EFFECTS OF SURFACE COAL-MINE RECLAMATION ON STREAM QUALITY IN A SMALL WATERSHED NEAR NELSONVILLE, SOUTHEASTERN OHIO

By S. M. Hindall

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CONVERSION FACTORS

For the benefit of readers who prefer to use the International System of units (SI), conversion factors for terms used in this report are listed below:

Multiply inch-pound units	By	To obtain SI units
inch (in.)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
acre	0.4047	hectare (ha)
gallon per minute (gal/min)	0.06308	liter per second (L/s)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second - days	2.447	cubic meter (m^3)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3)
ton(short)	0.9072	Megagram (Mg) or metric ton
ton per square mile per year ($ton/mi^2/yr$)	0.03753	Megagram per square kilometer per year ($Mg/km^2/a$)

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ABSTRACT

Abandoned surface coal mines in southeastern Ohio have caused degradation of the area's water resources. A study began in 1981 to determine the effects of abandoned-mine reclamation on water quality in the "Yost tract" near Nelsonville, Ohio. Data on streamflow, water quality, and sedimentation were collected in Yost Run before, during, and after reclamation of the Yost tract.

Results of the study indicate that there has been very little change in the chemical quality of Yost Run 10 months after reclamation; pH remains low, about 3.2-4.1, whereas specific conductance continues to be high, about 1,000 to 2,600 micromhos per centimeter (at 25°C). Concentrations of sulfate and dissolved iron also show no appreciable change, remaining about 550 to 1,800 milligrams per liter and 1,300 to 17,000 micrograms per liter, respectively. The suspended-sediment yield for Yost Run is 2,830 tons per square mile per year.

The results of the study reflect water-quality conditions for a 10-month period after reclamation, but do not necessarily indicate that the reclamation will prove to be unsuccessful. A longer period of data collection is likely to be needed to measure trends in water quality that may occur as a result of the reclamation.

INTRODUCTION

Background

Coal mining has been an important activity in eastern Ohio since the early 1800's. Most of the early mining was from underground mines, whereas about two-thirds of the coal mined in the area today is from surface mines (Sneeringer, 1983). As the amount of mining increased, so too did the detrimental effects of mining on the environment. The enactment of Public Law 95-87, "Surface Mining Control and Reclamation Act of 1977," marked the beginning of the reversal of this trend of environmental degradation. To date, important progress has been made in cleaning up the environment and water resources in mining areas throughout the United States.

Eastern Ohio, however, contains thousands of acres of abandoned surface coal mines. Various detrimental effects of many of these mines still exist throughout the area. A considerable amount of this acreage is located in the Wayne National Forest (fig. 1). The U.S. Forest Service is reclaiming many of these abandoned mines in cooperation with the U.S. Department of the Interior, Office of Surface Mining, and the Ohio Department of Natural Resources, Division of Reclamation. It is commonly

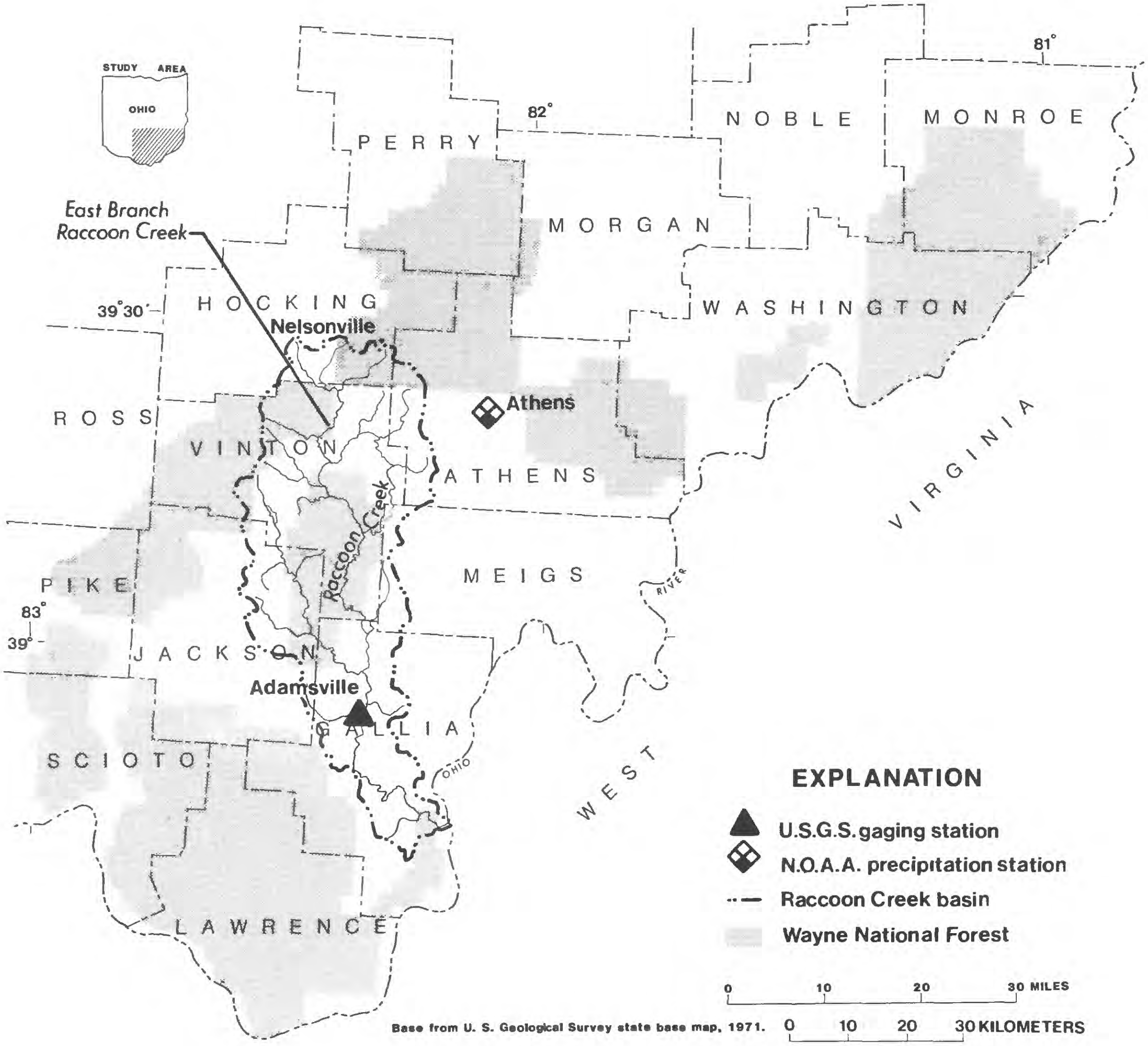

Figure 1.--Location of Wayne National Forest and Raccoon Creek basin.

assumed that reclamation using readily available and presently accepted techniques will improve water quality; however, there are insufficient data in many areas to support this conjecture.

Water-quality problems resulting from abandoned surface mines have been well documented, but effects of reclamation of surface mines have not. In much of the coal-mining area of eastern Ohio, stream water affected by abandoned surface mines has a low pH, high specific conductance, excessive concentrations of sulfate, metals and sediment, and supports few or no aquatic organisms. Such water generally is too corrosive and (or) hard for industrial use and too hard and (or) toxic for agricultural or domestic use. These factors, as well as length of time required to stabilize hydrologic systems, will have to be studied with respect to reclamation processes and methods before even general statements can be made on the effects of reclamation on water quality.

Purpose and Scope

This project was begun in May 1981 with the purpose of collecting data to assess the effects of reclamation on stream quality at one site in the Wayne National Forest. Initially, the project was designed to operate through September 1985, in order that postreclamation conditions could be adequately evaluated, that the time required for the hydrologic system to stabilize could be determined, and that insight into the effectiveness of reclaiming abandoned surface mines could be gained. If stabilization were not evident by 1985, additional data collection would be proposed. However, lack of funds limited the period of postreclamation data collection. The study of ground water, although a factor in hydrology associated with reclamation, was not included in this project.

The final scope of data collection was from May 1, 1981 through November 1982. The streamflow data consist of daily discharges from a continous-record station near the mouth of Yost Run near Nelsonville. Most of the water-quality data collected at this site are from a U.S. Geological Survey minimonitor (instrumented to collect continuous pH, temperature, and specific-conductance data) and a stage-activitated automatic sediment sampler. Supplementary chemical-quality and sediment data were collected monthly and during storm events using manually operated samplers.

Data were collected before, during, and after reclamation. Lack of funds limited the amount of postreclamation data to only a few months; however, some miscellaneous chemical-quality data were collected 15 months after reclamation. Specific conductance, pH, sulfate, and dissolved iron were the major properties and constituents considered in the data analysis for this report.

Description of Study Area

Yost Tract

The drainage basin of an unnamed tributary to East Branch Raccoon Creek in the Wayne National Forest was selected as the site for the project (fig. 1). This basin contained parts of a mined area known as the "Yost tract," and was chosen for study because of the reclamation method planned for the area. There was also no interference from other types of land disturbance or sources of pollution, particularly abandoned drift mines. The study basin has an area of 0.53 square mile and is located in Hocking County, about 4.5 miles southwest of Nelsonville. The data-collection station was located on the unnamed tributary at the bridge on County Road 325, 0.1 mile upstream from the mouth of the unnamed tributary. In this study, the unnamed tributary is referred to as Yost Run near Nelsonville, station number 03201535 (fig. 2).

The Yost tract consists of 595 acres. Approximately 177 acres of surface-mined area within the tract have been reclaimed in three individual units and several subunits (Moss, 1981; Krajnak, 1982). Figure 2 shows the three units and their subunits. The Yost I unit, which is entirely within the Yost Run basin, consists of 37 acres of surface-mined area that was reclaimed prior to this study in 1978. For the purpose of this study, the Yost I unit was considered to be hydrologically stabilized and to have no continually changing effect on water quality. The Yost II and III units, 120 and 20 acres of disturbed area, respectively, were reclaimed during this study; it is the effects of these reclamation efforts that are being evaluated.

The Yost II unit is made up of two subunits; only the part of subunit 2 within the Yost Run basin was included in this study. Any further mention of the Yost II unit in this report refers to that part of subunit 2. The Yost III unit has three subunits, however, only a part of one subunit is within the study area. This part of the Yost III unit is so small that the effects of its reclamation are considered indistinguishable from those at Yost II. Throughout this report, any mention of the Yost tract refers only to the Yost II and III units unless specifically stated otherwise.

Physical Setting

The physiography and hydrology of the Yost tract is typical of the unglaciated Appalachian Plateaus physiographic province (Fenneman, 1938). Relief ranges from 300 to 400 feet in the Raccoon Creek basin, of which the Yost Run basin is a part. Slopes generally range from 10 to 35 degrees. Basin characteristics for the Yost Run basin are given in table 1.

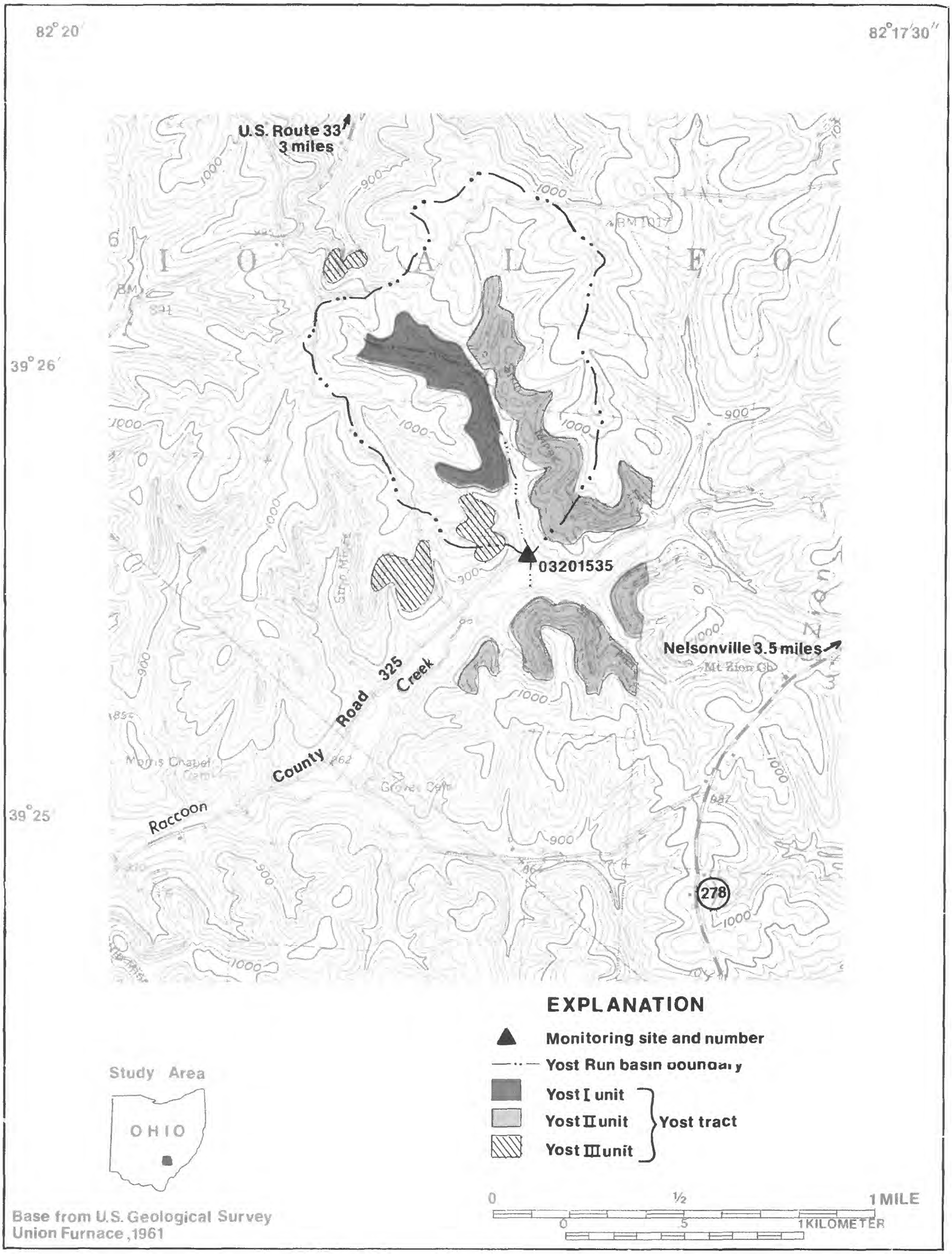

Figure 2.--Location of Yost tract study area.

Table 1.--Basin characteristics, Yost Run near Nelsonville, Ohio

Characteristic	Value
Drainage Area	0.53 square miles
Main-channel slope	141 feet per mile
Main-channel length	.66 mile
Average basin elevation	910 feet above sea level
Surface-water storage	0.5 percent
Forest area	15.9 percent
Average annual precipitation	39 inches
Maximum 24-hour, 2-year rainfall	2.5 inches

Coal in the upper Raccoon Creek basin is found in Allegheny and Pottsville Formations of Pennsylvanian age. The Lower and Middle Kittanning coal seams, numbers 5 and 6 respectively, are the most commonly mined coals in the area. Figure 3 is a general stratigraphic section for the coal-producing region of southeastern Ohio. The Middle Kittanning coal (no. 6) was surface mined in the Yost tract. There was no underground mining done in this basin.

Soils in the vicinity of the study area are derived from sandstone and shale and belong to the Muskingum-Dekalb-Latham soil association (Ohio Department of Natural Resources, Division of Lands and Soil, 1973). They are well drained, shallow to moderately deep, and acidic (pH from 4.5 to 5.0). Because these soils are on slopes too steep for cultivation, their use is generally restricted to forest and pasture. Erosion is a problem where vegetation has been stripped from the slopes.

The climate in the general area of the Yost tract is continental, and is characterized by moderate extremes of temperature and precipitation. Average precipitation for the area is about 40 inches and is heaviest from April to September, and lightest in autumn and the early winter months. Annual snowfall averages 20 to 25 inches (Pierce, 1959).

Streamflow in the upper Raccoon Creek basin varies seasonally with precipitation and evapotranspiration. Flow is maintained by surface runoff and ground-water inflow. Stream stage responds rapidly to runoff, and only meager flows are sustained by ground-water inflow during dry periods. The mean annual discharge for streams in the area is 13 inches or about 1.2 cubic feet per second per square mile (Roth, D. K., U.S. Geological Survey, written commun., 1983).

Sandstones of the Allegheny and Pottsville Formations are the primary aquifers that sustain low flow in streams and supply water to shallow wells in the upper Raccoon Creek area. These sandstones generally yield less than 5 gallons per minute (Ohio Department of Natural Resources, Division of Water [no date]). Water levels in wells in these aquifers vary seasonally with recharge from precipitation. Stripping for coal effectively destroys the surficial aquifers for most uses; new aquifers may become established in spoil or disturbed surficial materials after reclamation, however, the availability and quality of water in the new aquifers are generally unknown.

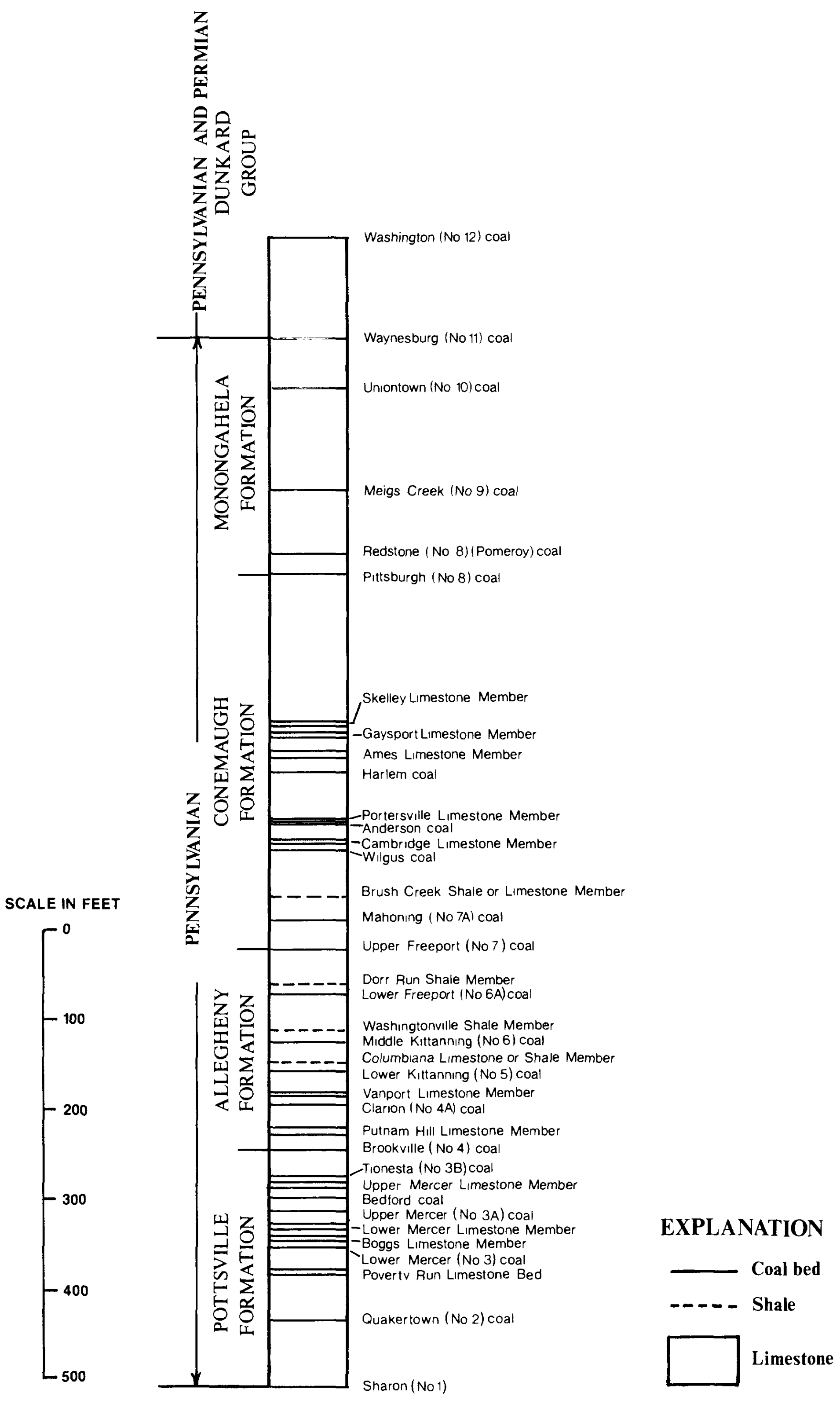

Figure 3.--Generalized stratigraphic column showing coal beds in Ohio (Modified from Collins, 1978)

Description of Reclamation Process

Surface mining of the Middle Kittanning coal seam in the Yost tract took place on two different occasions (Krajnak, 1982). The initial mining by contour stripping began in 1947, but because of equipment limitations, the actual disturbed acreage was small. As new and more powerful equipment was developed, a mining operation in 1965-66 went farther into the hillside and created highwalls up to 40 feet high. Reclamation prior to the "Surface Mining Control and Reclamation Act of 1977" required only minimal revegation efforts. Consequently, the only reclamation undertaken was some haphazard tree planting.

The configuration of the Yost tract before recent reclamation was characterized by a series of very steep highwalls; long, linear ponds at the base of the highwalls; leveled benches; some irregular mounds and pits; and steep outslopes generally devoid of vegetation. Reclamation of the Yost I unit was done conventionally (prior to 1978) by pushing the spoil material upgradient to the top of the highwall. Very little vegetation existed in Yost I, and what did exist was not saved. Only about 14 acres out of 37 received topsoil, and failure of the revegetation effort is clearly evident where topsoil is lacking. Some successful tree planting has recently been completed as part of the Yost II reclamation; it is hoped this will help stabilize soil materials and contribute to the natural reclamation of the Yost I unit.

The 120 acres of mined area to be reclaimed in the Yost II unit consisted of 54 acres of revegetated soils, 33 acres of water and highwall, and 33 acres of barren spoils (Moss, 1981). The 54 acres of revegetated soils that contained planted and natural trees and other vegetation were considered stable, and were left in place where possible during reclamation. The Yost III unit had approximately 16 acres of ponded water, highwall, and barren spoils to be reclaimed, and only 4 acres that was revegetated or needed minimal reclamation. Only about one-half of the Yost II and one-third of the Yost III units are within the Yost Run basin. The remainder of the Yost tract drains directly to East Branch Raccoon Creek (figs. 1 and 2) or other small streams.

The reclamation technique used in both the Yost II and III units is known as "green island reclamation." In this procedure, as much as possible of the well revegetated area of earlier reclamation is retained. Actual reclamation of the tract consisted of draining and backfilling the ponds; removing and burying the more toxic spoils; reducing slopes by regrading; resoiling all low-pH spoil areas; revegetating all disturbed areas; and reestablishing, grading, and riprapping drainageways. Reclamation in the Yost II unit began on September 15, 1981, and continued through November 10, 1981, when construction was suspended for the winter. During this period, major grading was completed, 90 percent of the topsoiling was completed, and the entire area was temporarily seeded. Reclamation resumed in April of the following year and was completed according to plan by May 20, 1982 (Moss, R. G., U.S. Forest Service, written commun., 1983). Reclamation of the Yost III unit began in May 1982 and was completed by July 19, 1982. Only two of the many ponds in the Yost tract contained water of sufficient quality for the ponds to be retained. More detailed descriptions of the reclamation process in the Yost tract are available from the U.S. Forest Service in Bedford, Indiana (Moss, 1981; Krajnak, 1982).

Acknowledgments

The gaging station was installed and data were collected through the 1981 water year in cooperation with the U.S. Forest Service; data collection through the 1982 water year was in cooperation with the Eastern States Office, U.S. Bureau of Land Management. This report was prepared in cooperation with the U.S. Forest Service and the U.S. Bureau of Land Management. The authors would like to thank both agencies, and specifically, Robert C. Moss of the U.S. Forest Service in Bedford, Indiana, for the support provided in this study.

HYDROLOGIC-DATA COLLECTION AND ANALYSIS

The U.S. Geological Survey collected streamflow, water-quality, and sediment data at the Yost Run site from May 1981 through November 1982. Some miscellaneous water-quality data were again collected in July 1983. The data collected from Yost Run were in the vicinity of the gage at the lower end of the Yost tract reclamation site. Continuous streamflow data were collected from July 1981 through November 1982 to determine daily average discharge. Lack of funding however, made it necessary to terminate most of the data collection in November 1982.

Data to determine the physical and chemical characteristics of the runoff from the Yost Run site were collected during this same period. A single streambed-material sample was collected for analysis of trace-metal concentrations. Continuous pH, temperature, and specific-conductance data were collected with a three-parameter water-quality monitor equipped with *in situ* probes. The water-quality monitor data were collected concurrently with streamflow data; however, the experimental pH probe for the water-quality monitor yielded spotty and often unreliable record. As a backup to the water-quality monitor (and for calibration purposes), field determinations of temperature, pH, and specific conductance were made at approximately 2-week intervals.

In addition to the data collected by the U.S. Geological Survey, water-quality data were collected by the U.S. Forest Service at several locations in and near the Yost tract (Moss, R. C., U. S. Forest Service, written commun., 1983). Monthly sampling was done from 1975 through completion of reclamation in November 1982, and quarterly sampling continued thereafter. Physical, chemical, and suspended-sediment data were collected. Both the U.S. Geological Survey and U.S. Forest Service data were used in this report to determine the effects of reclamation.

Streamflow

The streamflow characteristics of Yost Run near Nelsonville are similar to those of other small headwater streams in the mining areas of southeastern Ohio. Low flow is poorly sustained by ground-water inflow, whereas high flow results from surface runoff from precipitation or snowmelt. The high-flow events are usually very flashy and of short duration. At certain times of the year, many of these streams become dry.

The mean discharge for Yost Run for the July 1981 through November 1982 period of record was 0.54 cubic feet per second (ft^3/s). Figure 4 shows the monthly distribution of streamflow. The maximum daily average discharge for this period was 19 ft^3/s on March 12, 1982, whereas the minimum was zero on several days in August, September, and October of 1981 and January 1982. The maximum instantaneous stage was 4.33 feet on May 29, 1982, at 1555 hours and had a corresponding discharge of 103 ft^3/s. There were 62 days with a daily average flow greater than 1.0 ft^3/s, six days with flows greater than 5 ft^3/s, and two days with flows greater than 10 ft^3/s.

A critical period for water quality is during low flow, when discharge is 100 percent ground-water inflow. Analysis of the low flow of Yost Run revealed that the 7-day, 2-year recurrence interval low flow and the 7-day, 10-year recurrence interval low flow are both zero, as is the 30-day, 10-year low flow. The 30-day, 2-year low flow was determined to be 0.1 ft^3/s.

Streamflow in Yost Run during large runoff events can contribute significantly to flooding downstream on East Branch Raccoon Creek. The 2-year and 5-year recurrence-interval floods, as computed from regional equations (Webber and Bartlett, 1977), are 74.4 and 163.0 ft^3/sec, respectively. These flows are estimates based on basin characteristics, and are not actual statistical analyses of recorded data for Yost Run.

Chemical quality

Stream

Chemical-quality data collection began in May 1981 and continued at approximately monthly intervals through September 1982. An additional sample was collected in July 1983. All samples for determining physical and chemical characteristics were collected manually. The collected samples were analyzed for the following constituents:

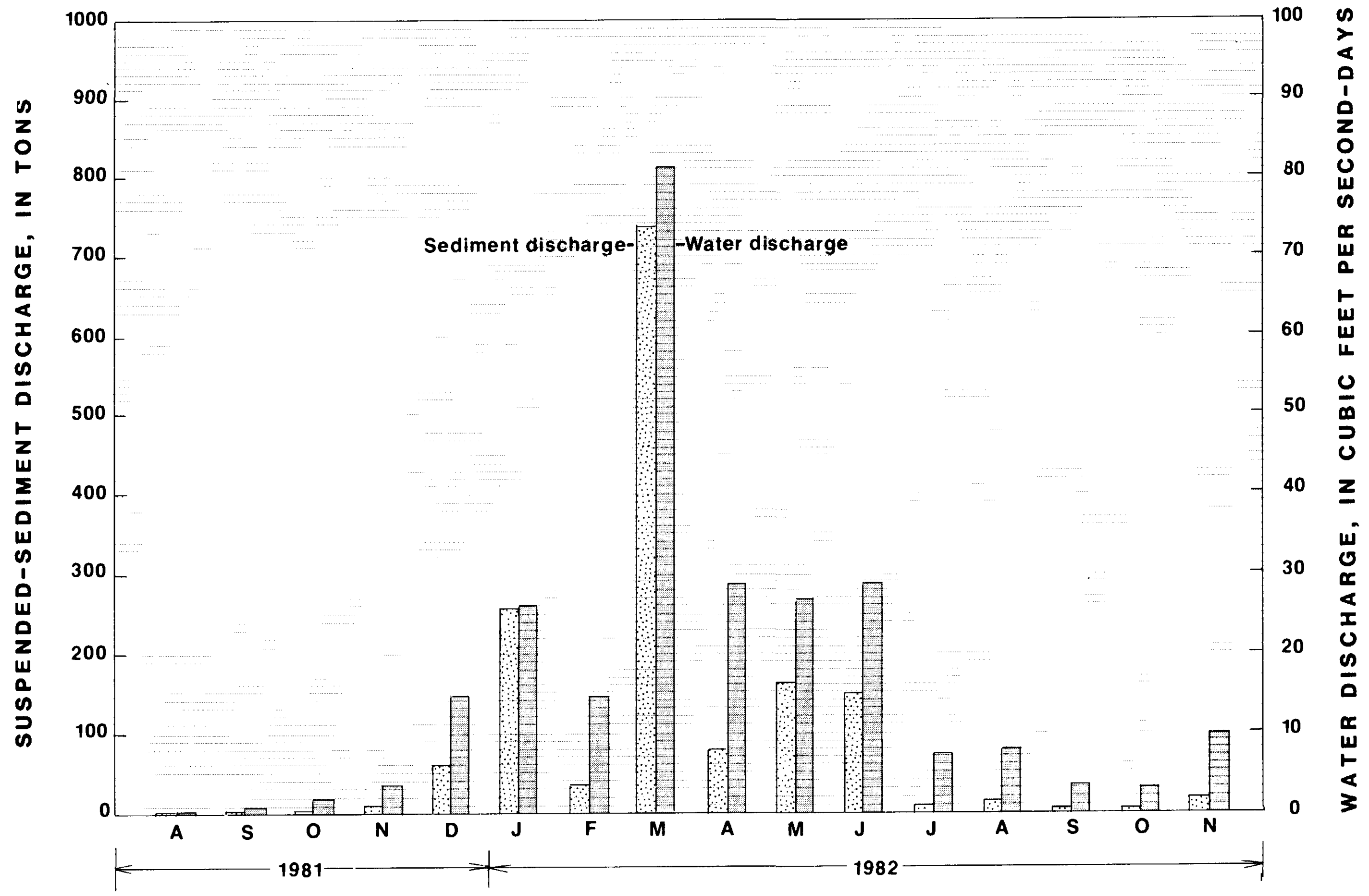

Figure 4.--Distribution of suspended sediment and water discharge for Yost Run near Nelsonville, Ohio August 1981 through November 1982.

Dissolved solids
Hardness (as $CaCO_3$)
Acidity (as H)
Calcium (dissolved)
Magnesium (dissolved)
Sodium (dissolved)
Potassium (dissolved)
Sulfate (dissolved)
Chloride (dissolved)
Silica (dissolved, as SiO_2)
Aluminum (total and dissolved)
Iron (total and dissolved)
Manganese (total and dissolved)

Data are not available on the water quality of Yost Run before mining began in 1947. However, streams in southeastern Ohio that are not influenced by mining generally have pH values of about 7.5, specific conductance of about 400 micromhos per centimeter (µmho/cm), sulfate concentrations near 40 milligrams per liter (mg/L), and iron concentrations near 60 micrograms per liter (µg/L) (Hren, Janet, U.S. Geological Survey, written commun., 1983). Before reclamation of the Yost tract, the pH of Yost Run ranged from 3.0 to 3.5; specific conductance ranged from about 1,500 to 2,800 µmho/cm; sulfate concentrations ranged from 890 to 1,800 mg/L; and dissolved-iron concentrations ranged from 5,200 to 13,000 µg/L. Surface-mining activity caused the pH to decline and the specific conductance, sulfate, and dissolved iron to increase dramatically.

Chemical quality of streamflow generally degrades during surface mining and should begin a slow recovery after reclamation. Data collected during the study and after reclamation indicate essentially no change in the water quality from prereclamation conditions; the pH ranged from 3.0 to 4.1, specific conductance ranged from about 1,000 to 2,600 µmho/cm, and sulfate and dissolved iron concentration ranged from 550 to 1,800 mg/L and 1,300 to 17,000 µg/L, respectively. The results of chemical analysis of a sample from Yost Run collected 1 year after reclamation are essentially identical to the previous samples, and indicate that recovery of chemical quality did not begin in the Yost tract reclamation site 1 year after reclamation. Tables 2 and 3 (at back of report) list the results of chemical-quality analyses and other water-quality data collected from Yost Run. Constituent concentrations in samples collected by the U.S. Forest Service fall within the range of those in samples collected by the U.S. Geological Survey.

The quality of water in Yost Run is influenced by hydrologic and geologic factors. Climate affects stream-water quality through variations in temperature and precipitation. Topography and drainage affect stream-water quality by influencing the magnitude and rate of overland runoff. The source of streamflow, however, has the most profound effect on water quality. A high fraction of ground water inflow tends to produce highly mineralized water of relatively constant quality in streams, whereas a high fraction of overland runoff tends to make streamflow quality highly variable and lower in total mineralization. Periods of high ground-water inflow to streams and little or no overland runoff can produce critical water-quality problems.

The quality of ground-water inflow is dependent on the mineralogic composition and physical characteristics of the aquifer, availability of soluble materials in the rocks, texture and type of soils in the recharge area, rate of ground-water movement, and the quality of the precipitation reaching the ground-water reservoir. During the mining process, some aquifers present in premining times are destroyed and new ones are created from the spoils or combinations of spoils and undisturbed materials. Reclamation can significantly alter the spoil aquifers, however, the effects of reclamation on ground water in spoil aquifers are not known. By isolating some of the more toxic spoils, covering the spoils with soil, and controlling drainage, changes in quality of the ground-water inflow may occur.

Graphs of temperature, pH, specific conductance, and water discharge for Yost Run for the July 1981 to September 1982 period of data collection are shown in figure 5. The graphs were constructed from the manually collected data (table 3) used to calibrate the water-quality monitor. The seasonal trends of the water-quality characteristics are evident from the graphs. In addition, variations with water discharge may be seen, but no discernible long-term trends show up in this relatively short period of record.

Virtually continuous water temperature, pH, and specific-conductance data for Yost Run indicate not only daily fluctuations, but seasonal trends as well. Although equipment problems precluded a complete record, sufficient data were collected to analyze water-quality fluctuations and seasonal trends.

Monthly maximum and minimum instantaneous values and monthly mean values of specific conductance, pH, and water temperature recorded by the water-quality monitor are shown in figure 6. The recorded temperature for Yost Run ranged from 0.0 to 29.5°C, the maximum occurring on September 5 and 6, 1982; pH ranged from a low of 2.8 on November 1, 1981, to a high of 4.1 on December 1, 1981; and specific-conductance ranged from 150 to 8,180 µmho/cm, the minimum value occurring on June 16, 1982, and the maximum on May 15, 1982. Because the water-quality values listed above and those used for figure 6 are from the water-quality monitor data, which have more than 20 percent missing record, the dates should not be used for detailed statistical or technical analyses.

A measure used in this study to determine the effectiveness of of mine reclamation in improving water quality is called the neutralization ratio (Hollyday and McKenzie, 1973). This ratio is calculated by dividing the gross alkalinity by gross acidity; the ratio is 1.00 if the gross alkalinity produced during production of mine drainage is equal to the gross acidity produced at the same time. A neutralization ratio greater than 1.00 indicates that the alkalinity formed was more than enough to neutralize the gross acidity

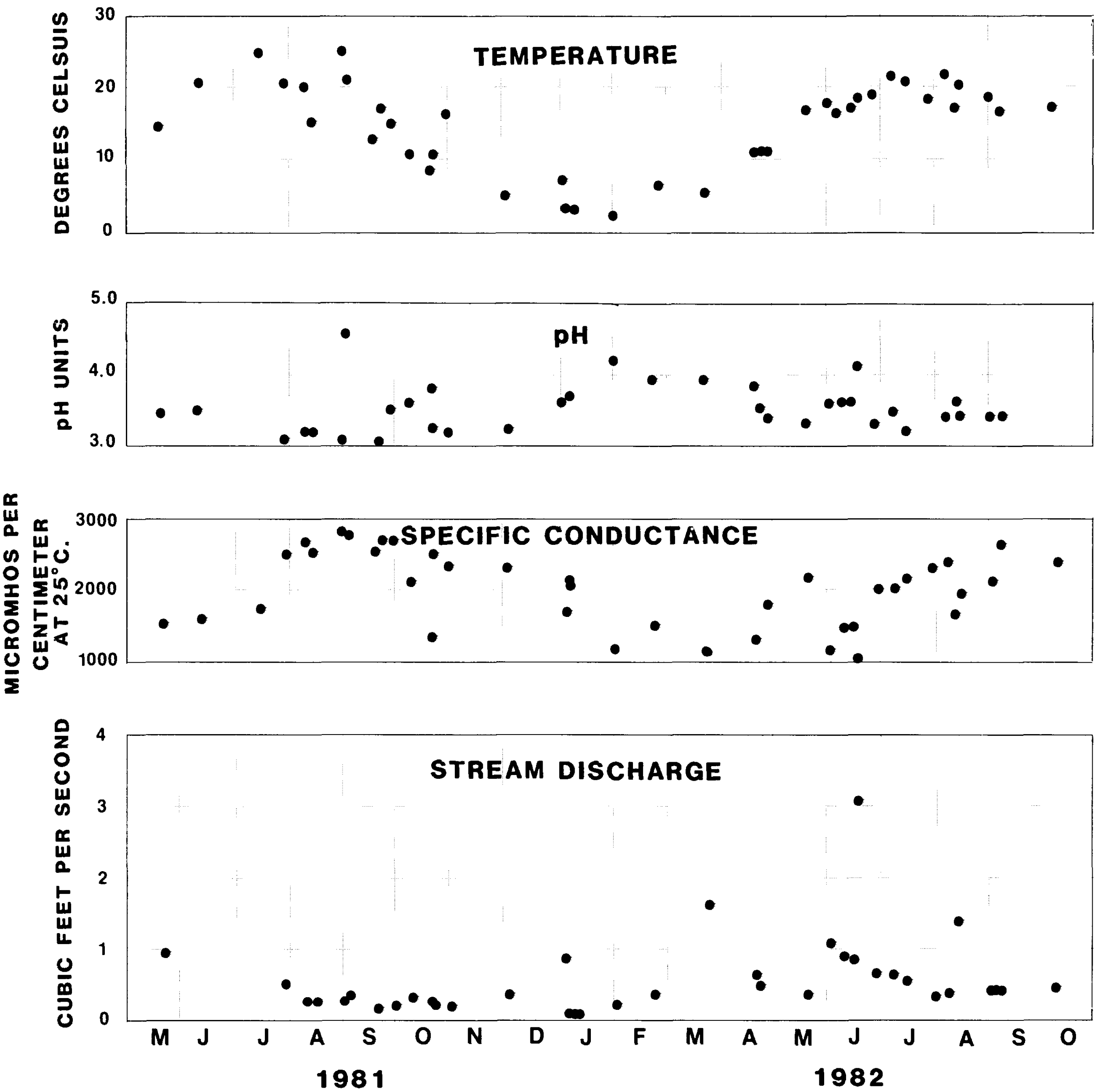

Figure 5.--Graphs of field-determined chemical-quality characteristics, Yost Run near Nelsonville, May 20, 1981 through October 7, 1982.

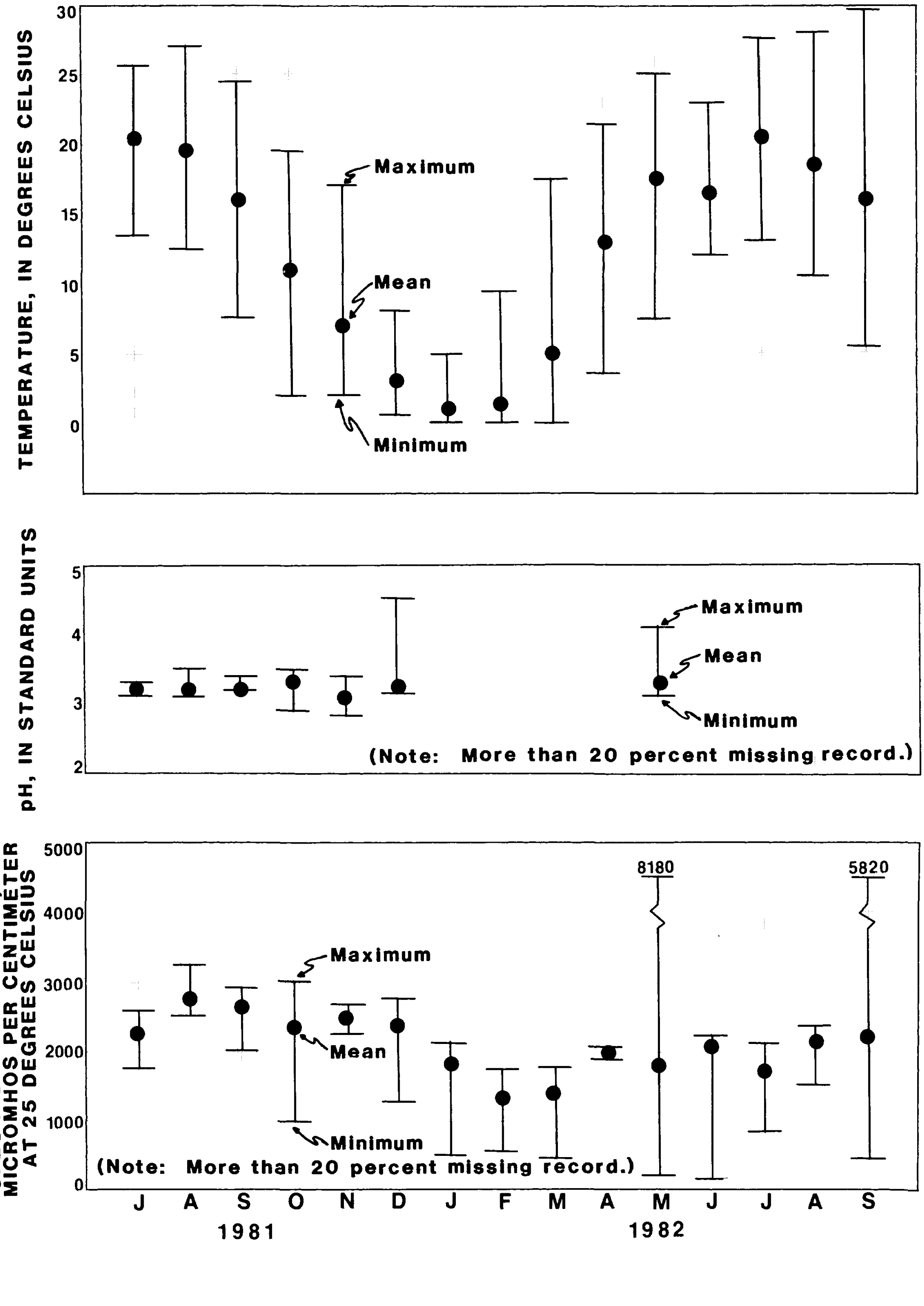

Figure 6.--Monthly maximum, minimums, and means of water quality monitor recorded temperature, pH, and specific conductance for Yost Run near Nelsonville, July 1981 through September 1982.

from sulfuric acid released to the water by oxidation of iron sulfide. The neutralization ratios for samples from Yost Run were 1.00 or less (table 2), which indicates that neutralization of acidic mine drainage is not taking place at the present time (1982), and thus, that the reclamation has had little effect on this water-quality constituent.

Bed Material

The chemical analysis of a bed-material sample from Yost Run indicates that trace metal concentrations are similar to those in bed material in other small streams in southeastern Ohio.

Concentrations of seven trace metals in that sample were as follows:

Arsenic	micrograms per liter	1
Cadmium	do	3
Chromium	do	10
Copper	do	10
Lead	do	30
Mercury	do	0.08
Zinc	do	36

Premining or prereclamation bed-material (chemical quality) data are not available for Yost Run; therefore, comparisons of water quality among unmined, abandoned, and reclaimed conditions cannot be made. However, bed-material chemical-quality data from other studies (Hren, Janet U.S. Geological Survey, written commun., 1983) show that there is very little difference in bed-material quality in streams from unmined, abandoned, or reclaimed basins.

Sediment

Sedimentation is the one characteristic that can be affected most dramatically by reclamation of abandoned surface mines. Grading, seeding, diversion, and channelization all tend to reduce erosion and, hence, reduce sediment transport from a basin. The suspended-sediment discharge from Yost Run for the period August 1981 through November 1982 was approximately 1,510 tons. The discharge for water year 1982 (October 1971 through September 1972) was about 1,500 tons or a yield of 2,830 tons per square mile per year. This yield is extremely high when compared to the estimated 100 to 200 (tons/mi^2)/yr for streams in south-central Ohio and the measured 68 (tons/mi^2)/yr for the Raccoon Creek basin above Adamsville (Antilla and Tobin, 1978).

Suspended-sediment data were collected periodically from May 1981 through November 1982. Low and high flows were sampled. Low-flow samples were collected manually, whereas the high flow was sampled by automatic and manual methods. Because of mechanical problems with the automatic sampler, only a very few high-flow events were sampled. Although the high-flow sediment records are incomplete, the data collected are sufficient for general analysis.

The period of suspended-sediment record coincided with reclamation of the Yost II and III tracts. No prereclamation and very little postreclamation sediment data were collected. The available data are more representative of on-going reclamation, in that the seedings and other ground covers did not have a chance to become fully established within the period of data collection.

About half of the suspended sediment transported from Yost Run during the period of record was produced in March 1982, and most of that during a single storm on March 20. Figure 4 shows the monthly distribution of suspended sediment and water discharge for the period of record. January, April, May, and June were the other months that had significant suspended-sediment production and corresponding surface runoff. The remaining 11 months produced less than 5 percent of the total suspended sediment transported from the area. Because there were very few significant runoff events, the estimated suspended-sediment yield for Yost Run during this period is probably much less than the long-term average.

The relationship between suspended-sediment discharge and water discharge is shown in figure 7 and is represented by the regression equation

$$Q_s = 2.17\ Q^{1.75}$$

where Q_s is the instantaneous suspended-sediment discharge in tons/day and Q_w is water discharge in ft^3/s. This equation is only valid for the range of measured streamflow used to develop the relation and for the period of data collection. As vegetation becomes established and sediment production is reduced, the relationship would probably have less slope and different coefficients.

A visual inspection of the Yost Run basin in September 1983 showed the Yost II and III reclamation efforts to have succeeded in establishing a dense cover of vegetation, thereby reducing erosion. However, the Yost I reclamation appears to be less than successful. There is very little ground cover established, and much evidence of active erosion in the form of rills and gullies throughout the Yost I unit. It is very apparent that most of the postreclamation sediment production is from the Yost I unit, and until it is better vegetated or again reclaimed, suspended-sediment yield from Yost Run will continue to be extremely high.

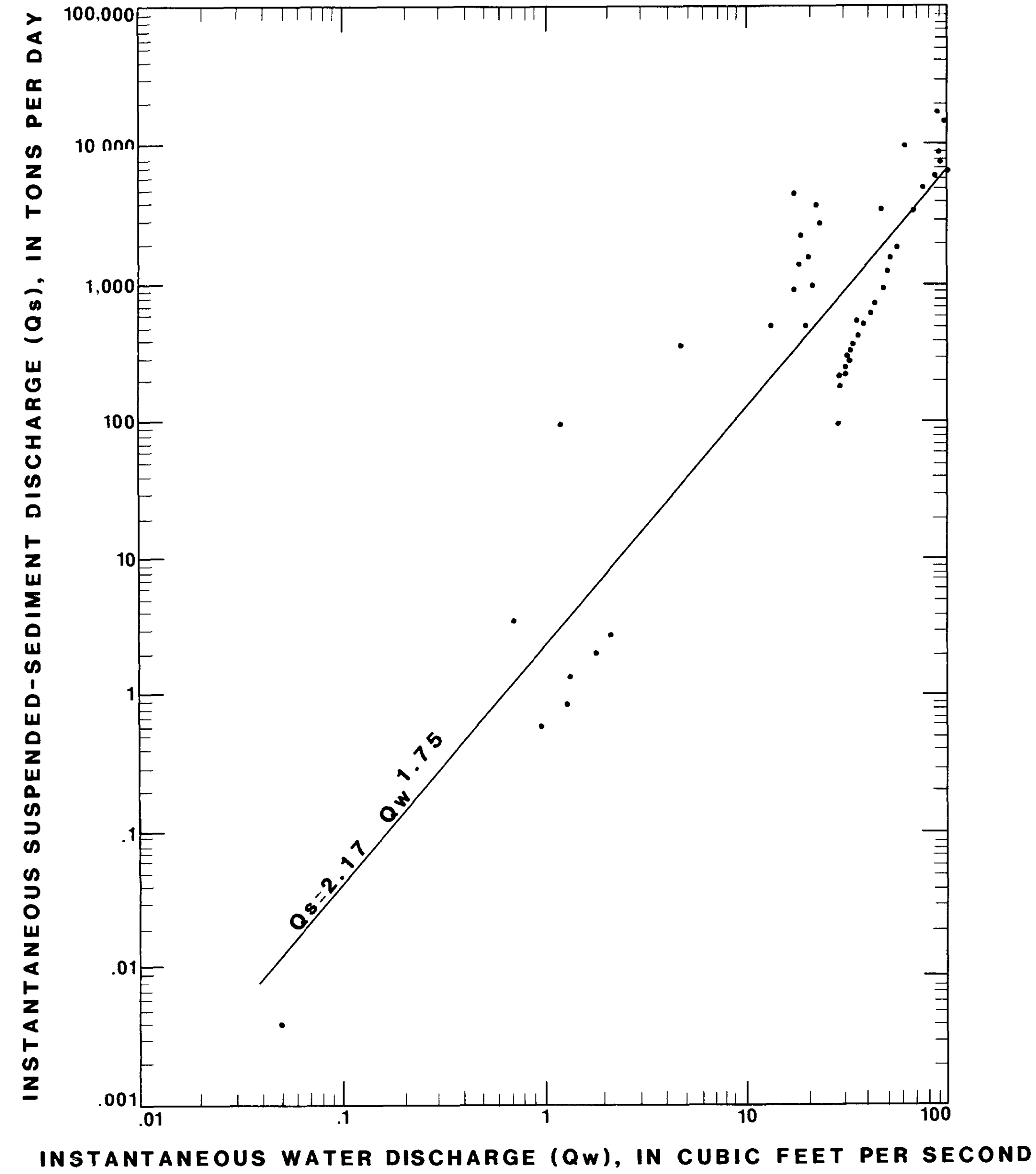

Figure 7.--Relation between suspended sediment and stream discharge for Yost Run near Nelsonville, Ohio, August 1981 through November 1982.

Bedload, or sediment transported along the streambed was not measured in this study. However, long-term bedload data are available for Raccoon Creek at Adamsville and can be used to estimate bedload at Yost Run. Antilla and Tobin (1978, p. 47) estimated that for Raccoon Creek at Adamsville, 25 to 50 percent of the total-sediment discharge is transported as bedload. Therefore, assuming sediment characteristics at Yost Run are similar to those in Raccoon Creek, the total sediment yield for Yost Run could be as high as 5,600 tons per square mile per year. No particle-size analysis of Yost Run sediment was made, but samples from Raccoon Creek at Adamsville indicate that about 61 percent of the suspended sediment is claysize particles (0.004mm), 32 percent is silt (0.004 to 0.062mm) and 7 percent is sand (0.062 to 2.0mm) (Antilla and Tobin, 1978, p. 40).

SUMMARY AND CONCLUSIONS

Reclamation of abandoned surface mines is continuing throughout southeastern Ohio. The U.S. Forest Service, in cooperation with the U.S. Office of Surface Mining, reclaimed the Yost tract near Nelsonville in three separate efforts. Water quality, sedimentation, and streamflow data were collected from May 1981 through November 1982 by the U.S. Geological Survey in cooperation with the U.S. Forest Service and the U.S. Bureau of Land Management to determine if the reclamation efforts had a significant effect on the hydrology of the Yost Run basin. Some data (4 months) were collected prior to the Yost II and III reclamation efforts by the U.S. Geological Survey and the U.S. Forest Service. Additional data (11 months) were collected during the reclamation process and a small amount of data (4 months) was collected after reclamation was completed and vegetative cover established. An additional chemical-quality sample was collected 12 months after reclamation was completed.

Streamflow patterns of Yost Run appear to be characteristic of most small streams in southeastern Ohio. The limited discharge data collected for this project are not adequate to make any statements of the effects of reclamation on streamflow. The maximum recorded instantaneous discharge for the period of record was 103 ft^3/s and the minimum was zero. The daily average discharge ranged from zero to 19 ft^3/s, and the 17-month mean daily discharge was 0.54 ft^3/s.

The water quality of Yost Run has not changed significantly since completion of the Yost II and III reclamation efforts -- pH has remained low (in the 3.2-4.1 range), specific conductance is high, (1,000 to 2,600 μmho/cm), and concentrations of sulfate and dissolved iron are high (550 to 1,800 mg/L and 1,300 to 13,000 μg/L, respectively). The lack of change in water quality in Yost Run does not necessarily indicate that the reclamation will prove to be unsuccessful. It merely indicates that, to date, its effects are not apparent in the water quality of Yost Run. It may take considerable time before the water stored in the aquifers created by the abandoned-mine spoils are affected by the reclamation efforts.

Sediment is one characteristic that may have an immediate response to reclamation in the Yost tract. The sediment discharge for Yost Run for the 1982 water year was about 1,500 tons/yr, or 2,880 (tons/mi^2)/yr. The long-term average for other streams in this area of Ohio is about 100 to 200 (tons/mi^2)/yr (Antilla and Tobin, 1978). The tenfold difference in sediment yield is directly attributable to surface mining and reclamation activities. Although available data are insufficient to make any quantitative conclusions on the change in sediment transport in Yost Run due to reclamation, qualitative conclusions can be made. A post-reclamation inspection of the Yost Run basin in September 1983 showed a dense vegetation cover and little or no visible erosion in Yost II and III units. On the other hand, the Yost I unit was almost completely devoid of vegetation and contained many eroding rills and gullies. It is obvious that most of the erosion in Yost Run basin is from the Yost I unit. Until Yost I unit is re-reclaimed, sediment discharge in Yost Run will remain very high, which makes a quantitative assessment of sedimentation and reclamation of the Yost II and III units impossible.

ADDITIONAL DATA NEEDS

The data collected thus far in the Yost Run basin are inconclusive with respect to the effects of the Yost tract reclamation on water quality. Additional data collected over a longer term would be needed before any definitive statements can be made.

An alternative for a future data-collection program would be continued water-quality data collection. Quarterly measurements of streamflow, pH, specific conductance, and temperature could be made, and water samples could be taken annually during low flow for chemical analysis of selected characteristics. In addition, three wells for sampling and measuring ground water could be installed to measure changes in the ground-water system. Two wells could be located in the spoils or reclaimed material, one near a discharge area and a second in a recharge area. A third well could be placed in undisturbed consolidated material beyond the limits of mining. Water levels in all wells could be measured quarterly and water-quality samples collected annually for analysis of the same chemical characteristics as for the surface-water samples. If the data-collection program continued for a sufficient length of time, a meaningful qualitative analysis could be made to determine if any changes in water quality or sedimentation had taken place.

A second alternative might be to reestablish a sediment data-collection program. The gaging station on Yost Run could be reactivated at 3- to 5-year intervals and operated in conjunction with an automatic sediment sampler for 1 year; the station could then be discontinued for another 3- to 5-year period. This cyclic operation could continue until a sufficient length of record were available to make conclusive statements on the effects of reclamation on sedimentation.

The first alternative addresses the chemical quality problem; the second, sedimentation. These alternatives for future action are complementary; however, either could stand alone or in some combination to provide much-needed data to assess the effects of reclamation on water quality in small watersheds such as Yost Run.

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Table 2.--Chemical-quality data, Yost Run near Nelsonville, May 20, 1981 - July 11, 1983

[Al, aluminum; CA, calcium; CACO3, calcium carbonate; CL, chloride; DEG. C, degrees Celsius; FE, iron; H, hydrogen ion; K, Potassium; MG, magnesium; MG/L, milligrams per liter; MN, manganese; NA, sodium; SIO2, Silica; SO4, sulfate; UG/L, micrograms per liter]

DATE	TIME	HARD- NESS (MG/L AS CACO3)	ACIDITY (MG/L AS H)	CALCIUM DIS- SOLVED (MG/L AS CA)	MAGNE- SIUM, DIS- SOLVED (MG/L AS MG)	SODIUM, DIS- SOLVED (MG/L AS NA)	POTAS- SIUM, DIS- SOLVED (MG/L AS K)
MAY , 1981							
20...	1100	609	4.7	130	69	5.2	1.9
JUN							
11...	1320	650	5.8	140	73	4.6	1.9
JUL							
29...	1130	1242	8.2	250	150	7.1	3.1
SEP							
01...	1200	1664	16	320	210	8.3	3.4
18...	1000	1424	9.1	290	170	7.7	2.9
29...	1500	1458	11	320	160	7.8	2.8
OCT							
29...	1300	1424	11	290	170	9.6	3.2
DEC							
02...	1300	1490	8.0	300	180	10	3.6
APR , 1982							
20...	1000	685	7.9	139	82	6.0	1.9
MAY							
19...	0900	1160	12	250	130	8.0	3.3
JUN							
16...	0940	481	3.8	110	50	5.0	4.1
JUL							
14...	1000	1068	8.7	230	120	6.1	2.9
AUG							
12...	1445	907	5.1	200	99	7.1	3.1
SEP							
07...	1000	1251	5.1	270	140	8.0	3.2
JUL , 1983							
11...	1050	1317	7.3	280	150	8.0	3.4

Table 2.--Chemical-quality data, Yost Run near

DATE	SULFATE DIS-SOLVED (MG/L AS SO4)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL)	SILICA, DIS-SOLVED (MG/L AS SIO2)	SOLIDS, RESIDUE AT 180 DEG. C DIS-SOLVED (MG/L)	SOLIDS, SUM OF CONSTI-TUENTS, DIS-SOLVED (MG/L)
MAY , 1981					
20...	890	9.8	23	1340	1182
JUN					
11...	970	6.2	26	1510	1231
JUL					
29...	1600	2.0	28	2550	2138
SEP					
01...	1600	2.5	42	1060	2258
18...	1500	2.0	5.6	2710	2078
29...	1800	3.4	11	2790	2414
OCT					
29...	1700	4.1	29	2580	2264
DEC					
02...	1800	6.7	26	2660	2427
APR , 1982					
20...	930	2.2	22	1190	1228
MAY					
19...	1500	.6	28	--	1981
JUN					
16...	550	7.3	16	--	761
JUL					
14...	1300	3.1	30	--	1765
AUG					
12...	1100	9.7	31	--	1513
SEP					
07...	1400	9.5	34	--	1948
JUL , 1983					
11...	1700	3.3	36	--	--

Nelsonville, May 20, 1981 - July 11, 1983--Continued

ALUMINUM, TOTAL RECOVERABLE (UG/L AS AL)	ALUMINUM, DISSOLVED (UG/L AS AL)	IRON, TOTAL RECOVERABLE (UG/L AS FE)	IRON, DISSOLVED (UG/L AS FE)	MANGANESE, TOTAL RECOVERABLE (UG/L AS MN)	MANGANESE, DISSOLVED (UG/L AS MN)	NEUTRALIZATION RATIO
21000	20000	15000	13000	19000	18000	0.65
--	320	--	9100	--	20	.64
46000	42000	11000	11000	48000	45000	.75
53000	10000	5400	5200	57000	57000	1.0
31000	31000	11000	11000	58000	58000	.92
43000	43000	8000	7000	58000	58000	.78
39000	35000	20000	17000	72000	5700	.81
33000	33000	12000	11000	57000	57000	.80
21000	8200	24000	16000	22000	21000	.72
10000	10000	--	1300	--	47000	.75
13000	9900	--	6600	--	11000	.93
29000	29000	--	1400	--	41000	.79
27000	27000	--	4900	--	30000	.78
31000	31000	--	4300	--	46000	.86
55000	55000	6600	6200	47000	46000	.75

Table 3.--Chemical-quality field determinations, Yost Run, near Nelsonville May 20, 1981 - September 14, 1983

Date	Time	Stream-flow, instantaneous (ft^3/s)	Specific conductance (µmho/cm)	pH	Temperature (degrees C)	Dissolved oxygen (mg/L)
1981						
May 20--------	1100	0.96	1,530	3.4	14.5	--
June 11-------	1320	--	1,600	3.5	20.5	--
July						
14----------	1530	--	1,720	--	25.0	7.2
29----------	1130	.54	2,400	3.1	20.0	--
29----------	1200	.54	2,600	3.1	21.0	8.2
August						
10----------	1050	.26	2,660	3.2	20.0	8.0
14----------	1000	.26	2,500	3.2	15.0	9.0
September						
1----------	1200	.25	2,820	3.0	25.0	--
1----------	1500	.20	2,800	3.0	25.0	9.0
3----------	1115	.38	2,760	4.6	21.0	8.8
18----------	1000	.15	2,500	3.2	12.5	--
18----------	1025	.15	2,500	--	12.5	9.5
22----------	1300	.15	2,700	3.0	17.0	9.5
29----------	1452	.20	2,700	3.5	15.0	9.2
29----------	1500	.20	2,700	3.5	15.0	--
October						
8----------	1135	.32	2,100	3.6	11.0	--
20----------	1030	.26	1,330	3.8	8.5	--
21----------	1100	.20	2,480	3.2	10.5	--
29----------	1300	.20	2,330	3.2	16.5	--
29----------	1345	.26	--	3.2	16.0	10.1
December						
2----------	1300	--	2,300	3.2	5.0	--
2----------	1430	.38	2,300	3.2	5.0	12.6

Table 3.--Chemical-quality field determinations, Yost Run, near Nelsonville May 20, 1981 - September 14, 1983--Continued

Date	Time	Stream-flow, instan-taneous (ft^3/s)	Specific conduc-tance (umho/cm)	pH	Temperature (degrees C)	Dis-solved oxygen (mg/L)
1982						
January						
4----------	0930	.88	--	3.6	7.0	--
5----------	1100	.03	1,700	--	3.0	--
6----------	1145	.01	2,100	3.7	3.0	--
7----------	1130	.01	1,950	--	2.5	--
February						
2----------	1345	.20	1,140	4.2	1.5	--
24----------	1035	.38	1,500	3.9	6.0	--
March 23------	0945	1.63	1,175	3.9	5.0	--
April						
20----------	0938	.62	1,300	3.8	10.5	--
20----------	1000	.62	1,300	3.8	10.5	--
22----------	0925	.46	--	3.5	10.5	--
27----------	1000	--	1,800	3.4	10.5	--
May						
19----------	0900	.32	2,200	3.4	16.5	--
19----------	0925	.32	2,250	3.3	16.5	--
June						
1----------	1126	1.07	1,150	3.6	17.5	--
8----------	1000	.88	1,490	3.6	16.5	--
14----------	1000	.81	1,500	3.6	17.0	--
16----------	0940	3.08	980	4.1	18.0	--
16----------	1100	2.37	1,000	4.1	18.5	--
28----------	1000	.62	2,000	3.3	19.0	--
July						
7----------	0945	.62	2,000	3.5	21.0	--
14----------	1000	.54	2,190	3.2	19.5	--
14----------	1115	.54	2,150	3.2	21.0	--
30----------	1038	.32	2,300	--	18.0	--

Table 3.--Chemical-quality field determinations, Yost Run, near Nelsonville May 20, 1981 - September 14, 1983--Continued

Date	Time	Streamflow, instantaneous (ft^3/s)	Specific conductance (umho/cm)	pH	Temperature (degrees C)	Dissolved oxygen (mg/L)
1982						
August						
6----------	1030	.38	2,400	3.4	21.5	--
11----------	--	1.39	1,660	3.6	17.0	--
12----------	1445	--	1,930	3.4	20.0	--
September						
1----------	0918	.38	2,100	3.4	18.5	--
7----------	1000	.38	2,600	3.4	16.5	--
October 7-----	1110	.46	2,390	--	17.0	--
1983						
July 11-------	1050	.03	2,600	3.2	20.0	--
September 14--	0905	--	2,200	3.3	15.0	--

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