss can be expected to persist in both streams for many years. Not until the strip-mined area is healed and stream habitat restored will aquatic life return to the two streams in any great numbers.

FISH POPULATION

By J. R. SHERIDAN, U.S. Bureau of Sport Fisheries and Wildlife

Fish life disappeared from Cane Branch when its water became highly acid as a result of strip mining of coal during the period 1955–56. The fish population in Hughes Fork, which received the acid water from Cane Branch, was severely restricted. The results of fish population studies in Cane Branch and other streams in the Beaver Creek basin during the period 1956–58 were reported by Marvin A. Smith (in Collier and others, 1964, p. B80–B83). In this report, data on fish production in the sampled streams during the period 1959–66 are presented, and results for the entire study period are summarized. A more detailed discussion of the 1964 sampling is included to illustrate the distribution of species and individuals at the time of the most recent complete sampling of the basin.

METHODS OF CONDUCTING FISH POPULATION STUDIES

Fish population sampling was coordinated with bottom fauna sampling and with the collection of re-

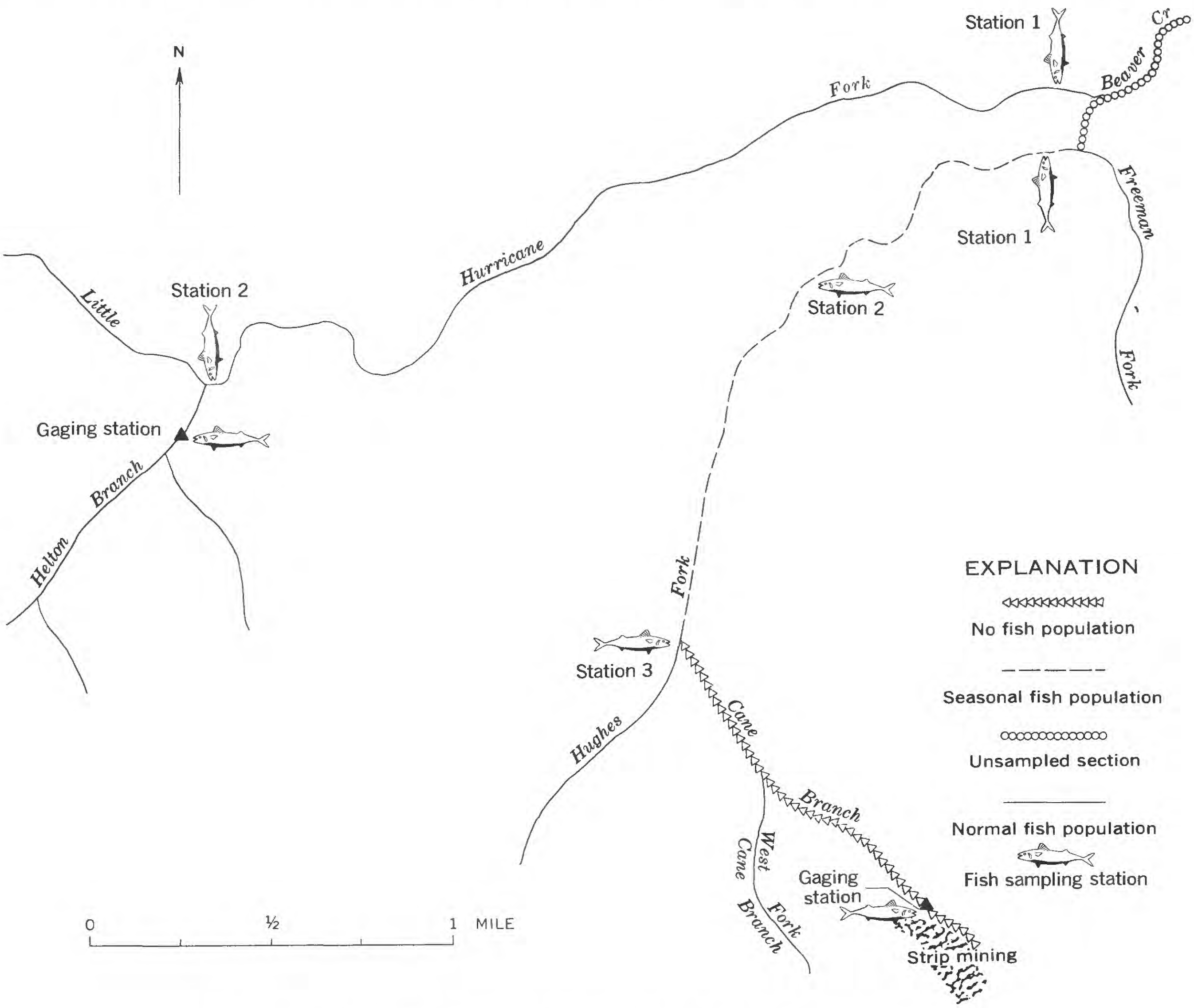

FIGURE 33.—Fish sampling sites in Beaver Creek basin, and distribution of fish in August 1964.

lated water-quality samples from 1956 to 1965, but only the fish population was sampled in 1966. Generally the same areas in each stream were sampled throughout the study period (fig. 33), but the 1965 and 1966 samplings were confined to Cane Branch and Helton Branch.

Fish population samples were collected by the use of cresol. Streamflow was estimated, and the cresol was applied at the head of the sampling section at the rate of 1 quart of cresol per cubic foot per second of flow. The chemical was mixed with water in order to maintain a sustained flow of cresol. Pickup of distressed fish began within 5 minutes after application of the cresol. The fish were first sorted according to species and then grouped by length. The groups were weighed and the data recorded. Mortality was negligible, and overall collection was essentially complete, except for the sample at station 2 on Little Hurricane Fork, where turbidity due to road construction made recovery of fish almost impossible in 1964. The water temperatures, pH, and surface areas of the sampling stations were recorded along with fish-population information.

RESULTS OF 1964 FISH POPULATION SAMPLING

The results of fish population sampling during 1964 are presented in table 13 by species for comparison of fish production in streams affected by acid mine drainage with that in unaffected streams. This was the last year that a complete survey of the upper Beaver Creek basin was made.

The interpretation of the data is straightforward because the only fish found in either Cane Branch or Hughes Fork below Cane Branch (the affected streams) were collected at station 1, just above the confluence of Hughes Fork with Freeman Fork. This fish production was less than 9.0 pounds per acre. Production of all species of fish in unaffected streams ranged from 15.9 to 33.6 pounds per acre and averaged 22.0 pounds per acre. The largest creek chubs observed were only 7 inches long.

In addition to differences in the total weight of fish per acre in affected streams as compared with unaffected streams, differences occurred in number of species. Three species were found in the affected streams, as compared with eight species in the unaffected streams (table 13).

TABLE 13.—*Abundance of fish in tributaries to Beaver Creek according to species, August 1964*

[Abundance, in pounds per acre. Tr., trace]

Species	Length range (inches)	Streams affected by acid mine drainage: Cane Branch above West Fork Cane Branch at gage	Streams affected by acid mine drainage: Hughes Fork, Cane Branch to Freeman Fork, Sta. 1	Streams affected by acid mine drainage: Hughes Fork, Cane Branch to Freeman Fork, Sta. 2	Streams unaffected by acid mine drainage: Hughes Fork above Cane Branch	Streams unaffected by acid mine drainage: Helton Branch at gage	Streams unaffected by acid mine drainage: Little Hurricane Fork, sta. 1 [1]
Creek chub	1–7	0	8.9	0	30.6	14.7	10.2
Arrow darter	1–4	0	Tr.	0	0	1.2	.9
Striped darter	1–4	0	Tr.	0	0	0	1.1
Rainbow darter	1–4	0	0	0	0	0	.1
Hogsucker	1–6	0	0	0	1.3	0	2.9
Rock bass	3	0	0	0	0	0	Tr.
White sucker	1–5	0	0	0	1.4	0	1.6
Southern redbelly dace	1–2	0	0	0	.3	0	0
Total		0	8.9	0	33.6	15.9	16.8

[1] Data for fish pick-up at station 2 incomplete owing to highly turbid water resulting from road construction.

A comparison of the average number of individual fish per acre in the two categories of streams (table 14) shows an average of 122 in the affected streams as compared with an average of 1,787 in the unaffected streams. Creek chubs comprised slightly more than 75 percent of the populations in both affected and unaffected streams. This is a reduction in the percentage of chubs as compared with previous samplings, in which they comprised 93.3 percent of the population, and is due to an increase in the abundance of darters in the 1964 sampling.

The chemical and physical properties of the affected and unaffected streams at the time of fish population sampling in 1964 are presented in table 15 for comparison. Streamflows in the several streams were not appreciably different except for the slightly higher discharge of Little Hurricane Fork near its mouth. Water temperatures were similar also. Differences in pH among the streams are very

TABLE 14.—*Average number of fish per acre of water in tributaries to Beaver Creek, August 1964*

Species	Affected streams		Unaffected streams [1]	
	Number	Percent	Number	Percent
Creek chub (*Semotilus atronaculatus*)	96	78.6	1,387	77.6
Arrow darter (*Etheostoma sagitta*)	26	21.4	52	2.9
Striped darter (*Etheostoma virgatum*)	Tr.	0	140	7.8
Rainbow darter (*Etheostoma caeruleum*)	0	0	39	2.2
Hogsucker (*Hypentelium nigricans*)	0	0	32	1.8
Rock bass (*Ambloplites rupestris*)	0	0	11	.6
White sucker (*Catastomas commersoni*)	0	0	21	1.2
Southern redbelly dace (*Chrosomus crythrogoster*)	0	0	105	5.9
Totals	122	100.0	1,787	100.0

[1] Does not include Little Hurricane Fork, station 2.

evident, especially the contrast between Cane Branch and the unaffected streams. The pH of 3.2 measured in Cane Branch is lethal to fish; pH values of 5.5 and 6.0 for the affected part of Hughes Fork (stations 1 and 2, respectively) suggest that the stream is certainly not toxic to all species; yet fish were not present at station 2 and were extremely sparse at station 1. The limited fish population in Hughes Fork may be due to the limited abundance of bottom organisms that provide food for the fish. (See "Stream Bottom Fauna.")

COMPARISON OF ACCUMULATED FISH SAMPLING DATA

Fish population samplings in Cane Branch and in Hughes Fork below Cane Branch show that fish have not been present in those streams since June 1956, when Cane Branch became highly acid, except for very limited poundages in 1957, 1959, and 1964 in Hughes Fork (table 16). In 1964, fish were found only at the lower end of Hughes Fork at station 1. Cane Branch continued to be devoid of fish through November 1966, as shown by samplings in the early summer of 1965 and fall of 1966. Its highly acid water (pH of 3.0–3.5) is assumed to have prevented return of fish to the stream.

Throughout the study period, fish populations were present in the unaffected streams. On the basis of individual surveys, fish production in pounds per acre ranged from 4.8 in the upstream part of Hughes Fork at station 3 to 370.0 in West Fork Cane Branch. Average production in pounds per acre, based on all samplings, ranged from 16.4 in Helton Branch to 192.2 in West Fork Cane Branch. The fish population in Helton Branch was low but consistent throughout the study period. Data on total fish production in both affected and unaffected streams for the entire study period are shown in table 16.

The results of sampling in Hughes Fork above Cane Branch (station 3) indicate considerable variation in the poundage of fish present, although the 1960 and 1964 results were about the same. Fish production in the upstream part of Hughes Fork and in West Fork Cane Branch declined after 1958, but results of the 1964 sampling appear to show

TABLE 15.—*Chemical and physical properties of streams in the Beaver Creek basin, August 4–5, 1964* [1]

[--------, not determined]

	Cane Branch at gage	Hughes Fork from Cane Branch to Freeman Fork		Hughes Fork above West Fork Cane Branch	Helton Branch at gage	Little Hurricane Fork	
		sta. 1	sta. 2			sta. 1	sta. 2
Discharge (cfs)	--------	0.16	0.28	0.13	0.13	0.76	0.10
Temperature (°F)	69	74	74	75	67	70	67
Average width of sampling section (feet)	4.0	9.0	15.0	9.0	11.0	13.0	--------
pH	3.2	5.5	6.0	7.0	6.6	6.7	7.0
Suspended sediment (ppm)	--------	--------	--------	--------	--------	--------	17
Conductance (micromhos at 25° C)	689	70	40	33	19	28	48
Hardness, as $CaCO_3$ (ppm)	178	20	12	13	9	11	21
Noncarbonate hardness as $CaCO_3$ (ppm)	178	19	7	3	1	1	3
Dissolved solids (ppm)	--------	40	36	26	--------	20	--------
Aluminum (ppm)	--------	--------	--------	--------	.1	--------	--------
Iron (ppm)	5.8	.32	.84	.7	--------	.54	.68
Manganese (ppm)	13	.46	4.2	.05	--------	.02	.71
Sodium (ppm)	1.5	1.5	1.8	1.2	.6	.6	1.9
Bicarbonate (ppm)	--------	1.0	6.0	12.0	10.0	12.0	22.0
Sulfate (ppm)	242	20	10	3.6	.4	2.4	4.8

[1] Chemical analyses by U.S. Geological Survey.

TABLE 16.—*Fish production in affected and unaffected streams*

Date	Sample area (sq ft)	Fish per acre (lb)	pH
AFFECTED STREAMS			
Cane Branch above West Fork Cane Branch (at gage)			
5–16–56	-----	(1)	----
6–27–56	350	0	3.2
9–12–56	350	0	3.0
6– 5–57	350	0	2.7
10–10–57	350	0	5.1
6– 3–58	350	0	3.9
10–22–58	350	0	3.2
5–25–59	350	0	3.7
9–16–59	350	0	3.6
5–24–60	350	0	3.6
8– 5–64	648	0	3.3
6–22–65	670	0	3.6
11– 3–66	670	0	4.4
Median			3.5
Cane Branch below West Fork Cane Branch			
5–16–56	-----	(2)	----
6–27–56	240	0	3.5
9–12–56	240	0	5.1
6– 5–57	240	0	5.2
10–10–57	240	0	3.5
6– 3–58	240	0	4.0
10–22–58	240	0	3.4
5–25–59	240	0	3.9
5–25–60	350	0	----
Median			3.9
Hughes Fork between Freeman Fork and Cane Branch			
9–13–56	80	0	6.8
6– 5–57	2,050	4.0	6.0
10–10–57	164–180–320	0	5.0
6– 3–58	240 & 790	(3)	4.8
10–22–58	164 & 310	0	4.2
5–25–59	835	Trace	5.4
9–15–59	1,800	1.6	5.2
5–25–60	835	0	5.2
8– 4–64	1,656 (sta. 1)	8.9	5.5
8– 4–64	3,000 (sta. 2)	0	6.0
Median			5.3

TABLE 16. *Fish production in affected and unaffected streams*—Continued

Date	Sample area (sq ft)	Fish per acre (lb)	pH
UNAFFECTED STREAMS			
Helton Branch at gaging station			
6–27–56	610	17.0	6.6
9–12–56	610	10.0	6.7
6– 5–57	610	9.3	7.1
10–10–57	610	19.3	7.2
6– 3–58	610	10.7	7.1
10–22–58	610	21.4	7.2
5–25–59	610	12.1	6.8
9–15–59	610	9.9	7.5
5–25–60	610	15.1	6.8
5–24–61	300	13.6	7.0
8– 5–64	682	15.9	6.6
6–22–65	1,077	31.9	6.8
11– 3–66	918	26.7	----
Average		16.4	----
Median			6.9
Hughes Fork above Cane Branch (station 3)			
5–16–56	-----	(2)	----
9–13–56	320	84.4	6.8
6– 5–57	270	4.8	6.8
10–10–57	420	69.5	7.3
6– 3–58	290	111.0	7.0
10–22–58	340	128.0	6.7
5–26–59	344	24.1	6.8
9–16–59	344	51.7	7.5
5–25–60	344	39.0	7.4
8– 4–64	1,800	33.6	7.0
Average		60.7	----
Median			7.0
Little Hurricane Fork (station 1)			
5–26–59	-----	(4)	6.8
8– 5–64	1,664	16.8	6.7
Median			6.8
West Fork Cane Branch			
9–13–56	28	228.0	----
6– 5–57	28	218.0	6.8
10–10–57	21	207.0	7.2
6– 3–58	27	370.0	6.8
10–22–58	28	233.0	6.8
5–26–59	30	166.0	6.8
9–16–59	100	61.5	7.5
5–25–60	100	54.2	7.0
Average		192.2	----
Median			6.8

[1] One creek chub was observed.
[2] Several unidentified fish were observed.
[3] Fry were observed.
[4] Numerous fish were observed.

leveling off in Hughes Fork for the time being. The reason for this decline is not known.

CONCLUSIONS

Fish population sampling in the Beaver Creek basin during the period 1956–66 showed that fish could not live in Cane Branch, owing to the acidity of the water and were severely restricted in number and species in Hughes Fork below the entry of the acid Cane Branch water. Some recovery apparently had occurred by 1964 in Hughes Fork just above Freeman Fork, but it certainly did not result in a fishable population.

MICROBIOLOGY OF STREAMS

By R. H. WEAVER and H. D. NASH, Department of Microbiology, University of Kentucky

INTRODUCTION

Microbiological investigations of Cane Branch and Helton Branch were begun in the spring of 1966 and continued through the winter of 1967–68. Although preceding sections of this report pertain only to data collected prior to October 1966, data for the entire 2-year study period are reported here in order to present as complete a picture as possible of the microbiology of the streams during all four seasons of the year.

Both streams are comparatively small and carry low volumes of water except after heavy rains, when the beds are thoroughly scoured out. The Cane Branch basin contains areas in which coal was strip mined between 1955 and 1959; no stripping has been done in Helton Branch basin.

This investigation was supported by grant 14-01-0001-10A5 from the University of Kentucky Water Resources Institute.

SAMPLING PROGRAM

Samples were collected seasonally from six sampling stations in the Cane Branch basin (fig. 34) and one station in the Helton Branch basin during the 2-year sampling period. Sampling stations 1 and 2 are on tributaries to Cane Branch which receive drainage from the southwest spoil bank. Station 3 is on Cane Branch downstream from these tributaries and at the foot of a 40-foot waterfall. Station 4 is on a tributary which drains the northeast spoil bank. Station 5 is on a tributary which drains the northern part of the southwest spoil bank and a nearby prospect pit. Station 6 is at the Cane Branch gaging station, downstream from the other five sampling sites. Station 7 is at the Helton Branch gaging station (pl. 2) and serves as a control station. Numbers and types of bacteria, fungi, and algae have been determined from the samples in an attempt to gain some insight into changes produced in the microbial ecology of Cane Branch by drainage from the strip-mined areas. Also, changes in the microbiology with distance from the strip-mined area were studied in an attempt to tie the effects of dilution to the partial recovery of microbiota in the stream. Both surface and bottom samples were studied. The temperature and pH of the stream were recorded at the time of sampling.

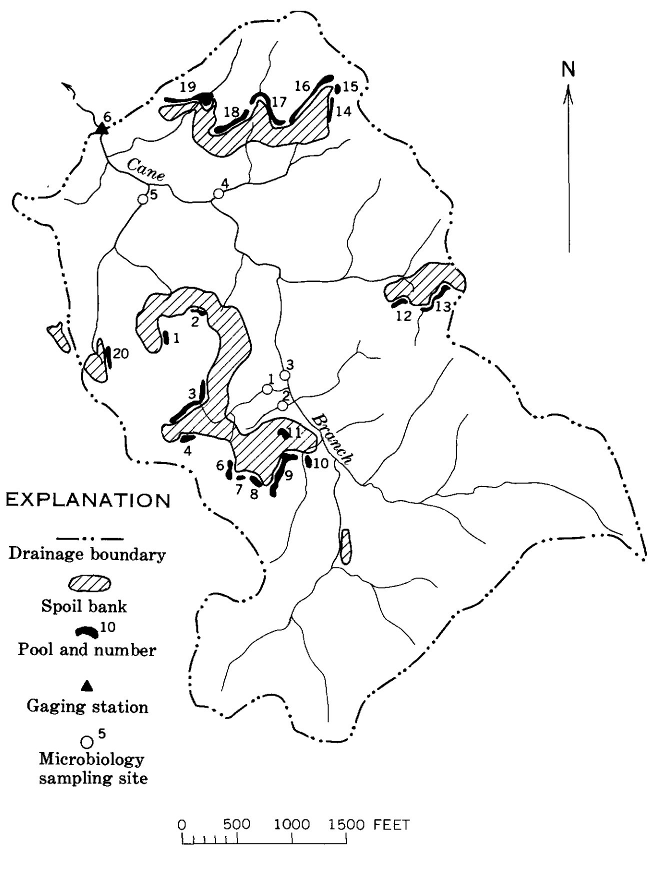

FIGURE 34.—Locations of microbiology sampling sites, 1966–68.

TEMPERATURE AND pH

Characteristic pH values for the four sampling seasons are given in table 17. The pH values at stations 3–6 are higher during the winter than during the other seasons. This is probably largely the result of dilution by other contributing drainage, but may also be due in part to reduced biological activity at lower temperatures. Since there appears to be no natural buffering in Cane Branch, changes in pH tend to persist for an appreciable time and distance downstream.

TABLE 17.—*Characteristic* pH *at microbiology sampling stations, by seasons, 1966–68*

Station		Summer	Autumn	Winter	Spring
1	Cane Branch tributary	3.0	3.0	3.2	3.0
2	Cane Branch tributary	3.5	3.0	3.2	3.5
3	Cane Branch below falls	3.2	3.3	3.6	3.2
4	Cane Branch tributary	3.3	3.2	3.8	3.3
5	Cane Branch tributary	3.5	3.5	4.1	3.5
6	Cane Branch at gage	3.3	3.4	3.9	3.3
7	Helton Branch at gage	6.5	6.7	6.3	6.5

The samples from stations 1 and 2 show less variation in pH than the samples from stations 3–6 because the water at stations 1 and 2 consists of relatively undiluted drainage from the nearby spoil banks. The characteristic pH at station 7 (Helton Branch) is lower in the winter than during the other seasons, possibly because of increased solution of carbon dioxide at the lower winter temperatures.

The water temperatures averaged 19° C (43°F) in the summer, 10°C (38°F) in the autumn, 3°C (34°F) in the winter, and 14°C (40°F) in the spring.

BACTERIA

Lowering of the pH, increase of sulfate, and almost total elimination of bicarbonate alkalinity in Cane Branch in the area that was strip mined (see "Geochemistry of Water") have resulted in the alteration of the bacterial population of the stream. These conditions have resulted in the establishment of *Ferrobacillus ferrooxidans,* which biologically contributes to the acidity of the stream. *F. ferrooxidans* is a chemosynthetic autotroph which oxidizes ferrous iron to ferric iron. This organism grows at a pH of 3.5 and utilizes ferrous iron as its sole energy source, producing ferric hydroxide and, where ferrous sulfate is present, sulfuric acid. It was isolated from Cane Branch during each of the four seasons and from Helton Branch once during the summer. Its isolation from Helton Branch is not surprising since *F. ferrooxidans* is believed to be indigenous to bituminous coal regions. However, the numbers in Helton Branch are probably small since it was found only once, and no pronounced biological effects were evident.

Standard plate counts were made at 20° and 35°C to determine the number of saprophytic bacteria in both Cane and Helton Branches. As a result of sporadic streamflow and turbidity in both streams, consistent counts were not obtained. However, counts did show a fluctuation between 100 and 2,000 bacteria per milliliter in Cane Branch and between 4,000 and 50,000 bacteria per milliliter in Helton Branch during the four seasons.

Attempts were made to observe periphytic bacteria by suspending slides in the streams. However, distance of the streams from the laboratory made frequent observation impossible, and many slides were lost during flooding. Those saved were covered with such a large amount of precipitate as to have little value.

FUNGI

The occurrence of filamentous fungi, yeasts, and true aquatic fungi in Cane and Helton Branches was investigated also. In tables 34–40 are listed the filamentous fungi isolated and identified at each sampling site during the four seasons. Certain genera were more abundant in spring, summer, and autumn than in winter—for example, *Cladosporium, Epicoccum, Mucor,* and *Phoma. Penicillium* was prevalent in all seasons but most abundant during the winter. *Trichoderma* also appeared regardless of the season. Except at station 2, more isolates were obtained from bottom samples during the spring and autumn and from the surface during the winter. Distribution was about equal during the summer.

TABLE 18.—*Summary of occurrence of genera of fungi in Cane Branch and Helton Branch, 1966–68*

Cane Branch and Helton Branch	
Cladosporium	*Cephalosporium*
Fusarium	*Beauveria*
Phoma	*Zygorhynchus*
Rhizopus	*Stemphylium*
Epicoccum	*Pestalotia*
Penicillium	*Monilia*
Mucor	*Gliocladium*
Trichoderma	*Aspergillus*
Alternaria	
Cane Branch	
Septonema	*Cunningamella*
Curvularia	*Thysanophora*
Rhinotrichum	*Mortierella*
Absidia	*Nematogonium*
Thielaviopsis	*Aureobasidium*
Phialophora	*Monosporium*
Botrytis	*Humicola*
Geotrichum	*Chaetomium*
Calcarisporium	*Verticillium*
Oidiodendron	*Myrothecium*
Gongronella	
Helton Branch	
Chrysosporium	*Monochaetia*
Peyronellaea	*Stachylidium*

Table 18 summarizes the filamentous fungi isolated from Cane and Helton Branches. The fungi were more numerous and diversified in Cane Branch; total of 42 genera were identified. Of these, 17 were isolated from both areas, 21 were found only in Cane Branch, and four were found only in Helton Branch. Drainage from the strip-mined area appears to have led to an increased fungal flora in Cane Branch.

Representatives of only three genera of true aquatic fungi were found: *Achlya, Aphanomyces,* and *Saprolegnia* were identified from Cane Branch, whereas only *Achlya* was identified from Helton Branch.

Yeast isolates were identified from the spring samples (table 19). Representatives of five genera were found: three only from Cane Branch, one only from Helton Branch, and one from both. The genus *Rhodotorula* was consistently found in Cane Branch but never in Helton Branch. The yeast flora in the two streams appear to be different; however, the only conclusive statement which can be made is that *Rhodotorula* is characteristic of Cane Branch. *Trichosporon* may be expected to be found in cultures not yet identified from Cane Branch.

Both *Rhodotorula* and *Trichosporon* have been

TABLE 19.—*Yeasts identified from spring samples, Cane Branch and Helton Branch, 1966–67*

Station		Isolates
1	Cane Branch tributary	*Rhodotorula glutinis* *Candida krusei*
2	Cane Branch tributary	*Torulopsis candida* *Rhodotorula glutinis* *Cryptococcus laurentii*
3	Cane Branch below falls	*Candida parapsilosis*
4	Cane Branch tributary	*Rhodotorula glutinis* *Rhodotorula mucilaginosa* *Candida parapsilosis* *Torulopsis versatilis*
5	Cane Branch tributary	*Candida humicola* *Candida parapsilosis*
6	Cane Branch at gage	*Cryptococcus laurentii* *Candida humicola* *Candida parapsilosis* *Rhodotorula glutinis* *Candida krusei*
7	Helton Branch at gage	*Trichosporon cutaneum* *Candida parapsilosis*

associated with streams draining strip-mined areas. *Rhodotorula glutinis* accelerates acid formation by *Thiobacillus ferrooxidans*, whereas the fungus *Penicillium waksmani* retards acid formation by the same organism.

Sufficient information is not available concerning the physiology and biochemistry of the fungi to determine their specific role in recovery of streams from the effects of acid mine drainage.

ALGAE

The algae identified during the four seasons in both Cane and Helton Branches are listed in table 41. The algae identified during the winter were found only in the winter of 1967–68. The sampling schedule may have been responsible for the failure to observe any algae during the preceding winter. Representatives of 23 genera (table 20) were found. Of these, four genera were found in both areas, 11 only in Cane Branch, and eight only in Helton Branch.

TABLE 20.—*Summary of occurrence of genera of algae in Cane Branch and Helton Branch, 1966–68*

Cane Branch and Helton Branch	
Mougeotia	*Ulothrix*
Microthamnion	*Stauroneis*
Cane Branch	
Rhizoclonium	*Zygnemopsis*
Bumilleria	*Tribonema*
Monocila	*Zygogonium*
Cladophora	*Zygnema*
Euglena	*Eunotia*
Hormidium	
Helton Branch	
Gyrosigma	*Oscillatoria*
Fragilaria	*Oedogonium*
Lyngbya	*Meridion*
Micrasterias	*Bulbochaete*

In Cane Branch, the amount of algal growth and the diversity of types increased from close to the strip-mined area, where algal growth was essentially confined to *Euglena* in pools with direct sunlight, to station 6, where extensive algal growth occurred. *Bumilleria sicula* was found only in Cane Branch and only at some distance from the strip-mine drainage area. *Bumilleria* was the predominant alga in the main stem of Cane Branch during the winter of 1967–68. During this particular season, it was found in Cane Branch at station 6 and upstream too, but not above the entry of the tributary sampled at station 4. *Bumilleria* was observed in all seasons except autumn, and was the dominant form near station 6 during these seasons. *Tribonema,* an alga belonging to the same order, Heterothrichales, and family, Tribonemataceae, as *Bumilleria,* was also found at the same locations as *Bumilleria* during the summer.

The morphology of *Bumilleria* in Cane Branch suggests a close relationship with acid mine drainage streams. The brown color of the "H-piece," located along the filament, suggests that *Bumilleria* may utilize ferrous compounds or that ferric compounds are precipitated by it in some manner. On the basis of this observation, similar acid-mine-drainage streams other than Cane Branch were investigated to determine if this genus was present. *Bumilleria* was found in one other stream, pH 2.7, which drains an active strip-mine area. It has not been found in any stream examined that does not contain acid mine wastes.

CONCLUSIONS

Drainage from strip-mined areas appears to have affected the microflora of Cane Branch. Chemical oxidation of pyritic compounds found extensively in spoil banks has resulted in the formation of ferrous sulfate and sulfuric acid. This appears to have led to the establishment in the mined part of the Cane Branch study area of *Ferrobacillus ferrooxidans,* which contributes to the production of acid entering the stream. The lowering of pH has enabled this organism to exist throughout the stream from the vicinity of the spoil banks downstream to the gaging station. Standard plate counts show a much smaller number of saprophytic bacteria in Cane Branch than in Helton Branch. This, too, can be attributed to the low pH of Cane Branch.

The filamentous fungi are more numerous and diversified in Cane Branch than in Helton Branch. In addition, the yeast, *Rhodotorula,* which is associated with increased acid production by *Thiobacillus ferrooxidans*, and the alga *Bumilleria* were isolated only from Cane Branch. The fact that *Bumilleria* was found some distance from the mining area may tie it in some manner to the natural recovery of the stream. On the basis of observations in the Cane Branch basin, *Bumilleria* appears to be associated with streams containing acid mine drainage.

TREE GROWTH

By R. S. Sigafoos, U.S. Geological Survey

Strip mining in forested regions destroys trees in the stripped area and may also destroy trees downslope from the mine through burial by sediment and landslide deposits. Nevertheless, downslope from mines in regions of steep relief, many trees survive and are irrigated by flow from the mine. Elsewhere, tree seedlings become established on bare mine spoil banks. The objectives of this study are to determine the effect of mine drainage on tree growth and to determine the rate of establishment of trees on the mine spoil banks.

An earlier analysis of 10 years of data from 228 trees (Collier and others, 1964, p. B76) suggested that a significant percentage of trees watered by mine drainage grew faster than trees not irrigated by mine drainage. However, subsequent analysis of 20 years of growth of 143 trees, presented in this report, suggests that for the 10 years following mining, 1955–64, irrigation by mine drainage has not had a beneficial effect upon tree growth. In fact, there is some indication that trees irrigated by mine drainage grew more slowly than did trees not irrigated by mine drainage during the 10 years following mining.

The collection, compilation, and analysis of data for this study differ from those that formed the basis for the earlier study. In the earlier study, one core was collected from each tree, ring widths were measured, and radial growth rates were calculated. In an attempt to obtain a more accurate measure of growth for the present study, four cores were taken from each tree, at least one of which contained the innermost ring. From these cores the diameters of three circles were measured and their cross-sectional areas calculated. These consisted of an inner circle delimited by the 1945 ring, a middle circle delimited by the 1954 ring, and an outer circle delimited by the outer ring that grew in 1964. From these areas it was possible to calculate the cross-sectional areas of the trunk formed in the 10-year period prior to mining (1945–54) and in the 10-year period during and after mining (1955–64). In these calculations, the cross section of a trunk was assumed to be circular as is assumed in other methods of forest measurement, whether by plotless, basal area, or cruising methods. The area of wood formed after mining was then compared with that formed for an equal period prior to mining for trees irrigated by mine drainage and those not irrigated.

The 143 trees sampled for this study grow in 17 areas (fig. 35); 107 trees grow in 13 areas irrigated by mine drainage, and 36 trees grow in four areas not so irrigated. Each tree was identified, its trunk diameter was measured, and its position in the canopy or subcanopy was recorded. Trees at the two crown levels are not separated here because of the small number of subcanopy trees that were sampled and because of similar growth rates within the two groups. Criteria for the selection of areas and trees and a brief summary of the mechanism of tree growth were presented in the earlier report (Collier and others, 1964, p. B68–B69).

The cross-sectional area of wood formed during the 10-year period prior to mining was plotted against the area of wood formed during the period following mining for trees irrigated by mine drainage (fig. 36) and for trees not so irrigated (fig. 37). Growth data for these groups of trees are summarized in table 21. Relative growth is given in the summary as a percentage and was computed as follows:

$$\frac{\text{cross-sectional area, 1955–64}}{\text{cross-sectional area, 1945–54}} \times 100 = \text{percentage.}$$

The graphs show that tree growth, both above and below the mined area, was more rapid during the 10-year period following mining than during the 10-year period preceding mining. The summary indicates that after mining ended, a somewhat higher percentage of trees grew faster above the mine than below the mine, suggesting the possibility of a detrimental effect of mine drainage of tree growth. Thus, the sampling failed to support the previous evidence of a beneficial effect of mine drainage on tree growth in the Cane Branch study

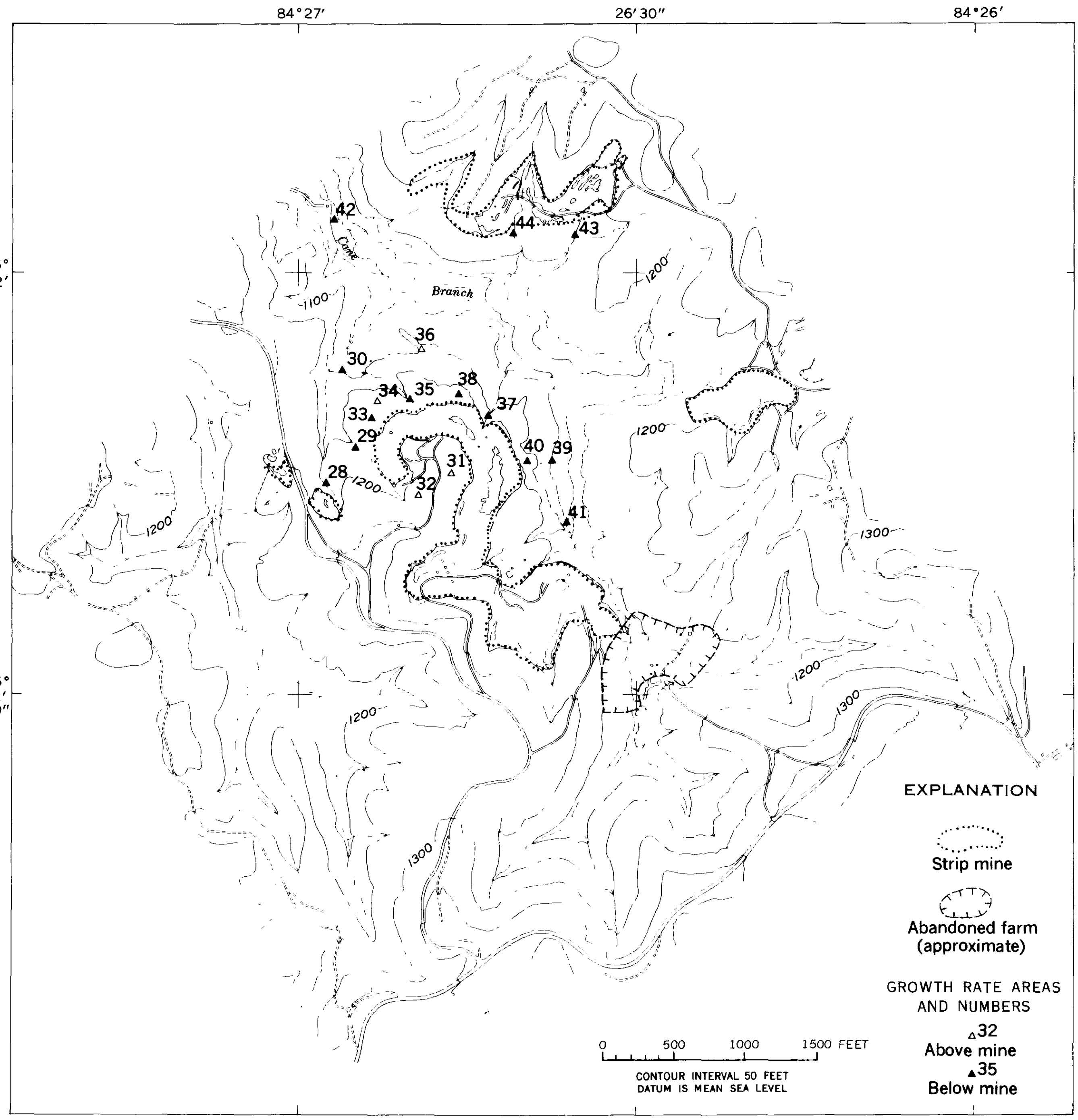

FIGURE 35.—Locations of botanical study areas.

area. The reason why these later results contradict those of the earlier study are not known.

A few observations were made in places where sediment from the mines had buried trees. Some of these trees had died, but evidence that burial alone had caused these deaths was lacking.

The numbers of trees in sample plots on the mine spoil banks were not counted because all plots could not be re-located, and trees in one plot had been cut for an electric power line. Although in places the spoil banks support trees that are growing rapidly, large areas of the banks are barren. Near the headwaters of Cane Branch, the fields of a farm that was abandoned sometime between

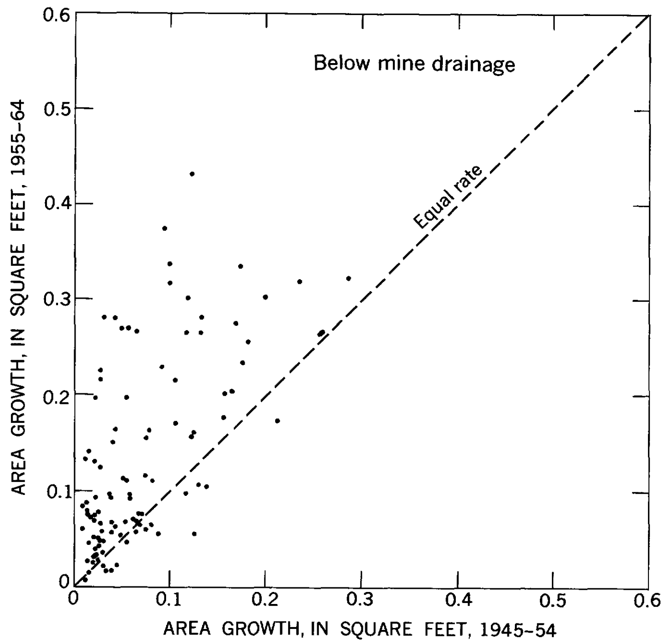

FIGURE 36.—Comparison of growth before mining with growth after mining for trees irrigated by mine drainage.

TABLE 21.—*Summary of tree growth data, Cane Branch study area, 1945–64*

Species	Number of trees sampled	Trees having larger growth since 1955		Relative growth (percent)	
		Number	Percent	Range	Average
Above the mine:					
White oak	15	12	80	76–1053	312
Chestnut oak	6	5	83	98–504	245
Pignut hickory	4	4	100	111–467	225
Black oak	2	2	100	166–700	433
Scarlet oak	2	2	100	143–167	155
Virginia pine	2	2	100	101–257	179
Red maple	2	2	100	380–754	567
3 other species	3	2	67	28–264	179
Total	36	31	86	--------	---
Below the mine:					
White oak	52	42	81	50–1228	353
Red maple	14	8	57	76–245	149
Yellow poplar	10	9	90	60–641	250
Hemlock	8	7	88	85–550	301
Sweet gum	4	3	75	90–222	150
Sweet birch	3	2	67	75–162	115
Red oak	3	1	33	84–107	94
Pignut hickory	3	2	67	49–150	111
Cucumber tree	2	2	100	124–152	138
8 other species	8	5	63	44–345	129
Total	107	81	76	--------	---

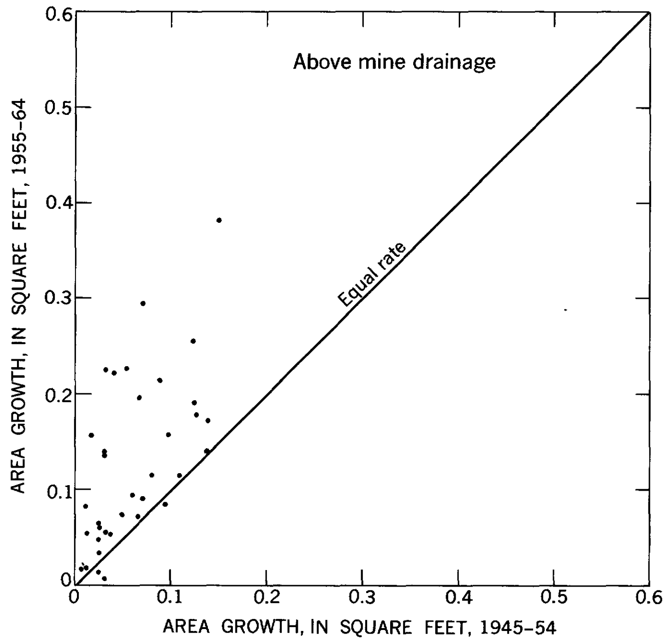

FIGURE 37.—Comparison of growth before mining with growth after mining for trees not irrigated by mine drainage.

1950–55 are now almost completely stocked with pine saplings. Superficial comparison of the area of the mine covered by pines with the area of pines in the abandoned fields show that natural reforestation of the mined area is only a fraction of natural reforestation on abandoned farmland in a nearly comparable period of time, possibly because of toxic minerals in the spoil.

The net effect of strip mining upon the forests in the Cane Branch basin is negative. The area mined was cleared of trees at the time of mining, and after a recovery period of 10 years did not support the number of trees that a comparable area of abandoned cultivated land supported. Furthermore, some trees that were not destroyed at the time of mining subsequently died, probably because of burial by sediment, and other trees may have had their growth inhibited as a result of irrigation by mine drainage.

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U.S. Geological Survey, issued annually through 1961, Surface water supply of the United States, Part 3B, Cumberland and Tennessee River basins:

Water year	Water-Supply Paper	Year published
1957	1506	1959
1958	1556	1960
1959	1626	1960
1960	1706	1961

———issued annually, 1961–64, Surface water records of Kentucky.

———issued annually, 1965–66, Water resources data for Kentucky, part 1, Surface water records.

———issued annually through 1963, Quality of surface waters of the United States, Parts 3 and 4, Ohio River basin and St. Lawrence River basin:

Water year	Water-Supply Paper	Year published
1956	1450	1960
1957	1520	1960
1958	1571	1962
1959	1642	1965
1960	1742	1968
1961	1882	1968
1962	1942	1964
1963	1948	1965

———1964, Water quality records in Kentucky and Tennessee.

———1965, 1966, Water resources data for Kentucky, part 2, Water quality records.

SUPPLEMENTAL DATA

TABLE 22.—*Discharge and runoff at stream-gaging station Cane Branch near Parkers Lake*

Location: Lat 36°52′05″, long 84°26′57″, on left bank 2,100 ft upstream from West Fork, 2.5 miles northeast of Parkers Lake, McCreary County, and 2.6 miles east of Greenwood.

Drainage area: 0.67 sq mi (428.6 acres).

Records available: February 1956 to September 1966.

Gage: Water-stage recorder and concrete control. Datum of gage is 979.4 ft above mean sea level, datum of 1929.

Extremes: 1955–66: maximum discharge, 198 cfs January 29, 1957 (gage height, 2.43 ft, backwater from ice); minimum, 0.005 cfs September 7, 8, 1957.

Month	Mean discharge (cfs)	Runoff: Cfs per sq mi	Runoff: Inches
Water year ending September 30, 1959			
Oct.	0.100	0.149	0.17
Nov.	.261	.390	.43
Dec.	.200	.299	.34
Jan.	.865	1.29	1.49
Feb.	1.34	2.00	2.08
Mar.	.888	1.33	1.53
Apr.	1.50	2.24	2.49
May	.251	.375	.43
June	.185	.276	.31
July	.313	.467	.54
Aug.	.195	.291	.33
Sept.	.158	.236	.26
Year	0.514	0.767	10.40
Water year ending September 30, 1960			
Oct.	0.239	0.357	0.41
Nov.	.897	1.34	1.49
Dec.	2.39	3.57	4.12
Jan.	1.20	1.19	2.06
Feb.	2.42	3.61	3.90
Mar.	2.43	3.63	4.18
Apr.	.764	1.14	1.27
May	1.18	1.76	2.03
June	1.78	2.66	2.96
July	1.68	2.51	2.89
Aug.	.148	.221	.25
Sept.	.118	.176	.20
Year	1.27	1.90	25.76
Water year ending September 30, 1961			
Oct.	0.151	0.225	0.26
Nov.	.219	.327	.37
Dec.	.540	.806	.93
Jan.	.907	1.35	1.56
Feb.	2.01	3.00	3.13
Mar.	2.93	4.37	5.05
Apr.	2.06	3.07	3.42
May	1.05	1.57	1.80
June	.385	.575	.64
July	.325	.485	.56
Aug.	.0974	.145	.17
Sept.	.8939	.125	.14
Year	0.890	1.33	18.03
Water year ending September 30, 1962			
Oct.	0.107	0.160	0.18
Nov.	.138	.206	.23
Dec.	1.10	1.64	1.89
Jan.	2.45	3.66	4.21
Feb.	4.69	7.00	7.28
Mar.	2.74	4.09	4.72
Apr.	3.51	5.24	5.85
May	.266	.397	.46
June	.244	.364	.41
July	.112	.167	.19
Aug.	.099	.148	.17
Sept.	.128	.191	.21
Year	1.27	1.90	25.80

Month	Mean discharge (cfs)	Runoff: Cfs per sq mi	Runoff: Inches
Water year ending September 30, 1963			
Oct.	0.134	0.200	0.23
Nov.	.360	.537	.60
Dec.	.390	.582	.67
Jan.	.434	.648	.75
Feb.	1.00	1.49	1.56
Mar.	4.83	7.21	8.32
Apr.	.226	.337	.37
May	.597	.891	1.03
June	.194	.290	.32
July	.237	.354	.41
Aug.	.197	.294	.34
Sept.	.097	.145	.16
Year	0.729	1.09	14.76
Water year ending September 30, 1964			
Oct.	0.078	0.116	0.13
Nov.	.122	.182	.20
Dec.	.097	.145	.17
Jan.	.758	1.13	1.30
Feb.	1.12	1.67	1.80
Mar.	2.05	3.06	3.52
Apr.	1.30	1.94	2.17
May	.239	.357	.41
June	.127	.190	.21
July	.076	.113	.13
Aug.	.095	.142	.16
Sept.	.207	.309	.34
Year	0.520	0.776	10.54
Water year ending September 30, 1965			
Oct.	0.163	0.243	0.28
Nov.	.267	.399	.44
Dec.	1.12	1.67	1.93
Jan.	1.58	2.36	2.71
Feb.	1.21	1.81	1.88
Mar.	3.21	4.79	5.53
Apr.	1.07	1.60	1.78
May	.231	.345	.40
June	.238	.355	.40
July	.195	.291	.33
Aug.	.047	.070	.08
Sept.	.061	.091	.10
Year	0.783	1.17	15.86
Water year ending September 30, 1966			
Oct.	0.053	0.079	0.09
Nov.	.087	.130	.14
Dec.	.062	.093	.11
Jan.	.950	.142	.16
Feb.	.604	.901	.94
Mar.	.690	1.03	1.19
Apr.	1.01	1.51	1.69
May	.707	1.06	1.22
June	.111	.166	.18
July	.092	.137	.16
Aug.	.191	.285	.33
Sept.	.302	.451	.50
Year	0.331	0.494	6.71

TABLE 23.—*Discharge and runoff at stream-gaging station Helton Branch at Greenwood*

Location: Lat 36°53'07", long 84°28'55", on left bank 250 ft upstream from mouth and 1 mile northeast of Greenwood, McCreary County.

Drainage area: 0.85 sq mi (541.0 acres).

Records available: January 1956 to September 1966.

Gage: Water-stage recorder and concrete control. Datum of gage is 993.8 ft above mean sea level.

Extremes: 1956–66; maximum discharge, 182 cfs February 27, 1962 (gage height, 1.45 ft); maximum gage height, 1.46 ft January 30, 1956 (backwater from debris); minimum discharge, 0.05 cfs October 2, 1956.

Month	Mean discharge (cfs)	Runoff	
		Cfs per sq mi	Inches
Water year ending September 30, 1959			
Oct.	0.201	0.236	0.27
Nov.	.307	.361	.40
Dec.	.259	.305	.35
Jan.	1.04	1.22	1.41
Feb.	1.51	1.78	1.85
Mar.	.983	1.16	1.33
Apr.	1.65	1.94	2.16
May	.437	.514	.59
June	1.25	1.47	1.64
July	.201	.236	.27
Aug.	.188	.221	.26
Sept.	.244	.287	.32
Year	0.680	0.800	10.85
Water year ending September 30, 1960			
Oct.	0.301	0.354	0.41
Nov.	.857	1.01	1.12
Dec.	2.77	3.26	3.76
Jan.	1.34	1.58	1.82
Feb.	2.69	3.16	3.41
Mar.	2.96	3.48	4.02
Apr.	1.09	1.28	1.43
May	1.08	1.27	1.46
June	1.93	2.27	2.53
July	1.59	1.87	2.16
Aug.	.213	.251	.29
Sept.	.199	.234	.26
Year	1.42	1.67	22.67
Water year ending September 30, 1961			
Oct.	0.276	0.325	0.37
Nov.	.483	.568	.63
Dec.	.893	1.05	1.21
Jan.	1.46	1.72	1.98
Feb.	2.23	2.62	2.73
Mar.	3.29	3.87	4.46
Apr.	2.38	2.80	3.13
May	1.26	1.48	1.70
June	.478	.562	.63
July	.306	.360	.41
Aug.	.182	.214	.25
Sept.	.188	.221	.25
Year	1.11	1.31	17.75
Water year ending September 30, 1962			
Oct.	0.169	0.199	0.23
Nov.	.210	.247	.28
Dec.	1.48	1.74	2.01
Jan.	2.87	3.38	3.89
Feb.	4.98	5.86	6.10
Mar.	3.18	3.74	4.31
Apr.	3.75	4.41	4.93
May	.464	.546	.63
June	1.02	1.20	1.34
July	.200	.235	.27
Aug.	.145	.171	.20
Sept.	.160	.188	.21
Year	1.53	1.80	24.40
Water year ending September 30, 1963			
Oct.	0.199	0.234	0.27
Nov.	.460	.541	.60
Dec.	.639	.752	.87
Jan.	.784	.922	1.06
Feb.	1.54	1.81	1.88
Mar.	5.56	6.54	7.55
Apr.	.369	.434	.48
May	.453	.533	.61
June	.340	.400	.45
July	.242	.285	.33
Aug.	.189	.222	.26
Sept.	.172	.202	.23
Year	0.913	1.07	14.59
Water year ending September 30, 1964			
Oct.	0.137	0.161	0.19
Nov.	.166	.195	.22
Dec.	.128	.151	.17
Jan.	.797	.938	1.08
Feb.	1.23	1.45	1.56
Mar.	2.38	2.80	3.23
Apr.	1.41	1.66	1.85
May	.235	.276	.32
June	.146	.172	.19
July	.136	.160	.18
Aug.	.215	.253	.29
Sept.	.271	.319	.36
Year	0.602	0.708	9.64
Water year ending September 30, 1965			
Oct.	0.379	0.446	0.51
Nov.	.529	.622	.69
Dec.	1.90	2.24	2.57
Jan.	2.19	2.58	2.97
Feb.	1.49	1.75	1.82
Mar.	4.05	4.76	5.49
Apr.	1.45	1.71	1.91
May	.310	.365	.42
June	.333	.392	.44
July	.248	.292	.34
Aug.	.165	.194	.22
Sept.	.165	.194	.22
Year	1.10	1.29	17.60
Water year ending September 30, 1966			
Oct.	0.176	0.207	0.24
Nov.	.181	.213	.24
Dec.	.141	.166	.19
Jan.	.207	.244	.28
Feb.	1.12	1.32	1.38
Mar.	.863	1.02	1.17
Apr.	1.29	1.52	1.69
May	1.02	1.20	1.38
June	.173	.204	.23
July	.170	.200	.23
Aug.	.307	.361	.42
Sept.	.327	.385	.43
Year	0.493	0.580	7.87

TABLE 24.—*Precipitation, in inches, at recording gages, October 1958 to September 1966*

Month and year	Cane Branch basin			West Fork Cane Branch basin [1]			Helton Branch basin		
	Gage 1	Gage 2	Average	Gage 3	Gage 4	Average	Gage 5	Gage 6	Average
1958									
October	0.83	1.10	0.96	1.10	1.07	1.08	1.00	1.43	1.22
November	5.22	4.70	4.96	4.91	4.59	4.75	4.03	4.21	4.12
December	1.12	1.37	1.24	1.36	1.25	1.30	1.01	1.18	1.10
1959									
January	3.20	3.56	3.38	3.51	3.45	3.48	3.14	3.37	3.26
February	3.92	3.85	3.88	3.99	3.93	3.96	3.94	3.98	3.96
March	2.87	2.85	2.86	3.03	2.90	2.96	2.65	2.75	2.70
Year ending March 31	44.90	45.43	45.14	47.88	44.97	46.41	43.32	45.06	44.20
April	4.35	3.96	4.16	4.50	4.26	4.38	3.68	4.25	3.96
May	3.63	3.28	3.46	3.68	3.25	3.46	4.35	4.09	4.22
June	4.02	3.26	3.64	3.81	3.77	3.79	4.97	4.87	4.92
July	7.23	6.79	7.01	7.34	6.10	6.72	2.43	4.52	3.48
August	3.71	3.84	3.78	4.05	4.02	4.04	2.32	4.53	3.43
September	2.58	2.47	2.52	3.10	2.82	2.96	2.41	2.50	2.46
Year ending September 30	42.68	41.03	41.85	44.38	41.41	42.88	35.93	41.68	38.83
October	4.88	4.88	4.88	5.11	4.81	4.96	4.48	4.49	4.48
November	5.34	5.44	5.39	5.24	5.02	5.13	4.52	4.86	4.69
December	5.66	5.93	5.80	5.91	5.62	5.76	6.03	6.46	6.24
1960									
January	2.70	2.80	2.75	2.78	2.57	2.68	2.57	2.65	2.61
February	5.42	5.21	5.32	5.62	5.07	5.34	4.75	4.67	4.71
March	4.13	4.65	4.39	5.06	4.43	4.74	3.99	3.71	3.85
Year ending March 31	53.65	52.51	53.10	56.20	51.74	53.96	46.50	51.60	49.05
April	2.23	2.35	2.29	2.50	2.63	2.56	1.70	1.95	1.82
May	4.01	3.99	4.00	4.05	4.13	4.09	4.01	4.15	4.08
June	9.70	9.73	9.72	10.00	9.68	9.84	9.23	9.34	9.28
July	5.75	5.22	5.48	6.07	5.54	5.80	4.71	4.67	4.69
August	2.35	2.26	2.30	2.88	3.02	2.95	2.39	3.29	2.84
September	2.85	2.88	2.86	3.22	3.14	3.18	2.88	3.21	3.04
Year ending September 30	55.02	55.34	55.18	58.44	55.66	57.03	51.26	53.45	52.33
October	3.20	3.24	3.22	3.23	3.33	3.28	2.91	2.99	2.95
November	3.04	2.95	3.00	3.07	3.11	3.09	3.37	3.57	3.47
December	4.33	4.09	4.21	4.06	3.96	4.01	3.77	3.78	3.78
1961									
January	2.09	2.01	2.05	1.89	2.00	1.94	1.90	1.81	1.86
February	4.79	4.70	4.74	4.84	4.38	4.61	4.11	3.82	3.96
March	6.66	6.49	6.58	6.74	6.66	6.70	6.10	5.95	6.02
Year ending March 31	51.00	49.91	50.45	52.55	51.58	52.05	47.08	48.53	47.79
April	4.61	4.66	4.64	4.26	4.13	4.20	4.17	3.83	4.00
May	2.72	2.73	2.72	3.12	3.03	3.08	2.28	2.49	2.38
June	4.83	5.03	4.93	5.62	5.06	5.34	4.49	4.28	4.38
July	4.36	4.43	4.40	4.62	4.37	4.50	4.07	4.78	4.42
August	1.63	1.62	1.62	2.05	1.79	1.92	1.52	1.57	1.54
September	.95	1.13	1.03	.95	.69	.82	.56	.67	.62
Year ending September 30	43.19	43.08	43.14	44.45	42.51	43.49	39.25	39.54	39.38
1961									
October	2.87	2.78	2.82	3.29	2.78	3.04	2.00	2.60	2.30
November	2.98	3.01	3.00	----	----	----	2.81	2.92	2.86
December	7.04	6.68	6.86	----	----	----	6.33	6.30	6.32
1962									
January	5.79	5.64	5.72	----	----	----	5.18	5.60	5.39
February	9.15	8.55	8.85	----	----	----	8.70	8.73	8.72
March	5.93	5.71	5.82	----	----	----	5.62	6.04	5.83
Year ending March 31	52.84	51.97	52.41	----	----	----	47.73	49.81	48.76
April	6.01	5.70	5.86	----	----	----	5.48	5.64	5.56
May	4.15	4.13	4.14	----	----	----	4.05	4.03	4.04
June	4.84	4.60	4.72	----	----	----	5.99	7.17	6.58
July	2.44	2.52	2.48	----	----	----	2.00	2.24	2.12
August	2.21	2.37	2.29	----	----	----	1.22	1.94	1.58
September	4.06	3.68	3.87	----	----	----	2.91	3.36	3.14
Year ending September 30	57.47	55.37	56.43	----	----	----	52.29	56.57	54.44
October	3.00	2.97	2.98	----	----	----	2.79	3.06	2.92
November	4.79	4.79	4.79	----	----	----	3.53	4.35	3.94
December	2.85	2.78	2.82	----	----	----	2.03	2.42	2.23

See footnote at end of table.

TABLE 24.—*Precipitation, in inches, at recording gages, October 1958 to September 1966*—Continued

Month and year	Cane Branch basin Gage 1	Cane Branch basin Gage 2	Cane Branch basin Average	West Fork Cane Branch basin [1] Gage 3	West Fork Cane Branch basin [1] Gage 4	West Fork Cane Branch basin [1] Average	Helton Branch basin Gage 5	Helton Branch basin Gage 6	Helton Branch basin Average
1963									
January	2.45	2.47	2.46	----	----	----	1.63	1.92	1.78
February	2.64	2.95	2.80	----	----	----	2.08	2.33	2.20
March	9.17	9.12	9.14	----	----	----	8.94	9.17	9.06
Year ending March 31	48.61	48.08	48.35	----	----	----	42.65	47.63	45.15
April	1.94	1.68	1.81	----	----	----	1.69	1.77	1.73
May	5.04	4.71	4.88	----	----	----	3.34	3.93	3.64
June	2.71	2.72	2.72	----	----	----	2.60	3.46	3.03
July	6.16	5.98	6.07	----	----	----	5.27	5.70	5.48
August	3.15	2.92	3.04	----	----	----	1.55	1.66	1.60
September	1.25	1.19	1.22	----	----	----	1.08	1.32	1.20
Year ending September 30	45.15	44.28	44.73	----	----	----	36.53	41.09	38.81
October	0	0	0	----	----	----	0	0	0
November	2.65	2.79	2.72	----	----	----	2.25	2.45	2.35
December	2.20	2.30	2.25	----	----	----	2.10	2.11	2.10
1964									
January	4.89	5.34	5.12	----	----	----	4.92	4.88	4.90
February	3.94	3.76	3.85	----	----	----	3.48	3.22	3.35
March	4.68	4.24	4.46	----	----	----	4.14	4.43	4.28
Year ending March 31	38.61	37.63	38.14	----	----	----	32.42	34.93	33.66
April	4.18	3.77	3.98	----	----	----	3.85	4.29	4.07
May	2.81	2.81	2.81	----	----	----	2.07	2.76	2.42
June	1.40	1.25	1.32	----	----	----	1.63	1.63	1.63
July	2.57	2.55	2.56	----	----	----	2.93	3.28	3.10
August	2.93	2.82	2.88	----	----	----	4.49	4.32	4.40
September	5.12	5.02	5.07	----	----	----	4.52	5.25	4.88
Year ending September 30	37.37	36.65	37.02	----	----	----	36.38	38.62	37.48
1964									
October	2.34	2.34	2.34	----	----	----	1.90	2.16	2.03
November	3.91	3.84	3.88	----	----	----	3.21	3.45	3.33
December	4.86	4.52	4.69	----	----	----	4.53	4.79	4.66
1965									
January	4.16	4.47	4.32	----	----	----	3.58	3.91	3.74
February	3.13	3.00	3.06	----	----	----	2.72	2.65	2.68
March	7.71	7.63	7.67	----	----	----	7.08	7.35	7.22
Year ending March 31	45.12	44.02	44.58	----	----	----	42.51	45.84	44.16
April	3.31	2.95	3.13	----	----	----	2.87	2.86	2.86
May	2.59	2.62	2.60	----	----	----	1.86	1.80	1.83
June	4.09	4.10	4.10	----	----	----	3.63	3.70	3.66
July	4.73	4.54	4.64	----	----	----	4.18	4.17	4.18
August	1.83	1.75	1.79	----	----	----	2.02	1.33	1.68
September	3.68	3.40	3.54	----	----	----	2.69	3.45	3.07
Year ending September 30	46.34	45.16	45.76	----	----	----	40.27	41.62	40.94
October	1.42	1.45	1.44	----	----	----	1.25	1.38	1.32
November	2.27	2.23	2.25	----	----	----	2.24	2.36	2.30
December	.51	.51	.51	----	----	----	.47	.47	.47
1966									
January	2.05	1.83	1.94	----	----	----	1.83	1.99	1.91
February	5.52	5.26	5.39	----	----	----	4.56	4.58	4.57
March	2.32	2.38	2.35	----	----	----	1.88	1.98	1.93
Year ending March 31	34.32	33.02	33.68	----	----	----	29.48	30.07	29.78
April	4.97	4.93	4.95	----	----	----	4.69	4.71	4.70
May	1.67	1.72	1.70	----	----	----	1.83	2.16	2.00
June	2.55	2.70	2.62	----	----	----	1.91	2.00	1.96
July	3.68	4.03	3.86	----	----	----	3.16	3.86	3.51
August	7.59	7.08	7.34	----	----	----	5.23	6.48	5.86
September	5.35	5.03	5.19	----	----	----	3.02	4.41	3.72
Year ending September 30	39.90	39.15	39.54	----	----	----	32.07	36.38	34.25

[1] Gages discontinued in November 1961.

TABLE 25.—*Maximum precipitation amounts recorded in Cane Branch and Helton Branch basins during selected storms*

[Maximum precipitation amounts in inches for indicated periods based on gage that recorded the greater amount in respective basin]

Date	Cane Branch basin						Helton Branch basin					
	30 min.	1 hr	2 hr	4 hr	8 hr	Storm total	30 min.	1 hr	2 hr	4 hr	8 hr	Storm total
1959												
July 19	0.75	1.15	2.00	2.49	2.49	2.49	0.32	0.55	0.56	0.56	0.56	0.56
Dec. 17–18	.23	.32	.50	.80	1.30	2.49	.30	.50	.60	1.20	1.77	3.10
1960												
May 7	.20	.35	.65	1.19	2.16	2.70	.25	.40	.65	1.15	2.12	2.49
June 11–12	.55	.94	1.17	1.35	1.88	2.20	.80	1.03	1.10	1.75	2.02	2.08
June 16–17	.68	1.16	1.20	2.14	2.46	2.97	.70	.90	1.10	2.10	2.48	2.89
June 22–23	1.10	1.38	1.43	1.50	1.98	2.42	1.38	1.42	1.43	1.46	1.78	2.04
July 10	.90	1.10	1.32	1.75	2.50	2.72	1.04	1.10	1.36	1.95	2.54	2.84
1961												
June 8–9	.48	.52	.67	.80	1.10	1.75	.86	.91	1.16	1.16	1.24	2.03
Dec. 9	.10	.20	.40	.75	1.10	2.30	.15	.20	.35	.65	.95	2.04
Dec. 16–18	.30	.53	.63	.76	.98	2.44	.34	.50	.60	.75	1.00	2.47
1962												
Feb. 25–28	.40	.50	.85	1.38	2.18	5.80	.45	.60	1.00	1.38	2.30	5.71
Mar. 30–31	.20	.40	.80	.94	1.20	1.94	.30	.55	.73	.93	1.16	2.08
Apr. 5–7	.25	.35	.50	.63	1.05	2.92	.18	.25	.33	.49	.90	2.71
Apr. 10–11	.20	.38	.50	.85	1.65	2.06	.15	.25	.50	.85	1.65	2.02
Sept. 16	.45	.60	.80	1.28	1.98	2.29	.25	.50	.75	1.05	1.65	1.81
Oct. 2–3	.25	.45	.85	1.27	1.36	1.75	.25	.50	.85	1.50	1.63	2.04
Nov. 8–10	.12	.22	.43	.90	1.52	3.12	.13	.25	.50	.90	1.35	2.68
1963												
Mar. 11	.25	.50	.75	1.36	2.25	3.64	.25	.45	.85	1.46	2.50	3.89
May 26–28	.50	.90	1.13	1.50	1.50	2.72	.65	.85	1.00	1.15	1.15	1.90
1964												
Aug. 22	.32	.62	.80	.80	.80	.80	.60	1.20	1.22	2.03	2.03	2.08
Sept. 28–29	.75	1.00	1.18	1.50	1.80	4.27	.55	1.00	1.20	1.50	2.15	4.28
1965												
Mar. 24–26	.50	.60	.87	1.02	1.32	2.62	.47	.72	.85	1.03	1.32	2.50
Mar. 28–29	.50	.75	.92	1.02	1.52	2.00	.40	.60	.90	1.02	1.50	2.05
July 2–3	1.00	1.97	2.52	3.03	3.05	3.05	1.00	2.00	2.60	3.16	3.16	3.16

NOTE.—Table 8 in Professional Paper 427–B has incorrect column headings. Values in the 30-minute columns are inches per hour, and values in all other columns are inches.

TABLE 26.—*Flood data for Cane Branch by water years*

[Peak discharges greater than 40 cfs, 60 cfs per sq mi]

Water year and date	Discharge: Cfs	Discharge: Cfs per sq mi
1956		
Feb. 4	42	63
18	84	125
Mar. 14	75	112
Apr. 6	98	146
1957		
Dec. 21	61	91
Jan. 22	73	109
29	198	296
1958		
Nov. 18	96	143
Apr. 24	154	230
1959		
July 19	[1] 30	[1] 45
1960		
May 7	60	90
June 17	43	64
23	61	91
July 10	71	106
1961		
Mar. 8	44	66
1962		
Feb. 27	184	275
Mar. 31	42	63
Apr. 7	44	66
11	50	75
1963		
Mar. 11	127	190
17	45	67
1964		
Sept. 29	[1] 27	[1] 40
1965		
Mar. 26	40	60
29	54	81
July 23	42	63
1966		
Mar. 4	[1] 24	[1] 36

[1] Maximum discharge for water year, less than base discharge.
[2] Approximate.

TABLE 27.—*Flood data for Helton Branch by water years*

[Peak discharges greater than 25 cfs, 29 cfs per sq mi]

Water year and date	Discharge: Cfs	Discharge: Cfs per sq mi
1956		
Jan. 30	64	75
Feb. 4	38	45
18	76	89
Mar. 14	60	71
Apr. 6	104	122
1957		
Dec. 22	41	48
Jan. 22	76	89
29	136	160
1958		
Nov. 18	54	64
Dec. 20	27	32
Apr. 25	36	42
1959		
June 2	[1] 18	[1] 21
1960		
Dec. 18	54	64
Feb. 10	27	32
May 7	34	40
June 23	31	36
July 10	65	76
1961		
Mar. 8	32	38
1962		
Jan. 22	34	40
Feb. 27	182	214
Mar. 31	27	32
Apr. 7	30	35
11	40	47
1963		
Mar. 5	35	41
11	[2] 130	[2] 153
17	38	45
1964		
Mar. 8	[1] 21	[1] 25
1965		
Mar. 26	39	46
29	46	54
1966		
Apr. 28	26	31

[1] Maximum discharge for water year, less than base discharge.
[2] Approximate.

TABLE 28.—*Annual maximum discharges for West Fork Cane Branch*

Water year	Date	Discharge	
		Cfs	Cfs per sq mi
1956	Mar. 14	[1] 92	[1] 355
1957	Jan. 29	129	496
1958	------	65	250
1959	------	62	238
1960	------	20	77
1961	Mar. 8	28	108
1962	Feb. 27	48	185
1963	Mar. 11	24	92
1964	Mar. 8	20	77
1965	Mar. 29	53	204
1966	Mar. 4	21	81

[1] For period March 9 to Sept. 30, 1956.

TABLE 29.—*Chemical analyses of samples from pools in Cane Branch study area, 1960–66*

Location and date of collection	Silicia (SiO_2)	Aluminum (Al)	Iron [1] (Fe)	Manganese [1] (Mn)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Hardness, divalent cations as $CaCO_3$	Acidity to pH7 (H+)	Specific conductance (micromhos at 25° C)	pH
Pool 1											
Oct. 27, 1966	0.7	2.2	0.14	0.06	0	31	1.0	7	0.6	123	4.0
Pool 2											
Feb. 15, 1960	---	3.3	.39	2.8	0	54	---	32	---	157	4.0
Sept. 13	---	3.9	.29	.47	0	33	---	14	---	143	4.1
May 22, 1961	---	---	---	---	0	24	---	17	.2	85	4.0
Oct. 27, 1966	.3	.9	.12	.32	0	21	.5	9	.2	77	4.4
Pool 3											
Feb. 15, 1960	---	12	10	6.7	0	249	---	149	---	649	3.3
Sept. 13	---	12	5.9	4.6	0	266	---	84	---	809	3.0
Sept. 14	---	15	6.1	4.6	0	272	---	117	---	826	3.0
May 22, 1961	---	4.6	2.3	2.9	0	112	---	76	1.1	391	3.4
May 24	6.5	---	---	---	0	122	3.0	66	1.2	424	3.2
Dec. 9	6.3	34	26	6.5	0	422	.0	239	5.8	1,020	3.0
June 26, 1963	3.4	7.1	1.6	2.4	0	154	---	70	1.9	512	3.3
May 25, 1965	2.5	2.6	.24	2.5	0	76	---	42	.8	279	3.8
July 1	1.7	9.6	1.5	2.6	0	145	---	68	2.2	480	3.8
July 20	2.4	11	70	8.5	0	169	---	78	2.1	553	4.2
Aug. 26	1.9	17	1.5	3.4	0	230	---	100	2.8	618	4.1
Sept. 24	2.7	22	---	---	0	260	---	112	3.4	742	3.0
Oct. 20	2.9	21	---	---	0	258	---	98	3.9	698	3.6
Nov. 24	2.2	44	23	9.8	0	464	---	136	8.1	1,180	3.2
Dec. 20	2.1	24	5.3	3.7	0	258	---	94	8.4	689	3.3
Feb. 22, 1966	6.3	18	1.2	4.7	0	216	---	96	3.1	575	3.4
Mar. 22	6.5	10	.80	32	0	169	---	84	2.2	472	3.7
May 2	5.6	3.4	1.2	1.5	0	64	---	38	.8	206	3.6
May 25	5.1	5.4	---	---	0	89	---	48	1.1	300	3.4
June 29	1.7	16	.11	3.2	0	217	---	86	3.3	612	3.2
July 19	2.8	28	.47	.05	0	310	---	112	4.9	817	3.1
Aug. 31	2.5	16	1.2	2.3	0	190	2.0	74	2.6	533	3.4
Sept. 27	2.5	13	.90	2.1	0	149	5.0	56	2.2	453	3.5
Oct. 27	1.0	14	.81	1.4	0	162	1.0	62	1.6	494	3.6
Pool 4											
Oct. 27, 1966	.6	6.3	.91	.03	0	70	2.0	21	1.2	237	4.1
Pool 6											
Sept. 14, 1960	---	12	1.4	8.8	0	336	---	234	---	858	3.2
Pool 8											
Oct. 27, 1966	1.3	6.8	1.4	3.1	0	141	2.0	78	1.4	412	3.9
Pool 9											
Feb. 15, 1960	---	8.7	4.5	3.9	0	252	---	182	---	612	3.4
Sept. 13	---	10	1.7	4.0	0	320	---	120	---	595	3.5
May 22, 1961	---	2.8	4.8	2.2	0	133	---	111	.6	348	3.3
Oct. 27, 1966	4.5	14	1.0	2.8	0	170	2.0	110	1.4	488	3.7
Pool 10											
May 22, 1961	---	---	---	---	4	7.4	---	8	.1	25	5.3
Pool 11											
Sept. 13, 1960	---	25	4.0	8.0	0	464	---	208	--	1,060	3.1
Sept. 14	---	25	4.5	7.8	0	469	---	268	---	1,030	3.0
May 22, 1961	---	13	1.2	6.9	0	327	---	228	2.4	803	3.2
Sept. 27, 1966	2.1	17	1.8	1.2	0	131	3.0	48	1.8	474	3.6
Oct. 27	.8	6.7	.57	.95	0	114	1.0	46	1.6	385	3.9
Pool 12											
Feb. 16, 1960	---	.9	.82	2.9	--	105	---	103	---	257	4.7
Sept. 13	---	.4	.17	2.3	--	59	---	64	---	171	6.5
Oct. 27, 1966	1.2	.1	.24	.40	4	30	1.0	26	.2	89	5.5
Pool 13											
Feb. 16, 1960	---	.1	.13	.99	--	41	---	53	---	126	6.5
Sept. 13	---	.0	.10	.40	--	53	---	58	---	149	6.6
Oct. 27, 1966	2.0	.0	.19	.05	14	72	1.0	78	.1	187	6.6
Pool 14											
Feb. 16, 1960	---	9.8	6.3	9.3	0	808	---	688	---	1,370	4.1
Sept. 13	---	30	9.8	11	0	1,260	---	852	---	2,160	3.1
May 23, 1961	---	---	---	--	0	518	---	520	.4	945	4.2
Pool 15											
Feb. 16, 1960	---	4.9	2.2	8.0	--	594	---	614	---	1,060	4.7

See footnote at end of table.

TABLE 29.—*Chemical analyses of samples from pools in Cane Branch study area, 1960–66*—Continued

Location and date of collection	Silica (SiO_2)	Aluminum (Al)	Iron [1] (Fe)	Manganese [1] (Mn)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Hardness, divalent cations as $CaCO_3$	Acidity to pH 7 (H+)	Specific conductance (micromhos at 25° C)	pH
Pool 16											
Feb. 16, 1960	---	2.4	1.2	2.8	0	293	---	293	---	609	4.5
Sept. 13	---	5.2	.29	3.6	--	512	---	448	---	951	4.6
Oct. 27, 1966	3.3	.9	.10	1.6	6	290	2.0	286	0.2	596	5.1
Pool 17											
Feb. 16, 1960	---	4.2	20	16	0	454	---	319	---	1,050	3.2
Sept. 13	---	13	5.7	27	0	650	---	384	---	1,390	3.0
Pool 18											
Feb. 16, 1960	---	8.3	21	21	0	528	---	316	---	1,180	3.2
Sept. 13	---	18	12	23	0	582	---	310	---	1,380	2.9
Pool 17–18 (connected)											
May 23, 1961	---	8.2	2.8	16	0	331	---	300	1.6	839	3.3
Dec. 9	17	19	2.5	23	0	582	3.0	399	3.6	1,250	3.0
Oct. 27, 1966	13	12	2.5	12	0	450	1.0	300	2.8	1,090	3.5
Pool 19											
Feb. 16, 1960	---	.2	.58	.49	--	13	---	14	---	40	5.7
Sept. 13	---	.1	.21	1.6	--	28	---	24	---	99	6.9
May 23, 1961	---	.8	.91	2.5	0	58	---	44	1.6	191	3.9
Dec. 9	---	1.2	---	---	0	82	---	66	.2	211	4.5
Oct. 27, 1966	6.7	11	1.2	6.3	0	238	1.0	152	1.9	591	3.9
Pool 20											
May 23, 1960	---	5.7	1.0	.94	0	100	---	15	---	310	3.6

[2] In solution when collected.

TABLE 30.—*Chemical analyses of selected [1] samples of ground water in the Cane Branch and West Fork Cane Branch basins, 1958–66.*

[Results in parts per million except as indicated]

Hole number and date of collection	Silica (SiO_2)	Aluminum (Al)	Iron [2] (Fe)	Manganese [2] (Mn)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Hardness, divalent cations as $CaCO_3$	Acidity to pH 7 (H+)	Specific conductance (micromhos at 25° C)	pH
Ground water from southwest spoil bank											
Auger hole 1											
Nov. 17 1959	67	86	4.6	54	0	980	---	500	9.2	1,430	3.6
Sept. 14, 1960	33	52	24	10	0	762	---	290	11	1,960	2.4
June 26, 1963	31	4.3	56	4.9	0	211	---	78	2.2	862	3.0
Auger hole 2											
June 2, 1958	18	6.3	.04	19	0	240	1.0	135	1.8	681	3.2
July 1	20	4.1	----	----	0	361	---	85	.8	381	3.7
Sept. 14, 1960	10	27	----	----	0	818	---	360	11	2,250	2.4
June 26, 1963	42	129	96	71	0	1,600	---	700	20	2,600	2.8
Sept. 27, 1966	32	61	71	33	0	800	.0	293	12	1,220	4.0
Auger hole 3											
June 2, 1958	----	.5	----	----	330	118	---	122	---	712	6.1
Sept. 15	5.2	.0	----	----	17	36	---	50	---	140	5.3
Sept. 14, 1960	13	12	54	21	0	304	---	130	5.6	935	3.0
June 26, 1963	25	43	78	14	0	548	---	160	8.5	1,640	2.7
Nov. 21	14	3.6	190	4.3	0	288	---	160	4.0	614	3.8
Oct. 20, 1964	28	9.6	64	14	0	892	---	700	4.8	1,950	2.8
Dec. 8	33	56	85	14	0	608	---	204	8.2	949	4.1
Oct. 20, 1965	18	13	60	20	0	380	---	126	10	1,500	3.1
Dec. 20	6.0	9.9	84	8.2	0	219	---	92	5.4	500	3.2
Jan. 28, 1966	6.2	2.3	32	7.1	0	144	--	126	.9	395	3.5
Feb. 22	32	38	15	8.0	0	510	---	220	9.0	1,230	3.2
Sept. 27	7.7	8.1	82	9.0	9	243	.0	134	5.8	615	5.7
Auger hole 4											
June 2, 1958	10	27	----	----	3	29	---	36	---	146	5.2
Sept 5	4.0	.2	141	2.2	22	14	---	32	---	91	6.8
Dec. 4	----	----	----	----	3.9	11	---	24	---	715	6.3

See footnote at end of table.

TABLE 30.—*Chemical analyses of selected[1] samples of ground water in the Cane Branch and West Fork Cane Branch basins, 1958–66*—Continued

Hole number and date of collection	Silica (SiO_2)	Aluminum (Al)	Iron[2] (Fe)	Manganese[2] (Mn)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Hardness, divalent cations as $CaCO_3$	Acidity to pH 7 (H+)	Specific conductance (micromhos at 25° C)	pH
Ground water from southwest spoil bank—Continued											
Auger hole 4—Con.											
Sept. 14, 1960	6.3	1.0	23	5.9	0	115	---	72	3.8	338	4.0
June 26, 1963	6.2	5.8	200	2.3	138	59	---	56	---	353	6.0
Sept. 27, 1966	2.8	.6	59	2.8	136	40	.0	56	3.0	320	6.1
Auger hole 5											
June 5, 1958	---	22	218	31	0	1,390	---	693	12	2,360	2.8
July 1	12	5.5	288	22	0	1,350	---	480	11	3,190	2.4
Dec. 4	14	.0	23	9.1	0	706	---	114	3.0	1,830	2.8
April 29, 1959	---	16	179	---	0	1,350	---	532	9.6	2,970	2.6
Nov. 17	10	13	45	.18	0	586	---	410	4.3	1,600	2.8
Mar. 22, 1960	12	12	34	.10	0	714	---	556	5.0	1,700	2.8
June 15	5.3	2.0	248	31	0	1,340	---	968	7.6	2,730	2.6
May 2, 1961	38	49	190	31	0	1,900	---	1,370	12	3,420	2.6
Dec. 12	29	9.8	119	18	0	1,140	---	880	5.8	2,320	2.6
Jan. 3, 1962	28	7.1	98	---	0	1,140	---	890	6.1	2,290	2.7
Apr. 26	27	122	258	62	0	2,720	---	1,200	26	4,500	2.8
Apr. 22, 1963	28	70	60	37	0	1,830	---	1,200	15	3,140	3.0
Nov. 21	30	5.4	126	12	0	950	---	700	3.0	1,660	3.4
Apr. 22, 1964	---	195	254	110	0	2,980	---	1,640	27	3,770	3.0
Oct. 20	8.3	3.8	105	16	0	288	---	140	3.2	847	3.2
Jan. 5, 1965	28	13	125	18	0	958	---	760	4.8	1,970	3.0
Apr. 27	28	180	286	115	0	3,320	---	2,060	29	4,450	3.2
Mar. 22, 1966	32	177	17	---	0	2,560	---	1,540	---	3,530	3.2
Sept. 27	28	16	114	15	0	960	.0	562	5.4	1,990	3.1
Auger hole 6											
June 2, 1958	27	15	---	---	0	2,200	.0	1,450	12	3,610	2.6
July 1	25	6.0	---	---	0	1,840	---	1,360	10	3,720	2.4
Dec. 4	25	.0	157	31	0	1,060	---	434	6.4	2,300	2.8
Sept. 14, 1960	23	20	212	57	0	1,480	---	1,040	9.7	2,810	2.6
June 26, 1963	50	38	105	58	0	1,580	---	1,200	11	3,080	2.7
Sept. 27, 1966	47	39	299	78	0	2,180	2.5	987	18	3,370	3.1
Auger hole 7											
Sept. 30, 1959	39	19	84	59	0	992	---	508	---	2,440	2.5
Sept. 14, 1960	23	24	95	21	0	856	---	630	6.6	1,980	2.6
June 26, 1963	29	15	5.2	11	0	273	---	140	3.0	711	3.5
Sept. 27, 1966	64	226	41	54	0	1,810	.0	416	25	2,300	3.3
Auger hole 8											
Nov. 18, 1959	48	102	4.0	80	0	1,050	---	500	11	1,450	3.6
Sept. 14, 1960	25	6.7	.35	6.2	0	426	---	206	4.2	846	3.4
June 26, 1963	24	34	48	4.9	0	318	---	132	4.2	628	3.8
Auger hole 9											
July 1, 1958	35	1.6	---	---	0	402	---	324	1.8	1,170	3.0
Sept. 5	33	1.6	---	---	0	340	---	252	1.5	838	3.4
Sept. 14, 1960	9.4	4.4	33	11	42	543	---	406	---	1,080	6.0
June 26, 1963	12	10	40	13	0	265	---	180	1.7	662	3.5
Auger hole 10											
June 2, 1958	36	32	---	---	0	1,020	1.5	572	6.7	2,050	2.8
July 1	29	38	---	---	0	1,150	---	790	7.5	2,280	2.8
Oct. 2	32	36	55	12	0	896	---	636	6.2	1,960	2.8
Sept. 14, 1960	29	39	63	36	0	728	---	350	9.1	1,770	2.6
June 26, 1963	22	16	110	16	0	708	---	488	5.4	1,860	2.8
Sept. 27, 1966	23	21	105	10	0	536	1.0	258	5.0	1,450	3.0
Auger hole 11											
Nov. 18, 1959	20	5.4	15	77	0	734	---	620	3.0	1,640	3.0
Sept. 14, 1960	13	9.1	32	16	0	828	---	590	6.8	2,290	2.5
June 26, 1963	57	121	10	34	0	1,490	---	712	18	2,510	2.9
Auger hole 13											
June 5, 1958	---	17	---	---	0	579	---	346	4.6	1,030	4.2
Oct. 2	52	18	98	20	0	834	---	588	5.4	1,840	2.8
Sept. 14, 1960	24	11	---	---	0	429	---	310	2.8	1,090	3.0
Sept. 27, 1966	18	18	50	9.0	0	287	1.0	190	2.6	841	3.4

See footnote at end of table.

TABLE 30.—*Chemical analyses of selected[1] samples of ground water in the Cane Branch and West Fork Cane Branch basins, 1958–66*—Continued

Hole number and date of collection	Silica (SiO_2)	Aluminum (Al)	Iron[2] (Fe)	Manganese[2] (Mn)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Hardness, divalent cations as $CaCO_3$	Acidity to pH 7 (H+)	Specific conductance (micromhos at 25° C)	pH
Ground water from southwest spoilbank—Continued											
Auger hole 14											
June 2, 1958	12	0.1	---	---	16	35	0.0	38	---	134	6.3
Dec. 4	---	.0	---	---	0	818	---	200	4.9	2,010	2.6
Sept. 14, 1960	10	1.9	0.10	12	1	189	---	176	---	445	4.7
Sept. 27, 1966	11	12	99	18	32	458	2.5	212	4.4	695	5.6
Ground water from bedrock											
Well 12											
Mar. 13, 1958	26	0.2	3.1	0.96	24	35	30	82	0.0	319	5.8
June 26, 1959	22	.3	.73	.08	6	47	---	102	---	387	5.1
Dec. 16	12	.1	.43	.46	6	58	---	84	---	280	6.2
July 11, 1960	13	.3	.77	1.9	14	50	---	78	---	257	5.7
Aug. 24	27	.5	.38	7.9	--	78	---	103	---	462	5.2
Mar. 2, 1961	22	11	16	1.2	6	46	---	67	.1	231	5.5
July 14	26	14	.86	6.7	8	81	---	120	.1	432	5.2
Jan. 25, 1962	11	.1	.42	.45	4	48	---	63	.0	239	6.3
July 17	28	.6	.48	5.7	4	90	---	109	.1	434	5.1
Feb. 27, 1963	22	.1	.88	1.0	6	62	---	90	---	334	5.5
June 26	28	1.6	6.6	7.3	2	106	---	132	.4	529	4.6
June 24, 1964	30	.1	.48	2.5	4	64	---	106	.0	407	6.5
Dec. 8	16	.2	1.1	.72	6	47	---	70	.0	265	5.9
Jan. 5, 1965	14	.6	3.2	1.6	6	45	---	69	.0	269	5.5
May 25	29	.9	.34	3.1	10	79	---	104	.1	443	5.1
May 2, 1966	13	.3	.29	.47	7	42	---	56	---	182	5.8
July 19	26	.2	.36	.10	4	64	---	92	---	393	6.4
Sept. 27	35	.2	.15	1.3	10	73	41	108	1.0	376	5.3
Coal-test hole 16											
Apr. 29, 1969	---	.0	.64	3.9	46	179	---	211	---	450	6.1
June 26	16	.3	.72	.71	12	185	---	191	---	423	5.4
Dec. 16	14	.4	.59	6.9	22	346	---	382	---	677	5.9
Jan. 12, 1960	15	.1	1.2	5.0	31	237	---	262	---	518	6.6
May 12	14	.1	.26	.98	33	84	---	107	---	255	6.2
Nov. 11	15	.1	1.6	2.0	57	140	---	172	---	382	6.5
Mar. 29, 1962	17	.1	2.4	.70	34	77	---	102	.0	239	6.7
Nov. 26	14	.1	2.8	1.3	77	156	---	209	---	446	6.6
Apr. 22, 1963	22	.0	9.0	2.4	54	77	---	111	---	265	6.7
Nov. 21	15	.4	---	.38	210	128	---	288	---	561	6.6
Mar. 3, 1964	13	.0	1.9	1.7	96	132	---	200	.0	435	6.5
May 25	22	.0	2.1	.99	54	76	---	116	---	260	7.7
May 25, 1965	21	.4	.12	1.0	40	80	---	106	.8	253	5.7
Dec. 20	13	.1	.36	1.3	142	121	---	228	---	464	7.1
Mar. 22, 1966	11	.0	.51	.88	134	141	---	244	---	488	6.6
June 29	15	.1	.00	.79	116	110	---	194	---	411	6.7
Sept. 27	15	.0	.28	1.2	158	117	4.0	233	---	470	7.1
Well 17											
Apr. 23, 1958	10	.4	8.4	1.1	0	25	---	16	.2	84	4.2
Oct. 2	11	.7	1.0	.19	0	29	---	21	.2	105	4.2
Dec. 4	11	.0	1.1	.20	0	16	---	13	---	58	4.5
Nov. 17, 1959	12	1.0	1.7	.63	6	23	---	24	.1	75	5.3
Dec. 16	9.1	.1	.12	.34	2	8.8	---	9	---	39	5.1
Apr. 12, 1960	9.0	.2	1.5	.95	4	11	---	10	.0	41	4.8
July 11	9.0	.6	1.6	.92	2	25	---	18	---	80	4.7
Sept. 26, 1966	8.9	.1	.54	.07	2	12	.5	9	.6	45	5.0
Well 18											
Apr. 23, 1958	6.5	---	---	---	5	5.4	.5	4	---	23	6.4
May 12, 1960	6.1	.2	.10	.00	8	6.0	---	12	.2	28	5.7
July 11	6.5	---	1.2	.40	8	5.4	---	1	---	30	6.3
Well 19											
Apr. 23, 1958	12	---	1.6	.89	45	10	.2	38	---	96	6.2
Sept. 5	12	.0	27	1.1	53	16	---	51	---	125	7.1
June 26, 1959	9.7	.2	1.3	.26	48	15	---	50	---	127	6.1
Dec. 16	7.0	.0	1.2	.51	14	6.0	---	14	---	41	6.7
Mar. 22, 1960	8.0	---	2.2	.62	17	5.6	---	18	---	44	6.4
Sept. 14	9.0	.1	.30	.73	48	14	---	48	---	114	5.9
Sept. 26, 1966	9.3	.0	.29	.30	42	13	1.0	40	.7	141	6.3

See footnote at end of table.

TABLE 30.—*Chemical analyses of selected[1] samples of ground water in the Cane Branch and West Fork Cane Branch basins, 1958–66*—Continued

Hole number and date of collection	Silica (SiO_2)	Aluminum (Al)	Iron[2] (Fe)	Manganese[2] (Mn)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Hardness, divalent cations as $CaCO_3$	Acidity to pH 7 (H+)	Specific conductance (micromhos at 25° C)	pH
				Ground water from bedrock—Continued							
Well 20											
Apr. 23, 1958	13	---	3.8	0.65	28	9.8	0.5	26	---	73	7.2
Sept. 5	11	0.1	2.0	1.1	79	14	---	68	---	161	7.3
Aug. 1, 1959	10	.0	6.3	.02	82	8.8	---	79	---	168	6.8
Dec. 16	11	.1	.61	.45	10	3.6	---	7	---	32	6.5
Apr. 12, 1960	10	---	.72	.07	12	3.0	---	10	---	31	6.7
Sept. 14	8.8	.0	.48	.12	37	10	---	35	---	94	6.0
Sept. 26, 1966	6.4	.0	.15	.12	8	3.2	1.0	6	0.2	32	6.1
Well 21											
July 1, 1958	14	.5	---	---	0	32	---	26	.2	101	4.0
Sept. 5	25	1.1	4.6	1.3	0	63	---	96	.3	223	3.9
Jan. 9, 1959	19	2.3	.22	.10	0	84	---	62	.6	234	3.8
Oct. 29	8.2	.1	.07	.08	2	8.4	---	6	.1	26	5.1
Jan. 13, 1960	9.0	.2	.24	.17	4	20	---	16	.2	56	5.5
Sept. 14	13	1.2	1.4	.46	0	43	---	28	1.0	167	4.4
Sept. 26, 1966	10	.9	.26	.24	1	18	1.0	12	.5	75	4.6

[1] In general, where a large number of analyses are available, samples having maximum and minimum conductances for each year were selected for tabulation.
[2] In solution when collected.

TABLE 31.—*Chemical analyses of samples from selected tributaries of Cane Branch*

[Results in parts per million except as indicated]

Location and date of collection	Instantaneous discharge (cfs)	Silica (SiO_2)	Aluminum (Al)	Iron[1] (Fe)	Manganese[1] (Mn)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Dissolved solids (residue at 180° C)	Hardness, divalent cations as $CaCO_3$	Acidity to pH 7 (H+)	Specific conductance (micromhos at 25° C)	pH
Site B													
Apr. 30, 1957	----	5.8	0.1	0.36	0.30	6	7.4	0.5	23	8	0.0	27	6.3
Mar. 13, 1958	----	----	----	----	27	4	5.0	----	17	6	.1	31	5.9
Apr. 10	----	----	----	3.3	3.0	4	6.8	.5	----	7	.0	44	6.4
Apr. 21	----	7.0	----	----	----	4	4.4	----	16	6	----	21	6.3
May 23, 1969	0.017	----	----	----	----	7	12	----	----	16	----	43	6.2
May 25	.014	----	----	----	----	8	12	----	----	15	----	44	5.9
Aug. 10	.007	----	.2	.44	1.1	14	11	----	----	20	----	52	6.5
Nov. 5	.08	----	----	----	----	6	9.0	----	----	13	----	38	6.4
Feb. 15, 1960	.04	----	----	----	----	----	7.2	----	----	7	.0	27	6.5
May 24	----	----	----	----	----	----	13	----	----	16	.0	55	7.6
May 24, 1961	.1	----	----	----	----	8	11	----	34	21	.0	40	6.5
Site C													
Mar. 13, 1958	----	----	----	----	----	4	4.6	----	27	6	.1	31	6.2
Apr. 10	----	----	----	----	----	5	4.8	2.0	----	6	.0	23	6.4
Apr. 21	----	----	----	----	----	6	4.2	----	18	6	----	23	5.9
May 23, 1959	.005	----	----	----	----	11	2.6	----	----	7	----	26	6.5
Aug. 10	.005	----	----	----	----	10	2	----	----	8	----	26	6.4
Nov. 5	.03	----	----	----	----	8	4.8	----	----	10	----	35	6.3
Feb. 15, 1960	.02	----	----	----	----	----	4.8	----	----	6	----	21	6.3
May 24	.002	----	----	----	----	----	3.6	----	----	10	----	32	7.5
May 24, 1961	.05	----	----	----	----	10	4.6	----	31	15	.0	23	6.7
Dec. 11	----	----	----	----	----	6	9.6	----	----	9	.0	38	5.8
Site G													
Apr. 10, 1958	----	----	1.5	.08	4.1	0	51	.5	----	34	.4	178	3.7
Apr. 21	----	8.0	----	----	----	0	52	----	109	5	.3	160	3.9
May 23, 1959	.0007	----	3.0	4.2	9.7	0	98	----	----	59	.7	310	3.5
May 25	.011	----	21	7.9	5.3	0	214	----	----	37	3.2	595	3.2
Aug. 10	.003	----	6.2	3.6	16	0	138	----	----	32	----	500	3.4
Nov. 5	.04	----	----	----	----	0	383	----	----	71	----	1,060	3.0
Feb. 15, 1960	.02	----	----	----	----	0	117	----	----	44	----	352	3.4
May 23	.002	----	----	----	----	0	64	----	----	21	----	227	3.6
Sept. 13	.0005	----	----	----	----	0	70	----	----	43	----	259	3.7
May 24, 1961	.005	----	----	----	----	0	63	----	103	38	.6	219	3.2
Oct. 27, 1966	----	12	18	12	5.5	0	124	1.0	211	46	1.6	438	3.9
Site H													
Apr. 10, 1958	----	----	----	----	----	3	7.4	1.0	----	26	.0	26	6.0
Apr. 21	----	6.1	----	----	----	3	6.8	----	18	6	----	23	5.9
Aug. 10, 1959	----	----	----	----	----	5	9.6	----	----	9	----	29	6.2
Nov. 5	.1	----	----	----	----	8	16	----	----	16	----	53	6.0
Feb. 15, 1960	.03	----	----	----	----	----	10	----	----	9	----	41	5.3
Oct. 26, 1966	----	5.5	.0	2.6	12	1	61	3.0	116	54	.2	176	5.0

See footnote at end of table.

TABLE 31.—*Chemical analyses of samples from selected tributaries of Cane Branch*— Continued

Location and date of collection	Instantaneous discharge (cfs)	Silica (SiO_2)	Aluminum (Al)	Iron [1] (Fe)	Manganese [1] (Mn)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Dissolved solids (residue at 180° C)	Hardness, divalent cations as $CaCO_3$	Acidity to pH 7 (H+)	Specific conductance (micromhos at 25° C)	pH
Site M													
Sept. 26, 1956	----	49	46	40	31	0	1,210	0.5	1,750	771	----	2,080	2.8
Apr. 30, 1957	----	----	----	51	31	0	779	----	----	270	5.2	1,680	2.8
Mar. 13, 1958	----	28	41	67	22	0	898	3.0	1,260	538	7.9	1,780	2.9
Sept. 9	----	----	15	94	21	0	851	----	----	502	5.5	1,910	2.8
Apr. 26, 1959	----	----	16	148	35	0	1,150	----	----	560	12	2,310	2.5
May 23	0.008	----	33	100	40	0	1,050	----	----	298	11	2,370	2.5
May 25	.019	----	60	116	22	0	1,100	----	----	335	12	2,400	2.5
Aug. 10	.007	----	40	117	37	0	----	----	----	252	----	2,310	2.5
Nov. 5	----	----	----	----	----	0	1,150	----	----	386	----	2,190	2.6
Dec. 9	----	----	51	123	35	0	1,090	----	----	----	----	2,040	2.7
Feb. 15, 1960	.02	----	----	----	----	0	732	----	----	304	----	1,550	2.8
May 24	.03	----	----	----	----	0	1,140	----	----	384	----	2,330	2.6
Sept. 13	.001	----	----	----	----	0	1,070	----	----	316	----	2,260	2.6
May 24, 1961	.5	----	----	----	----	0	924	----	1,420	680	7.6	1,950	2.7
Dec. 11	----	----	----	----	----	0	576	----	----	284	5.8	1,290	3.0
Oct. 27, 1966	----	33	21	44	----	0	700	2.0	1,120	380	6.2	1,830	3.1
Site N													
Dec. 18, 1958	----	----	----	----	----	8	5.2	.6	----	10	----	48	6.9
Apr. 15, 1959	----	----	.1	.44	.36	3	11	----	----	10	.0	34	5.9
May 23	.004	----	.0	.44	2.0	6	42	----	----	42	----	117	6.7
May 25	.027	----	.6	2.0	2.2	2	36	----	----	32	.0	96	5.5
Aug. 10	.006	----	5.2	5.4	22	0	414	----	----	138	----	976	3.2
Nov. 5	.08	----	----	----	----	0	418	----	----	315	----	945	3.4
Feb. 15, 1960	.08	----	----	----	----	0	433	----	----	361	----	923	3.5
May 23	.06	----	----	----	----	0	538	----	----	304	----	1,340	2.9
Sept. 13	.017	----	----	----	----	0	526	----	----	318	----	1,390	2.8
May 24, 1961	.5	----	----	----	----	0	449	----	644	380	1.4	1,010	3.2
Dec. 11	----	----	----	----	----	0	350	----	----	296	1.4	770	3.6
Oct. 27, 1966	----	18	8.1	69	12	0	548	1.0	856	392	3.4	1,510	3.2
Site O													
Apr. 25, 1959	----	----	.4	.13	.10	6	30	----	----	32	.0	88	6.3
May 23	.005	----	.1	.37	.29	8	10	----	----	13	----	43	6.2
Aug. 10	.01	----	.2	.42	.11	12	9.2	----	----	16	----	50	6.4
Feb. 15, 1960	.04	----	----	----	----	----	13	----	----	13	----	56	6.4
May 23	.003	----	----	----	----	----	12	----	----	10	----	44	7.2
Sept. 13	.005	----	----	----	----	----	13	----	----	15	----	56	6.7
Oct. 27, 1966	----	6.8	.1	.17	----	2	40	2.0	78	37	.1	158	5.2
Site P													
Apr. 26, 1959	----	----	21	78	51	0	740	----	----	464	5.8	1,690	2.6
May 23	.005	----	16	88	47	0	710	----	----	246	5.8	1,770	2.6
May 25	.003	----	14	122	58	0	810	----	----	287	6.6	1,990	2.6
Aug. 10	----	----	12	60	49	0	644	----	----	251	----	1,710	2.6
Nov. 5	----	----	----	----	----	0	640	----	----	250	----	1,560	2.7
Feb. 15, 1960	.01	----	----	----	----	0	706	----	----	484	----	1,680	2.8
May 24	.005	----	----	----	----	0	668	----	----	242	----	1,790	2.6
Sept. 13	.001	----	----	----	----	0	552	----	----	224	----	1,690	2.6
May 24, 1961	.5	----	----	----	----	0	369	----	1,180	530	5.8	1,720	2.8
Oct. 27, 1966	----	15	9.9	111	----	0	794	1.0	1,280	480	7.2	2,290	2.9
Site R													
May 23, 1959	.0007	----	.0	----	----	5	12	----	----	13	----	41	6.1
Aug. 10	.0001	----	.2	.07	.82	3	19	----	----	18	----	62	5.8
Feb. 15, 1960	.01	----	----	----	----	----	45	----	----	41	----	155	4.7
May 23	.001	----	----	----	----	----	11	----	----	10	----	37	5.9
Sept. 11	----	4.2	3.9	.23	2.2	0	57	3.1	89	34	----	172	4.1
Sept. 13	.0005	----	----	----	----	----	8.4	----	----	5	----	22	6.4
May 24, 1961	.005	----	----	----	----	2	20	----	40	22	.1	59	5.1

[1] In solution when collected.

TABLE 32.—*Monthly runoff and loads of dissolved solids, sulfate, and equivalent sulfuric acid transported by Cane Branch from October 1958 to September 1966*

Year and month	Runoff (cfs-days)	Dissolved solids load (tons)	Sulfate load (tons)	Equivalent sulfuric acid [1] load (tons)
1958				
October	3.114	4.22	2.86	1.38
November	7.831	9.05	6.10	3.01
December	6.21	6.85	4.62	2.12
1959				
January	26.80	16.1	10.8	5.20
February	37.48	15.0	9.95	4.66
March	27.54	14.2	9.45	4.44
1959—Con.				
April	44.91	20.1	12.0	6.15
May	7.77	7.50	4.60	2.31
June	5.560	5.95	3.58	1.88
July	9.710	12.6	7.95	4.40
August	6.033	8.50	5.40	3.06
September	4.753	6.30	4.00	2.16
October	7.410	9.10	6.30	2.94
November	26.92	21.6	15.4	7.00
December	74.14	54.5	35.4	14.7

See footnote at end of table.

TABLE 32.—*Monthly runoff and loads of dissolved solids, sulfate, and equivalent sulfuric acid transported by Cane Branch from October 1958 to September 1966*—Continued

Year and month	Runoff (cfs-days)	Dissolved solids load (tons)	Sulfate load (tons)	Equivalent sulfuric acid [1] load (tons)
1960				
January	37.08	22.3	14.7	5.90
February	70.31	33.0	22.0	9.15
March	75.24	28.6	19.2	7.90
April	22.92	15.8	10.6	4.46
May	36.60	17.3	11.4	4.80
June	53.350	42.7	27.6	11.4
July	52.05	22.0	14.8	6.10
August	4.573	5.80	3.74	1.46
September	3.526	4.56	2.94	1.24
October	4.679	4.64	3.20	1.36
November	6.581	4.19	2.92	1.26
December	16.73	9.60	6.75	2.90
1961				
January	28.13	13.2	9.20	4.28
February	56.32	24.4	17.2	7.30
March	90.96	31.1	21.9	9.65
April	61.66	23.1	16.3	5.20
May	32.51	12.9	8.65	4.72
June	11.56	11.4	7.20	2.23
July	10.06	7.10	4.81	1.46
August	3.019	3.34	2.30	.76
September	2.517	2.78	1.90	.64
October	3.308	3.02	2.08	.70
November	4.135	4.18	2.90	1.06
December	34.019	20.8	13.7	4.72
1962				
January	75.89	29.8	19.0	6.60
February	131.20	32.5	21.2	7.40
March	85.07	35.6	22.6	7.30
April	105.33	32.0	21.1	6.85
May	8.24	7.60	5.05	1.54
June	7.335	7.15	4.54	1.56
1962—Con.				
July	3.482	3.91	2.46	.91
August	3.077	3.44	2.14	0.81
September	3.842	3.46	2.18	.76
1963				
October	2.42	1.86	1.23	.39
November	3.67	3.02	1.99	.67
December	3.01	2.49	1.67	.55
1964				
January	23.50	16.1	10.30	3.40
July	2.37	2.27	1.55	.55
August	2.95	2.70	1.72	.66
September	6.20	4.04	2.49	.85
1965				
January	48.85	18.5	12.2	4.63
February	33.94	17.8	11.7	4.50
March	99.57	31.0	21.0	7.80
April	32.09	13.3	8.75	3.16
May	7.15	4.98	3.29	1.21
June	7.13	4.76	3.12	1.18
July	6.03	4.02	2.63	0.98
November	2.60	2.30	1.49	.60
December	1.92	1.32	.82	.30
1966				
January	2.96	2.38	1.02	.59
February	16.90	13.6	8.65	3.41
March	21.39	12.3	7.65	3.01
April	30.37	11.4	6.40	2.46
May	21.93	9.00	5.10	1.88
June	3.32	2.98	1.96	.80
July	2.86	2.86	1.84	1.10
August	5.93	4.98	3.16	1.67
September	9.17	6.55	4.10	1.53

[1] Calculated from measured acidity, titrated to pH 7.

TABLE 33.—*Summary of sediment discharge by months, Cane Branch near Parkers Lake*

Year and month	Water discharge (cfs-days)	Sediment concentration [1] (ppm)	Sediment discharge (tons)
1959			
October	7.410	530	10.60
November	26.92	230	16.75
December	74.14	634	126.98
1960			
January	37.08	496	49.70
February	70.31	1,290	244.16
March	75.24	201	40.76
April	22.92	185	11.48
May	36.60	2,340	231.22
June	53.350	4,310	620.37
July	52.05	2,460	345.25
August	4.573	2,560	31.65
September	3.526	218	2.08
October	4.679	1,230	15.49
November	6.581	815	14.49
December	16.73	626	28.30
1961			
January	28.13	135	10.29
February	56.32	440	66.86
March	90.96	936	229.79
April	61.66	204	33.98
May	32.51	343	30.13
June	11.56	1,870	58.40
1961—Con.			
July	10.06	3,930	106.74
August	3.019	204	1.66
September	2.517	1,140	7.76
October	3.308	282	2.52
November	4.135	76	.85
December	34.019	666	61.20
1962			
January	75.89	966	198.03
February	131.20	3,680	1,303.84
March	85.07	552	126.78
April	105.33	402	114.37
May	8.24	2,000	44.50
June	7.335	1,960	38.92
July	3.482	3,820	35.94
August	3.077	7,590	63.09
September	3.842	2,740	28.38
1963			
October [2]	2.42	2	.01
November	3.67	33	.33
December	3.01	76	.62
1964			
January	7.71	97	2.03
July [3]	2.24	1,920	11.60
August	2.95	9,620	76.66

TABLE 33.—*Summary of sediment discharge by months, Cane Branch near Parkers Lake*—Continued

Year and month	Water discharge (cfs-days)	Sediment concentration [1] (ppm)	Sediment discharge (tons)
1964			
September	6.20	6,000	100.51
October	5.05	1,800	24.78
November	8.00	214	4.63
December	34.72	396	37.15
1965			
January	48.85	558	73.66
February	33.94	179	16.42
March	99.57	1,830	493.25
April	32.09	554	47.99
May	7.15	279	5.39
June	7.13	2,950	56.79
July	6.03	23,500	382.06
August	1.45	1,120	4.38
September	1.82	10,800	53.26
1965—Con.			
October	1.63	270	1.19
November	2.60	1,590	12.15
December	1.92	2	.01
1966			
January	2.96	13	.10
February	16.90	831	37.93
March	21.39	690	39.88
April	30.37	571	46.81
May	21.93	91	5.41
June	3.32	6,310	56.56
July	2.86	4,100	31.67
August	5.93	9,100	145.76
September	9.07	1,450	35.60

[1] Weighted with water discharge.
[2] No record October 1962 to September 1963.
[3] No record February to June 1964.

TABLE 34.—*Fungi isolated at station 1, Cane Branch study area, 1966–68*

Season	Surface	Bottom
Spring	*Cladosporium cladosporioides* *Septonema* sp. *Fusarium* sp. *Phoma* sp. *Aspergillus* sp.	*Rhizppus arrhizus* *Eciococcum purpurascens* *Penicillium* sp. *Mucor* sp. *Trichoderma viride* *Rhinotrichum* sp.
Summer	*Cladosporium cladosporioides* *Epicoccum purpurascens* *Aspergillus* sp. *Alternaria tenuis* *Cephalosporium* sp.	*Trichoderma viride* *Alternaria tenuis* *Aspergillus* sp. *Penicillium* sp. *Mucor angulisporus* *Epicoccum purpurascens* *Phoma* sp. *Absidia* sp.
Autumn	*Cladosporium cladosporioides* *Epicoccum purpurascens* *Alternaria* sp. *Curvularia* *Trichoderma viride*	*Mucor* sp. *Trichoderma viride* *Phoma* sp. *Alternaria* *Penicillium* *Epicoccum purpurascens* *Monosporium* sp.
Winter	*Alternaria* sp. *Fusarium* sp. *Thielaviopsis* sp. *Botrytis* sp. *Trichoderma viride* *Penicillium* (9 species)	*Phialophora fastigiata* *Trichoderma viride* *Penicillium* *Mucor*

TABLE 35.—*Fungi isolated at station 2, Cane Branch study area, 1966–68*

Season	Surface	Bottom
Spring	*Mucor* sp. *Fusarium* sp. *Beauveria bassiana* *Epicoccum purpurascens* *Phoma* sp. *Trichoderma viride* *Penicillium* sp.	*Phoma* sp. *Mucor* sp. *Trichoderma viride*
Summer	*Frusarium* sp. *Cladosporium cladosporioides* *Alternaria* sp. *Epicoccum purpurascens* *Trichoderma viride*	*Trichoderma viride* *Penicillum* sp. *Mucor* sp. *Alternaria* sp. *Cladosporium cladosporioides*
Autumn	*Mortierella* sp. *Penicillium* sp. *Mucor* sp. *Cladosporium cladosporioides* *Alternaria* sp. *Epicoccum purpurascens* *Trichoderma viride*	*Penicillium* sp. *Mortierella* sp. *Trichoderma viride* *Epicoccum purpurascens* *Pestalotia* sp. *Alternaria* sp. *Mucor* sp.

TABLE 35.—*Fungi isolated at station 2, Cane Branch study area, 1966–68*—Continued

Season	Surface	Bottom
Winter	*Zygorhynchus moelleri* *Trichoderma viride* *Mucor fragilis* *Penicillium* (3 species)	*Cladosporium cladosporioides* *Trichoderma viride* *Mucor* *Penicillium*

TABLE 36.—*Fungi isolated at station 3, Cane Branch study area, 1966–68*

Season	Surface	Bottom
Spring	*Penicillium* sp. *Aspergillus* sp.	*Geotrichum candidum* *Rhinotrichum* sp. *Epicoccum purpurascens* *Trichoderma viride* *Penicillium* sp. *Phoma* sp. *Cladosporium cladosporioides* *Fusarium* sp. *Mucor* sp.
Summer	*Calcarisporum* sp. *Oidiodendron* sp. *Trichoderma viride* *Cladosporium cladosporioides* *Alternaria* sp. *Mucor* sp. *Fusarium* sp.	*Alternaria* sp. *Cladosporium cladosporioides* *Trichoderma viride* *Mucor* sp. *Fusarium* sp. *Gongronella butleri*
Autumn	*Trichoderma viride* *Cladosporium cladosporioides* *Mortierella* sp. *Alternaria* sp. *Epicoccum purpurascens* *Penicillium* sp. *Aspergillus* sp.	*Penicillium* sp. *Trichoderma viride* *Zygorhynchus* sp. *Cladosporium cladosporioides* *Phoma* sp. *Alternaria* sp. *Epicoccum purpurascens* *Mortierella* sp. *Fusarium* sp. *Absidia* sp. *Humicola* sp.
Winter	*Phoma* sp. *Fusarium* sp. *Cephalosporium* sp. *Trichoderma viride* *Penicillium canescens* *Mucor*	*Penicillium* sp. *Mucor* *Trichoderma viride* *Gongronella butleri* *Phoma*

TABLE 37.—*Fungi isolated at station 4, Cane Branch study area, 1966–68*

Season	Surface	Bottom
Spring	*Cladosporium cladosporioides* *Fusarium* sp. *Penicillium* sp.	*Epicoccum purpurascens* *Trichoderma viride* *Phoma* sp. *Alternaria* sp.
Summer	*Trichoderma viride* *Stemphylium botryosum* *Epicoccum purpurascens* *Cladosporium cladosporioides* *Alternaria* sp. *Cephalosporium* sp. *Fusarium* sp.	*Penicillium* sp. *Epicoccum purpurascens* *Trichoderma viride* *Cladosporium cladosporioides* *Aspergillum* sp. *Cephalosporium* sp.
Autumn	*Trichoderma viride* *Penicillium* sp. *Mucor* sp. *Cladosporium cladosporioides* *Fusarium* sp. *Beauveria* sp. *Monosporium* sp. *Epicoccum purpurascens* *Alternaria* sp.	*Trichoderma viride* *Penicillium* sp. *Mucor* sp. *Cladosporium cladosporioides* *Beauveria* sp. *Fusarium* sp. *Phoma* sp. *Gliocladium* sp. *Epicoccum purpurascens* *Alternaria* sp.
Winter	*Humicola* *Cunninghamella japonica* *Trichoderma viride* *Fusarium* sp. *Penicillium* (4 species) *Mucor* *Geotrichum*	*Thysanophora penicilloides* *Trichoderma viride* *Mucor* *Penicillium*

TABLE 38.—*Fungi isolated at station 5, Cane Branch study area, 1966–68*

Season	Surface	Bottom
Spring	*Cladosporium cladosporioides* *Fusarium* sp. *Trichoderma viride*	*Epicoccum purpurascens* *Fusarium* sp. *Trichoderma viride* *Monilia* sp. *Phoma* sp. *Penicillium* sp. *Pestalotia* sp.
Summer	*Epicoccum purpurascens* *Cladosporium cladosporioides* *Penicillium* sp. *Mucor* sp. *Trichoderma viride* *Alternaria* sp. *Fusarium* sp. *Mortierella* sp. *Phoma* sp. *Nematogonium* sp. *Pestalotia* sp.	*Gongronella butleri* *Cladosporium cladosporioides* *Penicillium* sp. *Mucor* sp. *Trichoderma viride* *Fusarium* sp. *Cephalosporium* sp. *Aspergillus* sp.
Autumn	*Penicillium* sp. *Monosporium* sp. *Chaetomium* sp.	*Trichoderma viride* *Mucor* sp. *Cladosporium cladosporioides* *Penicillium* sp. *Verticillium* sp. *Mortierella* sp. *Fusarium* sp. *Beauveria* sp. *Epicoccum purpurascens*
Winter	*Phoma* *Fusarium* sp. *Absidia coerulea* *Penicillium* (2 species) *Trichoderma* *Mucor*	*Mucor* *Penicillium* *Trichoderma* *Myrothecium*

TABLE 39.—*Fungi isolated at station 6, Cane Branch study area, 1966–68*

Season	Surface	Bottom
Spring	*Aureobasidium* sp. *Phoma* sp.	*Pestalotia* sp. *Phoma* sp. *Penicillium* sp. *Alternaria* sp. *Cladosporium cladosporioides* *Trichoderma viride* *Mucor* sp. *Fusarium* sp.
Summer	*Cladosporium cladosporioides* *Phoma* sp. *Aspergillus* sp. *Alternaria* sp.	*Cladosporium cladosporioides* *Phoma* sp. *Trichoderma viride* *Penicillium* sp. *Cephalosporium* sp. *Beauveria bassiana* *Fusarium* sp. *Mortierella* sp. *Epicoccum purpurascens*
Autumn	*Trichoderma viride* *Epicoccum purpurascens* *Cladosporium cladosporioides* *Phialopora* sp.	*Trichoderma viride* *Penicillium* sp. *Mucor* sp. *Cladosporium cladosporioides* *Monosporium* sp. *Paecilomyces* sp. *Zygorhynchus* sp. *Cephalosporium* sp.
Winter	*Alternaria* *Cladosporium cladosporioides* *Thysanophora* sp. *Penicillium chrysogenum* *Trichoderma* *Mucor*	*Trichoderma viride* *Penicillium* *Verticillium* *Mucor* *Aspergillus*

TABLE 40.—*Fungi isolated at station 7, Helton Branch study area, 1966–68*

Season	Surface	Bottom
Spring	*Fusarium* sp. *Monilia* sp. *Cephalosporium* sp.	*Fusarium* sp. *Cladosporium cladosporioides* *Gliocladium roseum* *Penicillium* sp. *Mucor* sp. *Trichoderma viride*
Summer	*Stemphylium* sp. *Penicillium* sp. *Cladosporium cladosporioides* *Epicoccum purpurascens* *Phoma* sp. *Zygorhynchus* sp. *Rhizopus nigricans* *Beauveria bassiana*	*Trichoderma viride* *Fusarium* sp. *Cladosporium cladosporioides* *Pestalotia* sp. *Phoma* sp. *Mucor* sp. *Alternaria* sp. *Peyronellaea* sp.
Autumn	*Trichoderma viride* *Mucor* sp. *Cladosporium cladosporioides* *Fusarium* sp. *Alternaria* sp. *Penicillium* sp. *Aspergillus* sp.	*Trichoderma viride* *Cladosporium cladosporioides* *Mucor* *Alternaria* sp. *Fusarium* sp. *Penicillium* sp. *Monochaetia* sp. *Stachylidium* sp.
Winter	*Mucor fragilis* *Chrysosporium pannorum* *Fusarium* sp. *Gliocladium roseum* *Cephalosporium* sp. *Trichoderma viride* *Penicillium* (3 species)	*Mucor* *Trichoderma virido* *Penicillium* *Gliocladium* *Fusarium*

TABLE 41.—*Algae identified from Cane Branch and Helton Branch, 1966–68*

Season	Surface	Bottom
Spring	*Rhizoclonium hieroglyphicum* *Bumilleria sicula* *Monocila viridis* *Euglena polymorpha* *Stauroneis anceps*	*Mougeotia parvula* *Gyrosigma spencerii* *Fragilaria* sp. *Microthamnion strictissimum* *Lyngbya diguetii*
	Microthamnion strictissimum *Cladophora crispata* *Cladophora glomerata* *Euglena* sp. *Hormidium Klebsii*	*Micrasterias* sp. *Meridion circulare* *Oscillatoria formosa* *Ulothrix* sp.
	Mougeotia parvula *Ulothrix aequalis* *Zygnemopsis decussata*	
Summer	*Bumilleria sicula* *Tribonema bombycinum* *Zygogonium ericetorum* *Zygnema insigne* *Euglena* sp.	*Oedogonium* sp. *Oscillatoria* sp. *Lyngbya* sp. *Stauroneis anceps*
	Hormidium subtile *Microthamnion strictissimum* *Stauroneis anceps*	
Autumn	*Mougeotis* sp. *Euglena* sp. *Ulothrix* sp. *Microthamnion strictissimum* *Stauroneis* sp.	*Oedogonium* sp. *Stauroneis* sp.
Winter	*Bumilleria sicula* *Euglena* sp. *Zygogonium* sp. *Eunotia* sp. *Cladophora* sp.	*Oedogonium* sp. *Bulbochaete* sp.

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Hydrologic Influences of Strip Mining

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