To the Graduate Council:

I am submitting herewith a thesis written by Donald E. Dunning, Jr., entitled "Water Quality Characterization and Some Relationships to Coal Surface Mining Disturbance in Six Primary East Tennessee Watersheds." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Environmental Engineering.

Roger A. Minear, Major Professor

We have read this thesis and recommend its acceptance:

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Vice Chancellor
Graduate Studies and Research

Thesis
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WATER QUALITY CHARACTERIZATION AND SOME RELATIONSHIPS TO COAL SURFACE MINING DISTURBANCE IN SIX PRIMARY EAST TENNESSEE WATERSHEDS

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Donald E. Dunning, Jr.

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FOR NANCY,

Who makes everything possible.

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ABSTRACT

The environmental consequences of contour surface mining of the coal reserves in Tennessee, and in Appalachia in general, are not well defined. In this study six primary watersheds with various degrees of mining disturbance in the New River Basin of eastern Tennessee were studied over a period of one year; water samples were collected from each of the sites at roughly weekly intervals in an effort to identify any environmental effects attributable to coal surface mining. These samples were analyzed with standard wet chemical techniques for the major constituents, and with atomic absorption spectrophometry for trace metals.

Benchmark water quality of the area was characterized based on the three sample watersheds free of mining disturbance, and deviations from this baseline condition were noted in the three watersheds exposed to surface mining activity. Elevation of stream pH levels was observed, along with increases in the concentrations of solids, alkalinity, sulfate, iron, manganese, calcium, magnesium, aluminum, chromium, copper, nickel, and zinc. No significant increase in the concentrations of arsenic, cadmium, lead, or tin was observed in the mine-disturbed waters.

Effects of changing hydrologic and climatological conditions on the water quality of the study watersheds were also identified. Short-term variation in the water quality of each of the streams during the storm of March 5, 1976, was described. Surface flushing of several constituents was observed, resulting in maximum concentrations at the point of peak flow. The observed short-term variation in constituent

concentrations during this storm was of a much greater magnitude for the mined watersheds than for the undisturbed basins.

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I. INTRODUCTION

Thousands of miles of barren highwalls and spoil banks wind around the mountain slopes of the Appalachian region, providing a stark contrast to the natural beauty of the area. While these aesthetic consequences of coal surface mining are readily apparent to any observer, the effects on the water quality of the disturbed regions are not well understood. The Appalachian Regional Commission (1) estimated in 1970 that approximately 10,500 miles of streams had been polluted by mining activity. This pollution may occur either through surface runoff or by percolation through the spoil banks to the groundwater discharge. In either case, the water may pick up a load of suspended particulates as well as dissolved constituents.

Coal has once again resumed prominence in the United States as a probable alleviant to the growing demand for energy. Coal has long been an important source of energy production. However, from the turn of the century to 1972, the percent contribution to our total energy production declined from some 90 percent to a mere 17 percent, due largely to the availability and convenience of oil and natural gas (2).

With the realization of the problems that could result from dependence on foreign-supplied oil, following the Arab embargo of 1974, coal was pushed to the forefront as perhaps the best immediate approach to energy independence. Based on 1973 consumption levels, the United States has sufficient usable coal reserves to supply energy requirements

for 500 to 600 years (2). Approximately 26 percent of these deposits lie in the Appalachian region.

Surface mining of coal, or strip mining, has gained increasing prominence due to a lower rate of escalation of the associated operational costs, as compared to deep mining. Associated with this mining activity there are sizable pollutional problems. Clearly, it is necessary to develop a workable balance between expanding population and economic growth, and possible detriment to the quality of life in the region. In order to do so, one must first have an understanding of precisely what the environmental effects may be.

During the surface mining process, large areas of underground coal seams are exposed to weathering activity, and large spoil banks of spent earth are produced. Any loose particulates or readily leachable materials present in these surfaces may contribute significantly to the pollutant loadings of streams and stormwaters in contact with the mine area. The role of such mine drainage has been defined by the Appalachian Regional Commission as "working in concert with the other pollution and institutional deficiencies as an economic deterrent in the Appalachian region" (3). This detrimental role may result from a number of possible avenues, including adverse effects on the biota, loss of recreational value, and loss of potable water supplies. It is important, however, to note that the actual mine drainage should not be considered as an isolated culprit; associated with the mine site, various types of refuse dumps, sewage, and building wastes may also pose serious environmental consequences. Nevertheless, mine drainage

remains an extremely important and poorly understood component of the problem.

The principal objectives of this study are (1) to describe the benchmark water quality of small streams in the New River basin of Appalachia, which are unexposed to mining activity, (2) to identify deviations from the benchmark state attributable to coal surface mining, and (3) to identify some effects of hydrologic and climatological conditions on the resultant pollutant loadings, and other intervariate associations for future model development. The study is directed very specifically at six small watersheds in the New River basin of eastern Tennessee. However, these streams are thought to be essentially characteristic of the area, and general conclusions from the study may be applicable to other basins of similar characteristics. As always, extreme caution must be exercised when making such tenuous extrapolations to other sites until sufficient field data can be collected to justify any conclusions.

II. LITERATURE REVIEW

Much of the early work relating to the problem of coal mine drainage was conducted by the U. S. Bureau of Mines (4). Studies undertaken by this agency spanned a wide range of subjects, including the identification of sources, characterization of acid mine water, effects of associated pyrite strata, and treatment technology. Particular emphasis has been placed upon mine sealing and neutralization as treatment techniques.

Several studies have been undertaken in recent years to assess the water quality impacts of mine drainage on regional watersheds. Curtis investigated the relation of water quality to coal surface mining in Kentucky watersheds with regard to chemical (5, 6) and erosional (7) effects. He noted elevated concentrations of several chemical constituents in response to the mining activity. These results will be discussed later in the context of similar findings of this study.

Also in Kentucky, extensive work has been conducted by Collier and Musser (8,9,10). They have investigated the chemical, geologic, hydrologic, and biological perturbations of the Beaver Creek Basin resulting from mining activity in this area, noting marked increases in many of these same constituents. This is perhaps the longest-term study of this type to date.

Gang and Langmuir (11) conducted a study of the Clarion River-Redbank Creek watershed of Pennsylvania, in which they monitored the levels of eleven metals in addition to other common water quality

measurements and streamflow. Components analysis and logarithmic regression techniques were employed to develop predictive models for some constituents. Important in this study was the consideration of nonequilibrium kinetics and solubility limitations on trace metal concentrations.

Herricks and Cairns (12) investigated another Pennsylvania watershed to characterize the natural recovery processes of streams exposed to acid mine drainage. The assimilative capacity of a stream to cleanse itself, primarily by dilution and neutralization, was found to be dependent upon several factors; foremost among these was the quality and quantity of the water from incoming tributaries, thus indicating dilution as the principal recovery mechanism.

Plass (13) studied the water quality of four West Virginia watersheds before and during coal mining activity. In addition to water quality changes caused by the mining disturbance, he also found significant variation in the levels of most constituents between the growing season and the biologically inactive season, pointing to uptake and discharge of these constituents by the biota. We have noted marked seasonal cycles for some constituents in the New River study; however, it is felt that this is attributable primarily to temperature and hydrologic considerations rather than biological effects. Variation between different water-years was also found to be quite pronounced in the West Virginia study, apparently due to varying climatic conditions and streamflow.

Although not directly concerned with mine drainage effects, Delfino found wide variability in the chemical constituents of the Missouri (14) and Mississippi (15) Rivers as a function of flow. Particularly important was the link between discharge and suspended solids loadings, and the associated pollutant loadings incorporated in this particulate phase; several metals, including Cu, Pb, and Zn, were strongly correlated with hydroxides of Fe and Mn. Somewhat dissimilar relationships have been discerned in the current New River study, as discussed in Sections V-B and V-D. Delfino also noted a number of statistical associations among other water quality variables. Some of these will be discussed later in regard to similar correlations found in this study.

A first generation nonpoint source water quality model has been developed by Betson and McMaster (16), and regionalized for the Tennessee Valley. Water quality constituents are related to flow by means of rating curves for each of the individual constituents. A similar nonpoint source model may soon be applied to the New River basin.

Numerous hydrologic and water quality impact studies have been undertaken in recent years in the New River basin by various investigators from the University of Tennessee. Tung (17) has related the streamflow in the New River watershed to the percentage of surface area disturbed. Turnmire (18) has characterized the movement of groundwater through a spoil bank in the Indian Fork watershed. Rose (19) found significant water quality impacts attributable to mining disturbance in his study of nineteen sites on Indian Fork and David's Creek; he further noted the

varying importance of subsurface and surface flow components for the different sites. Work is continuing on this wide-ranging project in a number of areas. Tschantz (20) is continuing to study the overall changes in basin hydrology in response to strip mining, including the development of computer models to simulate streamflow and sediment transfer. Overton (20) is working to provide a modeling interface between chemical and hydrologic changes and interaction within the spoil banks. Geological characterization of the fluvial basin is also proceeding, as are biological impact analyses. All of these different phases of the study are designed in concert to provide a thorough basic understanding of the real impacts of Appalachian coal mining.

Franks (21) investigated the trace metal composition of coals and their associated lithologies in the Indian Fork basin. He found that most metals tended to be most highly concentrated in fine-grained sedimentary rock, rather than in coarser-grained strata or in the coal itself; this distribution may be attributed to the quiescent low-energy environment of these fine-grained sedimentary lithologies. Zubovic (22,23,24,25) has also studied the composition of coals within the Appalachian region and elsewhere with respect to minor element content. He has noted marked differences in the composition of these regional coals. Zubovic (26) has also found that the minor element content of coal may be increased significantly by weathering activity. Furthermore, metals forming small highly charged ions which subsequently form strong bonds tend to be concentrated near the source of a coal deposit, while other metals show substantially greater migrations.

The trace metal composition of stream sediments as a function of strip mining activity was studied by Upham (27) in Bills Branch. The metals under study were found to make up two distinct groups—one experiencing no enrichment in the stream sediment attributable to mining, and the other showing such an enrichment. These results will be further discussed in a later chapter, and contrasted to the situation with the dissolved metal enrichment.

Caruccio (28,29) found the severity of acid mine drainage from a particular site to be a function of the quantity of framboidal pyrite in the exposed strata. The type of the iron disulfide present, rather than the quantity, was found to be of principal importance. Of the watersheds monitored for the present New River study, only Indian Fork shows any characteristics of acid drainage, this coming primarily from the abandoned deep mine and auger sites. Caruccio (30) has also noted the presence of elevated sulfate concentrations as indicative of acid mind drainage, even when the pH is nonacidic. This is much the situation encountered in the mined study watersheds, particularly Indian Fork. The alkalinity present in the system neutralizes the acid released from pyrite oxidation, while the sulfate level remains high.

Studies concerning other phases of the coal fuel cycle may also provide insights into the problem of mine drainage. Guthrie and Cherry (31) noted the concentration of several constituents from coal-ash basin effluents in the benthos, and in biotic compartments of the system. Sedimentation and active biotic concentration were, therefore, indicated as major removal mechanisms for these constituents. Similar studies in

the mine drainage systems under study in the New River area are not yet available for comparison. It would, however, seem likely that some similarities may exist between the behavior of mine drainage and ash-basin effluents.

III. METHODOLOGY

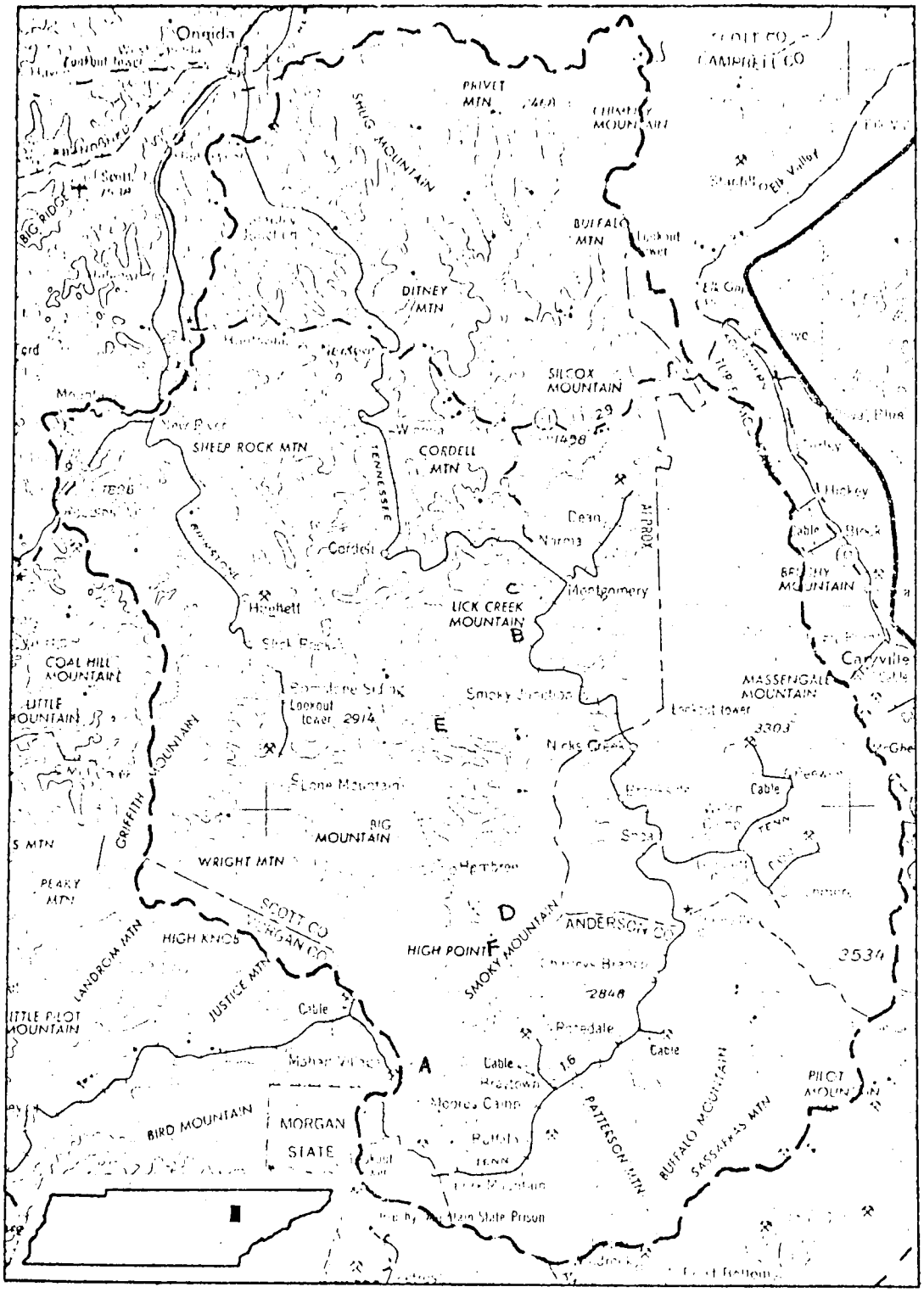
The study was conducted in the New River basin (Figure 1) of the Cumberland Mountains. This watershed lies in a four county area of eastern Tennessee, and supplies approximately 70 percent of the state's annual coal production, primarily from surface mining operations.

The area is primarily covered with heavy vegetation characteristic of eastern temperate forest stands, and the terrain is quite rugged. Elevation ranges from 1090 feet above sea level to more than 3300 feet, the average slope being approximately 14 degrees (32). Human habitation is rather sparce.

Surface mining in the area began in the 1940's and has continued to the present. Approximately 5 percent of the New River basin was disturbed by coal surface mining activity as of 1975 (32); the disturbance in many of the individual primary watersheds, however, greatly exceeds this figure.

The New River basin is located in the geologic province of the Northern Cumberland Plateau. Rock strata that experience disturbance and exposure during coal surface mining in this area are generally of late Cambrian to Pennsylvanian age. The principal coal deposits of economic importance for this study area are described below (32).

> Big Mary [2250 ft. elevation]—The Big Mary coal is immediately overlain by a 3- to 4-inch zone of coaly mudstone characterized by a concentration of marine fossils. The overlying sequence is primarily a homogeneous, medium to dark gray, carbonaceous mudstone of wide lateral extent. At elevations of about 20 and 30 feet (6.10 to 9.14 m) above the coal are horizons marked by large, dense, discoidal-shaped carbonate



Scale 1:250,000

Figure 1. Topographic map of the New River Watershed, Tennessee. Study basins lettered in figure are defined in Table I. [After Minear and Tschantz (32)].

masses known to the local miners as "flying saucers." These disc-shaped masses are sporadic in distribution, range in size up to four feet in diameter, and formed subsequent to the deposition of the layers in which they are found. Approximately 70 feet (21.34 m) above the Big Mary coal, the gray, marine shale grades upward into iron stained shales and interbedded silts and sands indicative of a lower delta plain depositional environment. The silt and sand layers represent overbank and crevasse splay deposits that were associated with the delta fluvial network.

Walnut Mountain [2560 ft.]—Seam and its overlying units are of an interdistributary bay area. Some marine fossils are found, but channels are quite common. Siderite beds are also found.

Pewee [2600 ft.]—Lies 40-50 feet (12.19 to 15.24 m) above the Walnut Mountain coal seam and is not as laterally persistent as the Big Mary. Made up of brackish and terrigenous clastics and it represents a middle to upper delta plain. Siderite nodules are oddly shaped and probably are formed by replacement of root systems. A carbonaceous unit immediately above the coal exists as it does in the Big Mary, but is considerably thicker. This layer was formed by fine-grained clastics filtering into a swamp which was comprised of great amounts of decayed organic material, stagnant water, and reducing conditions.

Several other seams of lesser importance are also encountered sporadically in the study area. These include the Windrock seam (elevation 2200 ft.), Red Ash (2500 ft.), Upper Grassy Spring (3000 ft.), Coal Gap (3100 ft.), and Jellico (1500 ft.).

Six primary watersheds within the New River basin were selected for study. These sites were chosen on the basis of geologic similarity, extent of current and projected surface mining disturbance (Figure 2), and accessibility for sampling. Three of these streams were completely unexposed to any mining activity at the onset of the study period (January 1975). These basins (Anderson Creek, Lowe Branch, and Bowling Branch) had experienced some human influence including logging and light cultivation, but disturbance was generally characterized as minimal.



Figure 2. Extent of contour strip coal mining in the New River Watershed, Tennessee, from 1943 to 1973 [After Tung (17)]. Study Watershed locations indicated by speckled areas.

From observation of these three sites it should be possible to discern what benchmark levels of various constituents are characteristic of the area. Mining was initiated at Anderson Creek subsequent to the study period, and continued monitoring of this site should be especially interesting. The other three watersheds (Bills Branch, Green Branch, and Indian Fork) were undergoing active mining during the study period. Further descriptions of the streams are given in Tables I and II. A rough chronology of mining activity is shown in Table III.

Collection of water samples began on January 7, 1975, at Lowe Branch and Bills Branch. The dates of initial sampling for each of the other sites were as follows: January 15 at Indian Fork, January 22 at Anderson Creek, January 27 at Bowling Branch, and February 3 at Green Branch. The final samples of the study were collected on December 15, 1975. Samples were taken from each of the six streams on every sampling trip, except as noted above, at roughly weekly intervals. Indian Fork and Bowling Branch were directly accessible by car, while sample collection at the other sites required hiking various distances. Beginning on February 26, samples filtered through a 0.45 micron membrane filter were also collected at each of the sites, in an effort to distinguish between the suspended and dissolved constituents. The procedure of fixing the water samples with nitric acid (1 ml.) was adopted in March to hold dissolved metals in solution and avoid adsorption to the walls of the polyethylene sample bottles. Subsequent comparisons of acidified and nonacidified samples indicate that the metal analyses for the samples taken prior to the initiation of this procedure may be in

TABLE I

STUDY WATERSHEDS
[AFTER MINEAR AND TSCHANTZ (32)]

Map Designation (Figures 1 & 2)	Watershed	USGS/TVA Sheet No.	Landuse Status
A	Indian Fork	129 NW (Fk. Mtn)	Previously mined (1967 law and revegated, active deep mine in operation)
B	Anderson	128 SW (Norma)	Virgin
C	Lowe Branch	128 SW (Norma) (Nearest Norma)	Virgin
D	Bills Branch	129 NW (Fk. Mtn.)	Under active mining (Dec. 1974, 2250 Ft. Seam)
E	Bowling	128 SW (Norma)	Virgin to mining (Has new logging roads)
F	Green Branch	129 NW (Fk. Mtn)	Mining activity completed Dec. 1974, (2250 ft. seam) reactivated in June, 1975 (2600 ft. seam)

TABLE II

GENERAL PHYSICAL DATA OF THE STUDY STREAMS
[AFTER MINEAR AND TSCHANTZ (32)]

Stream	Area of Watershed Acres	Average Slope %		Average Elevation (Ft.)	
		Watershed	Streambed	Watershed	Streambed
Indian Fork	3104	38.1	8.4	2314	1830
Bill's Branch	426*	38.4	26.0	2407	2130
Green Branch	911	36.8	17.6	2287	1845
Bowling Branch	1912	32.5	7.4	1967	1580
Anderson Creek	524	34.1	18.4	1890	1630
Lowe Branch	589	31.9	12.6	1820	1540

*Area above weir only. Lower portion of basin excluded due to active deep mine and minimal prior stripping at 1500 ft. contour.

TABLE III

APPROXIMATE TIME AND EXTENT OF SURFACE MINING
DISTURBANCE IN STUDY WATERSHEDS
[AFTER MINEAR AND TSCHANTZ (32)]

Watershed	Coal Seam and Elevation	Date Started	Date Completed	Acres Disturbed	Percent of Watershed Area
Indian Fork	Big Mary (2250') Walnut Mountain (2560') Pewee (2600')	∿ 1966	1972	522	16.9
Green Branch	Jellico (1500')	∿ 1972	∿ 1973	14.9	1.6
	Big Mary (2250')	∿ 1973	Dec. 1974	112.8	12.4
	Pewee (2600')	June 1975	Continuing	65.7	7.2
	Grassy Springs (300')	June 1975	Continuing	19.5	2.1
			TOTAL	212.9	23.3
Bills Branch	Big Mary (2150')	Dec. 1974	Continuing (but portion in study drainage completed August 1975)	36.5	8.6
	Pewee (2600')	Future	-	-	-

error due to reduced apparent concentrations. Nonacidified samples were also collected for acidity and alkalinity determinations.

Continuous streamflow gages and rainfall monitors were installed at all six of the sites during the study period. Only Indian Fork had such equipment at the onset of the study. In the interim period, the other sites were equipped with cumulative rainfall monitors and weir plates to permit instantaneous flow measurements.

The water quality variables monitored in this study are shown in Table IV, accompanied by the analytical methodology employed in each case. Hydrogen ion concentration and temperature were measured on site. The wet chemical analyses (alkalinity, acidity, chlorides, sulfates, solids, and turbidity) were performed as soon as possible after returning to the laboratory. It should be noted, however, that some considerable delays did occur between collection and analysis for some of the individual samples. Metal analyses were conducted by atomic absorption spectrophotometry with background correction. A hollow graphite atomizer (HGA) was employed when necessary. In the case of these metals analyses, the sample load rapidly became overwhelming, resulting in some very lengthy delays. This portion of the data still remains somewhat incomplete.

TABLE IV

STUDY WATER QUALITY VARIABLES
[AFTER MINEAR AND TSCHANTZ (32)]

Variable	Method	Comment
pH	Potentiometric	Field measurements with portable meter. Standardized and temperature adjusted.
Alkalinity Acidity	Standard methods (33)	Unfiltered samples (checked against filtered samples when suspended solids high)
Chloride	Standard methods	Unfiltered samples except for high solids
Sulfate	HACH kit Turbidimetric Method	Unfiltered samples except for high solids yielding appreciable blanks
Solids: Suspended	Filtration through tared 0.45u millipore filters. (Drying 2 hrs. @ 105°C, Desiccation 0.5 hr).	In lab determination
Total	Direct evaporation, Standard methods	
Turbidity	HACH laboratory Turbidimeter, Model 1860	
Metals: Al,Ca,Cd, Co,Cr,Cu,Fe,Mg,Mn, Ni,Pb,Sn,Zn	Atomic absorption Spectrophotometry, Perkin-Elmer Model 403	Direct flame or flameless atomizer (Perkin-Elmer HGA 2100) depending upon concentration

IV. THEORY AND BACKGROUND

A. Chemistry

During the strip mining process, large quantities of closely consolidated soil and rock strata which overlie the coal deposits are removed. These are generally pushed to the down slope, where they remain as loosely compacted spoil banks. These freshly exposed strata are then subject to weathering and leaching activity. The unconsolidated nature of the spoil tends to promote the leaching of constituents both by surface and groundwater flows.

Substances enter natural water systems at various points in the hydrologic cycle. One pathway of principal importance is that of weathering. Three types of reactions are important in weathering processes. These are incongruent dissolution, congruent dissolution, and redox reactions.

The most important class of reactions controlling the composition of most natural water systems is the incongruent dissolution of aluminum silicates, according to the general reaction (34),

cation Al-silicate + HA + H_2O = A^- + H_4SiO_4 + cation + Al-silicate(s) (Eq. 1).

These aluminum-silicates are essentially ubiquitous in natural systems. Illite (K_xAl_4 [$Se_{1-x}Al_xO_{20}$] $(OH)_4$), kaolinite ($Al_2SiO_5(OH)_4$), and quartz (SiO_2) comprise the dominant forms in the New River area (27). Consumption of acid, according to Equation 1, is an important component of the buffer system of the New River streams.

The solubilities of these compounds are very low at the pH conditions characteristic of the natural stream conditions. A depression in the pH, however, would be very favorable to enhanced dissolution. Such is the case with the acidic drainage from the mine sites.

One redox reaction of special importance in these systems is the oxidation of iron disulfides according to the reaction,

$$FeS_2(s) + 3\text{-}3/4O_2 + 3\text{-}1/2H_2O = Fe(OH)_3(s) + 4H^+ + 2SO_4^= \quad \text{(Eq. 2)}.$$

This reaction produces ferric oxide and acid, resulting in a depression in the pH of the effected waters. This lowered pH then enhances the solubilities of the aluminum-silicates, as mentioned above. Hydrogen ion concentration is quickly restored to normal levels in the stream due to the activity of the carbonate buffer system, and the aluminum becomes precipitated as illite or kaolinite.

Approximately 15 percent of coal is composed of mineral matter and other impurities, the predominant forms of which are silicates, sulfides, and carbonates (35,36,37). Illite, kaolinite and other aluminum-silicates are generally the most common mineral constituents. Iron disulfides are very common in coal deposits and associated strata. These are present primarily in two forms, marcasite and the more predominant pyrite. Caruccio (28) has determined that only the framboidal form of pyrite makes a major contribution to acid mine drainage. A thin layer of pyrite has been identified above the Walnut Mountain coal seam, but its presence in other parts of the area is quite limited. Sulfides of zinc (sphalerite), and of lead (galena) are also frequently encountered in many coals. Gluskotter (36) found the

cadmium in Illinois coals to be principally in the sphalerite as well. In the New River area, however, no sphalerite or galena has been identified in the present geologic studies.

Carbonates of calcium, magnesium, iron, and manganese are also quite commonly found in many coals. These include dolomite ($CaMg(CO_3)_2$), ankerite ($CaFe(CO_3)_2$), calcite ($CaCO_3$), and siderite ($FeCO_3$). The dominant forms of carbonate in the New River area are siderite (38) and calcite-rich concretions; dolomite is encountered more rarely. These carbonate deposits are often epigenetic in the coal seams as cleat fillings, formed subsequent to the coal formation.

Gluskotter (37) was able to categorize the trace elements in Illinois coals into four behavioral groups. He found Ge, Be, and B to be almost entirely in organic forms, while Hg, Zn, Zr, As, Cd, Pb, Mn, and Mo were predominantly in inorganic forms. Other trace elements occurred in both organic and inorganic forms. Of these, Co, Ni, Se, Cr, and Cu tended to be more common in the inorganic forms, while P, Ga, Sb, Ti, and V were largely associated with the organics. Zubovic (26) has studied coals of the same region, and identified a similar sequence of organic affinities.

The actual trace metal composition of a coal deposit may be quite variable. Zubovic (22-25) studied a number of different coal deposits from Appalachia and elsewhere in the United States, and found significant regional differences in their trace metal content. Franks (21) found coals in the Indian Fork watershed to be enriched in Ni, Cu and Pb relative to the surrounding rock strata. The rock strata held high concentrations of As, Cd, Co, Cr, Fe, Mn, and Zn.

Trace elements may also be tied up in the clays and major mineral deposits. Fleister (39) found As, Cu, Pb, Mn, Zn, Co, and Ni present in iron disulfides in appreciable quantities.

The presence of these various elements in waters associated with these strata (i.e., surface runoff and groundwater) may be limited by the individual solubilities. Gang and Langmuir (11) found mineral solubilities to be limiting for several metals in their study of Pennsylvania waters affected by coal mining. They found that for surface waters iron was limited by ferric hydroxides or by siderite, aluminum by kaolinite, and cobalt by $Co(OH)_2$). In groundwaters aluminum concentrations were limited by gypsum when sulfate levels were high, cobalt by $CoCO_3$, and chromium by $Cr(OH)_3$. Manganese, zinc, copper, cadmium, nickel and lead were determined not to be limited by mineral solubilities.

B. Statistical Methods

Some trends in constituent behavior may seem apparent upon visual inspection of a mass of data. To test these apparent relationships for significance, statistical techniques should be employed whenever possible. For the present study, Spearman rank correlation analyses have been used to test intervariate associations. All analyses were performed with the SAS-76 statistical package (40).

The use of correlation analysis rather than regression was dictated by the nature of the data in this study; water quality samples were collected randomly, and no attempt was made to control the sample

collection as a function of the value of any particular variable. Some degree of error or uncertainty was involved in all of the measurements. When one considers the different data requirements of the two techniques, the data from this study are clearly unsuitable for a typical Model I regression analysis, but are well suited for correlation analysis.

Bivariate correlation analysis is used to estimate the degree of association or interdependence between two variables, relative to that which would be expected due to chance alone. Several different techniques of correlation analysis are widely recognized. Each involves the generation of a coefficient to estimate the degree of interdependence of the given pair of variables. Principal among these are the Pearson product-moment correlation coefficient, Kendall's coefficient of rank correlation, and the Spearman rank correlation coefficient. The Pearson coefficient is perhaps the most common method, but it is based on the assumption that the variables in question have a bivariate normal distribution. From a graphical inspection of the data from this study, it was determined that not all of the variables followed this normal distribution, or a logarithmic transformation thereof. In the interest of consistency, therefore, a nonparametric method—that of Spearman—was selected. It should be noted, however, that comparisons between all three of the methods were conducted with the study data, and agreement was consistently very good in all of these analyses.

The Spearman rank coefficient, r_s, is basically a measure of the degree to which the rankings of the two variables correspond. The coefficient can be calculated from the differences between the ranks

R_{Y_1} and R_{Y_2} of variables Y_1 and Y_2 in the following manner for a set of n observations (41),

$$r_s = 1 - \frac{6\sum_{1}^{n}(R_{Y_1} - R_{Y_2})^2}{n(n^2 - 1)} .$$

For a more detailed discussion of the computational aspects of the method, the reader is referred to any text of nonparametric statistics.

It should be reemphasized that a significant correlation between two variables does not necessarily imply any direct causal relationship. A number of indirect models may yield a significant but spurious correlation between a given pair of variables. For example, a strong positive correlation exists between the number of Baptist ministers and the alcohol consumption in American cities with populations greater than 10,000 (41). This correlation is really a consequence of a third variable—city size—to which each of the other variables is positively related. In the area of water quality analysis, similar indirect linkages may be observed. A particularly likely candidate for the role of this third variable is time, since many water quality constituents follow seasonal cycles. Thus, it is apparent that one must consider each individual situation very carefully before drawing any conclusions from a given correlation analysis.

V. RESULTS AND DISCUSSION

A. Benchmark Water Quality

Constituent levels in Lowe Branch, Bowling Branch, and Anderson Creek are assumed to be characteristic of regional watersheds which are undisturbed with respect to surface mining. This assumption is strengthened by the observation that constituent behavior for the three streams is very similar over the study period.

All three sites experienced only intermittent flow during the summer months. This was an unusually dry season, and it remains to be seen whether such dramatic cessation of flow is actually characteristic of the unmined watersheds on a regular basis. Due to these dry conditions during the study period, sample collection at these sites was extremely limited during the summer season.

Bowling Branch and Anderson Creek experienced some logging activity over the tail end of the study period. Most constituent levels did not seem to be affected significantly, and these observations were included for calculation of the benchmark quality statistics. Some increase in the solids loadings was, however, apparent.

Table V lists the mean and median values for each of the constituents for which data are available. Levels of all the heavy metals are quite low, often pressing the detection limits of the HGA analysis. Iron concentrations were somewhat higher, as were those of manganese. Calcium and magnesium levels were quite constant at about 1 ppm. The mean values of the solids concentrations tend to be heavily

TABLE V

BENCHMARK WATER QUALITY[a]

Constituent	Mean	Median
pH	6.25	6.31
Alkalinity	6.33	6.07
Acidity	2.91	2.20
T Solids	38.36	25.00
S Solids	11.53	6.00
D Solids	26.83	16.00
Turbidity	6.52	0.00
Chloride	4.22	4.25
Sulfate	7.13	7.00
Fe-T	0.50	0.16
Fe-D	0.11	0.08
Mn-T	0.48	0.01
Mn-D	0.00	0.00
Ca-T	1.13	1.15
Ca-D	1.22	1.20
Mg-T	1.28	1.20
Mg-D	1.32	1.30
Cd-T	1.43E-4	1.00E-4
Cd-D	3.27E-4	1.00E-4
Cr-T	1.33E-3	1.50E-4
Cr-D	1.50E-4	0.00
Cu-T	3.76E-3	2.00E-3
Cu-D	3.96E-3	4.20E-3
Pb-T	2.25E-3	0.00
Pb-D	1.25E-4	0.00
Ni-T	2.26E-3	0.00
Ni-D	5.71E-4	0.00
Zn-T	5.64E-3	3.35E-3
Zn-D	3.56E-3	1.10E-3
Co-T	0.00	0.00
Co-D	0.00	0.00
Water Temp	12.80	12.25

[a]All measurements are mg/l except pH (pH units) and Temperature (degrees C).

influenced by a few unusually large observations; the medians, therefore, provide more representative values in many cases. After the prolonged dry period during the summer months, the accumulation of loose sediment and detrital material was rapidly picked up by the runoff during the first large rainfall, resulting in very high solids loadings for the streams. The logging activity in Anderson Creek and Bowling Branch also was responsible for a few elevated sample observations. When these high values are excluded from the calculations, the following statistics are produced (mg/l):

	Mean	Minimum	Maximum	Median
Total Solids	24.75	7.0	72.0	25.0
Suspended Solids	6.58	0	34.0	6.0
Dissolved Solids	18.65	2.0	52.0	19.0
Total Iron	0.101	0.011	1.40	0.1

These values may be more characteristic of the actual benchmark levels.

In the cases of Ca, Mg, Cd, Cr, and Cu the mean values for the dissolved metal concentration are greater than those of the total metal. Apparently, significant contamination was introduced during the field filtration of some of these samples; other explanations might be simple analytical variation, or matrix effects caused by the solids present. Nevertheless, it is evident that all of these constituents are present predominantly or entirely in dissolved form.

The streams carry a pH of about 6.2, with levels occasionally dropping below the state mining permit water quality standard of 6.0. There is very little alkalinity in these waters, indicating an absence of exposed carbonate strata in the watersheds. Because of this low alkalinity, stream pH is controlled largely by the atmospheric inputs.

Acidity levels are also very low, as are the concentrations of sulfate and chloride ions.

Obviously, levels of most constituents are quite low and stable over time, both on an absolute basis and relative to the disturbed watersheds. Seasonal variation due to temperature and hydrologic conditions is evident but of minor importance in these benchmark watersheds. Leaching of constituents from exposed strata or humus seems to be of little significance. Some flushing of constituents is apparent during storm periods, and this will be described in the subsequent chapter. The magnitude of this increase due to surface flushing phenomena is small relative to the annual mean constituent levels in comparison with the disturbed watersheds. Atmospheric inputs appear to be of principal importance in the undisturbed watersheds.

Thus, the overall character of these regional first-order watersheds can be seen to be quite pristine. Logging activity exerts a detrimental influence on the water quality primarily with regard to solids loadings. This perturbation, however, is of a much smaller magnitude than that caused by surface mining disturbance, as described in the following section.

B. Water Quality Impacts of Strip Mining

Table VI lists the mean values for each of the constituents studied over all six sampling sites. The complete listing of water quality data for the study period is given in the Appendix. Data for the major constituents are generally complete. Data for most metal analyses, however, are much less complete, due to the heavy analytical load.

TABLE VI

CONSTITUENT CONCENTRATIONS FOR ALL STREAMS

Constituent	Anderson Creek Mean	Anderson Creek Median	Lowe Branch Mean	Lowe Branch Median	Bowling Branch Mean	Bowling Branch Median	Bills Branch Mean	Bills Branch Median	Green Branch Mean	Green Branch Median	Indian Fork Mean	Indian Fork Median
pH	6.18	6.30	6.20	6.30	6.36	6.41	6.79	6.83	7.17	7.18	6.61	6.75
Alkalinity	6.38	6.30	6.43	6.12	6.19	6.05	12.34	11.71	29.21	31.07	13.60	10.75
Acidity	3.06	2.08	2.99	2.75	2.67	2.13	3.41	2.70	4.00	3.08	4.54	3.91
T Solids	45.84	25.00	31.28	20.00	39.63	25.00	1.77E+3	3.19E+2	2.93E+3	1.59E+3	2.68E+3	5.98E+2
S Solids	13.29	7.0	6.15	5.00	15.97	6.00	1.30E+3	2.06E+2	1.58E+3	2.17E+2	2.32E+2	63.00
D Solids	32.55	18.00	25.15	14.00	23.67	17.00	4.52E+2	1.30E+2	1.38E+3	7.90E+2	2.47E+3	5.97E+2
Set. Sol	0	0	0	0	0	0	0.51	0	1.04	0	0.05	0
Turbidity	3.81	0	0.32	0	15.66	0	90.52	6.50	2.47E+2	11.00	46.67	16.00
Chloride	4.27	4.30	4.17	4.25	4.22	4.20	3.99	3.97	4.83	4.87	4.71	4.85
Sulfate	6.19	6.00	8.82	9.00	6.09	6.00	25.32	24.50	1.33E+2	1.32E+2	4.58E+2	3.50E+2
Fe-T	0.35	0.16	0.21	0.19	0.95	0.11	2.48	1.00	6.02	1.15	9.73	6.35
Fe-D	0.14	0.11	8.7E-2	7.0E-2	9.0E-2	4.0E-2	0.16	7.5E-2	7.7E-2	5.0E-2	1.32	0.17
Mn-T	7.0E-2	7.0E-2	3.8E-2	4.0E-2	4.8E-2	8.0E-2	0.19	9.0E-2	0.37	0.30	1.28	1.00
Mn-D	ND	ND	ND	ND	3.1E-3	3.0E-3	3.3E-2	2.0E-2	0.22	0.21	1.28	0.97
Ca-T	1.01	1.00	1.39	1.30	0.95	0.90	4.59	3.60	30.96	31.50	65.84	58.00
Ca-D	1.11	1.20	1.51	1.40	1.01	1.00	5.53	5.00	34.64	35.54	72.24	64.00
Mg-T	1.09	1.10	1.44	1.40	1.27	1.20	4.01	3.90	15.82	18.00	27.91	21.00
Mg-D	1.10	1.10	1.56	1.50	1.26	1.15	4.25	3.80	16.49	18.00	29.63	24.00
Al-T	ND	ND	ND	ND	0.47	0.41	6.23	4.75	18.80	4.90	2.85	1.05
Cd-T	1.7E-4	2.0E-4	1.9E-4	1.0E-4	5.2E-5	0	8.4E-2	3.0E-4	3.4E-4	2.0E-4	5.0E-4	5.0E-04
Cd-D	4.3E-4	2.0E-4	4.6E-4	1.0E-4	3.3E-5	0	5.2E-2	3.0E-4	2.9E-4	2.0E-4	7.8E-4	5.0E-4
Cr-T	1.4E-3	0	0	0	1.9E-3	1.0E-3	3.5E-2	4.0E-3	2.1E-1	5.9E-2	2.4E-3	1.2E-3
Cr-D	1.4E-4	0	0	0	1.7E-4	0	3.4E-4	0	0	0	0	0
Cu-T	5.5E-3	4.2E-3	4.8E-3	3.5E-3	4.2E-5	0	2.8E-2	1.4E-2	2.8E-2	9.5E-3	1.6E-2	1.3E-2
Cu-D	5.7E-3	5.0E-3	5.3E-3	5.2E-3	0	0	7.0E-3	6.3E-3	5.6E-3	5.7E-3	8.8E-3	6.0E-3
Pb-T	2.1E-3	0	1.7E-3	0	3.0E-3	0	2.6E-2	0	9.3E-3	3.0E-3	6.2E-4	0
Pb-D	1.4E-4	0	0	0	2.3E-4	0	2.1E-4	0	0	0	0	0
Ni-T	2.1E-3	0	2.0E-3	0	2.7E-3	0	6.4E-3	0	4.8E-2	2.8E-2	4.0E-2	4.2E-2
Ni-D	0	0	1.9E-3	0	0	0	3.5E-4	0	2.2E-3	0	3.7E-2	4.1E-2
Zn-T	9.5E-3	6.0E-3	8.1E-3	5.0E-3	1.7E-3	7.0E-4	2.6E-2	1.7E-2	6.4E-2	1.1E-2	5.6E-2	6.0E-2
Zn-D	7.4E-3	6.0E-3	5.0E-3	5.0E-3	5.1E-4	3.0E-4	2.0E-4	2.0E-4	5.4E-3	5.4E-3	4.0E-2	4.0E-2
Co-T	0	0	0	0	0	0	0	0	4.0E-2	4.6E-2	1.8E-2	1.5E-2
Co-D	0	0	0	0	0	0	0	0	0	0	3.9E-2	3.8E-2
Water Temp	11.56	11.40	13.10	13.65	13.59	13.20	14.35	15.00	15.46	16.05	14.77	15.50

All concentrations are expressed in mg/l except for pH (pH units), turbidity (jtu), and temperature (°C).

The suffix "T" denotes total concentrations, while the suffix "D" denotes dissolved concentrations only.

It is apparent from a look at these results that the disturbance of the watersheds by coal surface mining has some dramatic impacts on the quality of the water in these streams. Many constituent levels are substantially elevated on an absolute basis, and weekly fluctuations are also greatly exaggerated over benchmark conditions. Behaviors of the individual constituents are delineated below.

Hydrogen ion concentrations became depressed as a result of mining disturbance. This behavior has been noted previously in Kentucky (5) and West Virginia (13) waters exposed to surface mine drainage. The specific reasons for this perturbation in the buffer system are unclear. Elevation of pH is less obvious at Indian Fork, due to the acid drainage from the deep mine and auger sites entering the system through the groundwater component. Under low flow conditions this influence becomes quite significant and depresses the pH to low levels.

Alkalinity experiences a marked increase during mining activity, probably due to the exposure of carbonate strata (predominantly in the form of siderite) to weathering processes as the overburden is removed. This increase occurs very rapidly with the onset of mining and appears to proceed with time. Plass (13) found the rate of increase in West Virginia watersheds to be only about 5 ppm per annum. The rate of increase in the New River area seems much more rapid, judging from the Bills Branch data. Again, the levels in Indian Fork were depressed by the reaction with the acid drainage described above. Acidity concentrations are elevated to only a slight extent by the mining activity. Although considerable amounts of acidity may be generated by the

oxidation of pyrite and other species, it is quickly reduced to low levels by the neutralization reactions with the exposed carbonate species.

Levels of total, suspended and dissolved solids were dramatically elevated by the mining disturbance. As a result of the massive quantities of soil and rock strata moved during the strip mining process, a great deal of loose sediment and debris became available for dissolution and suspension in the surface runoff. This increase in the solids loadings is immediately apparent in the early stages of mining and seems to continue with time. All three of the disturbed sites often exceed standards by an order of magnitude or more particularly during periods of high flow. In Bills Branch and Green Branch this solids loading is primarily in the form of suspended particulates, while dissolved solids form the most important component of the Indian Fork loading.

Chloride concentrations remained very similar for all six study sites throughout the study period. This would indicate that the principal input of chloride ion into these systems is atmospheric, with little importance being attributed to the leaching processes.

A rapid increase in sulfate concentrations was observed with the onset of mining in Bills Branch. This upward trend continued with the extent of the mining disturbance, as seen from the respective mean values for Green Branch and Indian Fork. Although the study covered only one year, there is an indication of a cyclic behavior in the sulfate concentrations, with a peak occurring during the late summer and fall. The lag time observed by Curtis (5) was not evident here. The sulfate concentration in Bills Branch increased immediately at the onset of mining. A lag period is apparent, however, if only increases of a

large magnitude are considered. Caruccio has attributed similar increases in sulfate concentrations in mined Pennsylvania watersheds to oxidation of pyrite (30).

Immediate increases in the levels of calcium and magnesium occurred as a result of the mining disturbance. These metals are both very common in the sedimentary rock strata which typically overlie the coal seams, and their increased mobilization with the disturbance of these strata is certainly not surprising. The increase in these concentrations appears to be directly proportional to the extent of mining.

Aluminum concentrations also increased with the onset of mining, contrary to the findings of Plass (13). Only the unfiltered samples from the three disturbed watersheds contained sufficient concentrations for conventional atomic absorption flame analysis. This strong association with the solid phase indicates the aluminum to be present primarily in the form of illite and other alumino-silicate clays of low solubility which are very common in this area (38). Gang and Langmuir (11) found the most important source of aluminum in stream waters to be the attack by acid mine drainage on these aluminosilicate underclays. In all of the streams in the present study, however, the hydrogen ion concentration is sufficiently low to maintain very low solubility of these aluminum species. Thus most aluminum is present only in particulate form and only in the mined watersheds. This suggests an initial dissolution by the acidic drainage waters which quickly becomes neutralized by the carbonate buffer system, precipitating the aluminum as alumino-silicate clays. Levels in the undisturbed streams are very low since no acidic drainage

was available for such initial dissolution of the clays. Furthermore, the clays in these watersheds remained compacted in the surface strata. Only when these strata are disturbed do the particulates become subject to suspension in the surface runoff.

Iron and manganese concentrations were increased by an order of magnitude over benchmark conditions. These metals are largely in dissolved form in the streams under most conditions due to the relatively high characteristic pH levels. However, in Indian Fork the stream bed often develops a distinctive orange coating of ferric-hydroxide under conditions of low flow, when the groundwater component becomes predominant and depresses the pH. In the other watersheds, the pH remains sufficiently high to keep the rates of oxidation quite slow.

Various trace elements may be tied up with these hydrous oxides of iron and manganese as they are precipitated out in the stream. Turner (42) has suggested that a similar scavenging process may provide a sink for several trace species in the Walker Branch Watershed at Oak Ridge. The high significance of the correlations relating iron and manganese concentrations to those of cadmium, copper, nickel, and zinc (aluminum, chromium, and lead being somewhat less significant) indicates that such behavior may also be active in the disturbed New River watersheds.

Delfino (15) has noted strong associations of copper, lead, and zinc with iron and manganese in the Mississippi River; here again, these metals are probably tied up in the hydrous oxides. Iron is also strongly associated with the suspended solids loadings in the study watersheds, suggesting the importance of the hydroxide form. The association

between manganese concentrations and solids, however, is not so clear; the hydroxide form may be substantially less prevalent in this case.

The apparent effects of the strip mining disturbance on trace metal concentrations in the stream waters differs somewhat from the behavior of these metal concentrations in the sediments as discerned by Upham (26). He found no increase in manganese or iron in the sediments of Bills Branch attributable to the mining disturbance. The levels of both of these metals, however, did show a substantial increase in the water. Furthermore, no definite increase was detected in the concentration of lead in the mine-disturbed waters, contrary to the behavior in the sediment. Increases were observed in the levels of zinc, nickel, and copper, while no such elevation was observed for cadmium. These findings are in agreement with the corresponding sediment analyses.

A few random samples from each stream were also tested for arsenic and tin concentrations. No detectable levels were observed, and these analyses were discontinued.

C. Effects of Streamflow

Good continuous flow data were available for Lowe Branch, Bills Branch, and Indian Fork for most of the study period. Mean daily flows for these three sites were tested for correlations with the water quality variables. In this way any changes in constituent flow dependence during the progression from virgin conditions to conditions of prolonged mining might be identified.

A positive correlation of a given water quality variable with streamflow indicates an increase in that variable with an increase in

flow. This situation would occur when the surface runoff from a precipitation event contains a higher concentration of that constituent than does the base flow component of the stream. Constituents which would display this type of behavior are those easily leached or suspended from the soil and humic material in the watershed. Similarly, a negative correlation with flow indicates an inverse proportionality, suggesting that the concentration of the constituent in question is higher in the base flow component of the stream than in the stormwater. In this case the decrease in the concentration of that variable is simply a dilution effect.

Tables VII through IX show all correlations that proved to be significant at the 5 percent level for each of the sites. Significant positive correlations are indicated by a plus (+) sign, while negative correlations are indicated by a minus (-) symbol. In Table VII all sample observations are included in the analysis. In Tables VIII and IX, however, the observations are differentiated as to rising and declining stream hydrographs. This technique was employed by Rose (19) and found to be very useful for discerning flow dependencies. The observations were classified as rising or falling flows according to the behavior of the mean daily flow on the previous and following days. It was quickly evident that the samples were heavily weighted toward the falling category, with 87 percent of the sample observations contained therein.

Due to this unbalanced distribution, the flow associations for the total sample population are essentially those of the decreasing flow population, or generally low flow conditions. Table VII is, therefore,

TABLE VII

CONCENTRATION VS. STREAMFLOW CORRELATIONS[a]
(ALL OBSERVATIONS)

Constituent	Lowe Branch	Bills Branch	Indian Fork
pH		-	+
Alkalinity		-	+
T Solids		-	
D Solids		-	-
Turbidity	+		
Chloride	+		
Sulfate		-	
Fe-T			-
Fe-D	+	+	-
Mn-T			-
Mn-D			-
Ca-T	-	-	-
Ca-D	-	-	-
Mg-T	-	-	-
Mg-D	-		-
Al-T			+
Cd-T			-
Cr-T			+
Cu-D			-
Ni-T			-
Ni-D			-
Zn-T			-
Zn-D			-
Water Temp	-	-	-

[a]Significant at the 5% level.

TABLE VIII

CONCENTRATION VS. STREAMFLOW CORRELATIONS[a]
(DECLINING FLOW OBSERVATIONS ONLY)

Constituent	Lowe Branch	Bills Branch	Indian Fork
pH			+
Alkalinity		-	+
T Solids			-
D Solids		-	-
Sulfate		-	
Fe-T			-
Fe-D	+		-
Mn-T			-
Mn-D			-
Ca-T	-	-	-
Ca-D	-	-	-
Mg-T	-	-	-
Mg-D	-		-
Cr-T			+
Cu-D			-
Ni-T			-
Zn-T			-
Zn-D			-
Water Temp	-	-	-

[a]Significant at the 5% level.

TABLE IX

CONCENTRATION VS. STREAMFLOW CORRELATIONS[a]
(RISING FLOW OBSERVATIONS ONLY)

Constituent	Lowe Branch	Bills Branch	Indian Fork
Acidity	+		
Turbidity	+		
Ca-T	-		
Ca-D	-		
Mg-T	-		
Mg-D	-		
Water Temp	-		

[a]Significant at the 5% level.

very similar to Table VIII. The small number of observations in the rising flow category also causes some substantial problems in the statistical analysis. The lack of significant correlations for Bills Branch and Indian Fork in the rising flow category might be explained as a direct result of this. With such a small number of observations (six) in a sample population, an extremely high correlation coefficient is required in order for the association to be considered statistically significant. Generally, the larger the sample population, the more significant a coefficient of a set value becomes. Therefore, no significant correlations were discerned for these two classes of this population, despite some very high coefficients.

Lowe Branch, however, did show a number of significant correlations in this category, as shown in Table IX. These associations are very similar to those determined for the decreasing flow category. This similarity indicates that the water quality of this watershed is essentially independent of the position on the hydrograph. This situation seems to be characteristic of Anderson Creek and Bowling Branch as well, although this observation was not tested statistically. From observation alone one might conclude that the water quality of the benchmark watersheds in the New River area is relatively independent of streamflow and climatological conditions with respect to most constituents. Concentrations are very low and regular. The small magnitude of these concentrations would tend to make any calculated correlations less meaningful, due to the influence of the random background "noise" in the system and in the chemical analyses. Any correlations for the

undisturbed watersheds, therefore, should be carefully thought out before much significance is attributed to them.

There appears to be a direct relation between the extent of surface mining disturbance and water quality constituent flow dependence. From Tables VII and VIII, one can readily see a progressive increase in the number of significant correlations as a function of land disturbance. Lowe Branch has the fewest significant associations, followed by Bills Branch and Indian Fork, respectively.

The variables developing flow dependencies as a result of mining activity are primarily solids and metal concentrations. This observation certainly comes as no surprise, since the extensive upheaval of the land surface which is characteristic of strip mining would naturally expose large quantities of suspendable soil and rock to surface runoff. Those metals associated with the coal and the surrounding rock strata are subsequently exposed to weathering processes as previously described. Franks (21) found the rock strata surrounding Indian Fork coal deposits to be relatively enriched in cadmium, cobalt, chromium, iron, manganese and zinc, while the coal itself contained nickel at concentrations approximately two to four times that of the associated rock strata.

The positive correlation between flow and pH in Indian Fork may be attributed to factors other than the surface mining disturbance. The acid drainage from the deep mine and auger sites in this watershed depresses the stream pH substantially under low flow conditions, when little dilution is possible. Under conditions of higher flow, the surface runoff adds considerable alkalinity to the system as well as

providing a dilution of the acidic drainage. Thus both the depression of metal concentrations and the elevation of pH and alkalinity in Indian Fork come about as a result of the dilution of the mine drainage. This is similar to the behavior observed by Gang and Langmuir (11) in groundwater wells in the Tobey Creek basin of Pennsylvania. It is clear from these observations why Indian Fork experiences the most dramatic changes in the levels of most constituents from week to week. The interface between streamflow, pH, and alkalinity creates a very sensitive balance in the buffer system. The strength of the buffer system active at any given time then is a function of the flow conditions.

The apparent trend toward inverse relationships between flow and metal concentrations seems to implicate a slow leaching process and dilution as being of principal importance in supplying these metals to the streams. In such a case, the length of contact time between the water and sediments would be the critical factor, and groundwater input would be strongly implicated.

D. Other Intervariate Associations

Spearman correlation coefficients were generated for all possible pairs of water quality variables for which data were available. The results of these analyses are presented in Tables X through XV. Individual tables are given for each watershed, displaying those correlations (Spearman) found to be significant at the 5 percent level. Positive correlation coefficients are indicated as a plus (+) symbol, while significant negative coefficients are denoted as a minus (-).

TABLE X

ANDERSON CREEK CORRELATION MATRIX

Variable	pH	Alkalinity	Acidity	T. Solids	S. Solids	D. Solids	Turbidity	Chloride	Sulfate	Fe-T	Fe-D	Mn-T	Mn-D	Ca-T	Ca-D	Mg-T	Mg-D	Al-T	Cd-T	Cd-D	Cr-T	Cr-D	Cu-T	Cu-D	Pb-T	Pb-D	Ni-T	Ni-D	Zn-T	Zn-D	Co-T
Alkalinity																															
T. Solids		+	+																												
S. Solids		+	+	+																											
D. Solids			+	+																											
Turbidity		+	+	+	+	+																									
Chloride				-		-																									
Sulfate																															
Fe-T		+	+	+	+		+																								
Fe-D	-		+	+	+		+			+																					
Mn-T																															
Mn-D																															
Ca-T		+	+				+			+																					
Ca-D		+	+							+				+																	
Mg-T		+	+	+	+		+			+				+	+																
Mg-D		+	+	+	+		+		-	+				+	+	+															
Al-T																															
Cd-T		+	+				+							+		+	+														
Cd-D			+	+	+	+										+	+		+												
Cr-T		+								-						+			+												
Cr-D									-												+										
Cu-T		+	+	+			+			+				+	+	+	+		+	+	+										
Cu-D		+	+	+	+		+			+	+			+	+	+	+		+	+			+								
Pb-T																+			+	+			+								
Pb-D																															
Ni-T			+												+		+														
Ni-D																															
Zn-T										+																					
Zn-D								+																	+				+		
Co-T																															
Water Temp		+	+											+	+	+	+		+	+	+		+		+						

TABLE XI

LOWE BRANCH CORRELATION MATRIX

Variable	pH	Alkalinity	Acidity	T. Solids	S. Solids	D. Solids	Turbidity	Chloride	Sulfate	Fe-T	Fe-D	Mn-T	Mn-D	Ca-T	Ca-D	Mg-T	Mg-D	Al-T	Cd-T	Cd-D	Cr-T	Cr-D	Cu-T	Cu-D	Pb-T	Pb-D	Ni-T	Ni-D	Zn-T	Zn-D	Co-T
Alkalinity																															
Acidity	-	+																													
T. Solids		+																													
S. Solids	+		-																												
D. Solids		+	+	+																											
Turbidity	-	+	+	+	-	+																									
Chloride							-																								
Sulfate																															
Fe-T		+	+	+		+																									
Fe-D				+		+	+																								
Mn-T																															
Mn-D																															
Ca-T		+	+					-			-																				
Ca-D			+					-			-			+																	
Mg-T		+	+							+	-			+	+																
Mg-D			+					-			-			+	+	+															
Al-T																															
Cd-T		+	+					-		+				+	+	+	+														
Cd-D			+																												
Cr-T																															
Cr-D																															
Cu-T										+	+			+		+			+												
Cu-D		-																		+			+								
Pb-T																															
Pb-D																															
Ni-T		+	+					+		+				+	+	+	+		+												
Ni-D			+											+	+	+	+														
Zn-T																															
Zn-D																															
Co-T																															
Water Temp		+	+							+	-			+	+	+	+		+				+				+	+			

TABLE XII

BOWLING BRANCH CORRELATION MATRIX

Variable	pH	Alkalinity	Acidity	T. Solids	S. Solids	D. Solids	Turbidity	Chloride	Sulfate	Fe-T	Fe-D	Mn-T	Mn-D	Ca-T	Ca-D	Mg-T	Mg-D	Al-T	Cd-T	Cd-D	Cr-T	Cr-D	Cu-T	Cu-D	Pb-T	Pb-D	Ni-T	Ni-D	Zn-T	Zn-D	Co-T
Alkalinity																															
Acidity	+																														
T. Solids		+																													
S. Solids			+																												
D. Solids		+	+																												
Turbidity	+	+	+		+																										
Chloride																															
Sulfate																															
Fe-T	+	+	+		+	+																									
Fe-D		+	+		+	+				+																					
Mn-T	+	+	+	+	+	+			+	+																					
Mn-D																															
Ca-T	+																														
Ca-D	+	+												+																	
Mg-T	+	+										+		+	+																
Mg-D	+										-			+	+	+															
Al-T	+									+		+				+															
Cd-T													-																		
Cd-D																			+												
Cr-T	+									+		+						+													
Cr-D	+	+							+	-	-		+	+	+	+	+														
Cu-T																						+									
Cu-D																															
Pb-T	+	+									-					+	+						+	+							
Pb-D																						+	+		+						
Ni-T	+	+									-			+	+	+	+		+		+		+		+	+					
Ni-D																															
Zn-T											-	+																			
Zn-D															+		+					+									
Co-T																															
Water Temp	+							+			-			+	+	+	+	+			+	+			+		+				

TABLE XIII

BILLS BRANCH CORRELATION MATRIX

Variable	pH	Alkalinity	Acidity	T. Solids	S. Solids	D. Solids	Turbidity	Chloride	Sulfate	Fe-T	Fe-D	Mn-T	Mn-D	Ca-T	Ca-D	Mg-T	Mg-D	Al-T	Cd-T	Cd-D	Cr-T	Cr-D	Cu-T	Cu-D	Pb-T	Pb-D	Ni-T	Ni-D	Zn-T	Zn-D	Co-T
Alkalinity	+																														
Acidity																															
T. Solids			-																												
S. Solids				+																											
D. Solids	+		-	+	+																										
Turbidity	-			+	+																										
Chloride																															
Sulfate	+	+				+																									
Fe-T	-			+	+	+																									
Fe-D		+	+						+																						
Mn-T		+	+	+		+			+	+	+																				
Mn-D		+			-		-			-	+																				
Ca-T	+	+			-		-		+	-	+	+	+																		
Ca-D	+	+				+			+		+	+		+																	
Mg-T	+	+	+		-		-		+		+	+	+	+	+																
Mg-D		+							+		+	+	+	+	+	+															
Al-T					+		+			+		+																			
Cd-T				+	+		+			+		+						+													
Cd-D		+									+	+				+	+														
Cr-T																															
Cr-D																															
Cu-T	-		+	+	+		+			+		+						+	+												
Cu-D			+				+			+	+	+			+	+	+						+								
Pb-T				+	+		+			+		+		-				+	+	+			+	+							
Pb-D																															
Ni-T	-			+	+		+			+		+		-		-		+	+				+	+	+						
Ni-D									-																						
Zn-T	-	-		+	+		+		-	+			-	-	-	-	-	+	+				+		+		+				
Zn-D																															
Co-T																															
Water Temp	+	+		+		+	-	+	+			+		+	+	+	+												-		

TABLE XIV

GREEN BRANCH CORRELATION MATRIX

Variable	pH	Alkalinity	Acidity	T. Solids	S. Solids	D. Solids	Turbidity	Chloride	Sulfate	Fe-T	Fe-D	Mn-T	Mn-D	Ca-T	Ca-D	Mg-T	Mg-D	Al-T	Cd-T	Cd-D	Cr-T	Cr-D	Cu-T	Cu-D	Pb-T	Pb-D	Ni-T	Ni-D	Zn-T	Zn-D	Co-T
Alkalinity	+																														
Acidity		+																													
T. Solids																															
S. Solids			-	+																											
D. Solids				+	+																										
Turbidity		+		+	+	+																									
Chloride																															
Sulfate	+	+	+	+		+	+																								
Fe-T				+	+	+	+																								
Fe-D		+	+		-																										
Mn-T				+	+	+																									
Mn-D																															
Ca-T	+	+	+						+		+																				
Ca-D	+	+	+						+		+			+																	
Mg-T		+	+	+		+	+		+	+	+			+	+																
Mg-D		+	+		-				+		+			+	+	+															
Al-T		-		+	+	+	+			+		+																			
Cd-T		+	+	+	+	+	+		+	+				+		+															
Cd-D		+															+		+												
Cr-T		+		+	+	+	+			+						+		+	+												
Cr-D				+	+	+																									
Cu-T		+		+	+	+	+		+	+		+		+		+		+	+		+									
Cu-D				+		+				+	+			+		+	+	+	+	+		+	+								
Pb-T		+		+	+	+	+		+	+						+		+	+		+		+	+							
Pb-D																						+									
Ni-T		+		+	+	+	+		+	+						+			+		+		+								
Ni-D						+										+		+					+								
Zn-T				+	+	+	+			+								+	+	+	+		+	+	+			+			
Zn-D																															
Co-T																															
Water Temp	+	+		+	+	+	+		+		-			+		+					+		+				+				

TABLE XV

INDIAN FORK CORRELATION MATRIX

Variable	pH	Alkalinity	Acidity	T. Solids	S. Solids	D. Solids	Turbidity	Chloride	Sulfate	Fe-T	Fe-D	Mn-T	Mn-D	Ca-T	Ca-D	Mg-T	Mg-D	Al-T	Cd-T	Cd-D	Cr-T	Cr-D	Cu-T	Cu-D	Pb-T	Pb-D	Ni-T	Ni-D	Zn-T	Zn-D	Co-T
Alkalinity	+																														
Acidity																															
T. Solids	-	-																													
S. Solids	-	-		+																											
D. Solids	-	-		+	+																										
Turbidity					+																										
Chloride	-	-																													
Sulfate	-	-		+	+	+		+																							
Fe-T	-	-	+	+	+	+	+		+																						
Fe-D	-	-																													
Mn-T	-	-	+	+		+	+		+	+	+																				
Mn-D	-	-		+		+			+	+	+	+																			
Ca-T	-	-	+	+		+			+	+	+	+	+																		
Ca-D	-	-		+		+			+	+	+	+	+	+																	
Mg-T	-	-	+	+		+			+	+	+	+	+	+	+																
Mg-D	-	-		+		+			+	+	+	+	+	+	+	+															
Al-T	+				+						-	-	-	-	-	-	-														
Cd-T	-		+							+		+		+	+	+	+														
Cd-D			+																+												
Cr-T					+							-																			
Cr-D																															
Cu-T		-		+	+	+	+			+		+		+		+		+	+												
Cu-D											+			+	+					+											
Pb-T																															
Pb-D																															
Ni-T	-	-	+						+	+	+	+	+	+	+	+	+										+				
Ni-D												+	+	+	+	+	+														
Zn-T	-	-	+	+		+	+		+	+	+	+	+	+	+	+	+		+	+			+	+			+				
Zn-D	-	-	+							+	+	+	+	+	+	+	+							+			+		+	+	
Co-T																					+									+	
Water Temp	-	-		+	+	+			+	+		+	+	+	+	+	+		+	+	-		+	+							

In this type of blind generation of coefficients one must be very cautious about attributing too much importance to any given association until a plausible explanation can be found, as noted in Chapter IV-B. A correlation analysis of two variables may often produce a significant coefficient even when there is no direct relationship between the two. This may be caused by a third variable to which each of the others is related. Furthermore, there is always the possibility of the given coefficient being caused purely by chance.

Constituent concentrations in the three undisturbed watersheds were often at or near detection level of the analytical techniques. At these levels, any background noise or perturbation introduced during the sample collection or subsequent analysis may be highly important in disguising the actual behavior of the constituent in question. It is, therefore, not surprising to note that the correlations produced for these sites are often not very sensible or easily explained. In Lowe Branch, for example, the suspended solids concentration shows an inverse correlation with turbidity, and total and dissolved metal concentrations rarely have strong positive correlation with one another.

In this section only a few of these intervariate relationships are discussed, and some reasonable explanations are suggested. Concentrations of a number of metals correlate significantly with the water temperature for all streams. This behavior might be explained as a relationship between temperature and solubility, with substantial validity in many cases. There is, however, a third factor of great importance influencing these temperature relationships. Streamflow has a very strong inverse

relationship to temperature, since winter is the wet season in the area. The significant correlations between temperature and metals concentrations are essentially the same as those between streamflow and the metal concentrations, but of inverse sign. Thus, it is apparent that a strong interplay exists between temperature (and subsequently, solubility) and streamflow with regard to influencing constituent concentrations.

The combination of these factors tends to result in an increase of the levels of many constituents during the summer months in all streams. This elevation is less pronounced in the undisturbed basins, but it is nevertheless evident. Curtis (5) has explained this tendency as a consequence of the intermittent wet and dry periods characteristic of the summer season, building up high salt concentrations at the soil surface. This appears to be the case in this study as well; the highest concentrations of many constituents were observed upon a rainfall following a prolonged dry period.

Similarly, the correlations between pH and other constituents for Indian Fork are very similar to those between streamflow and those same constituents. Hydrogen ion concentration is inversely related to flow as described in the previous section. Here again, these apparent pH effects are actually attributable to streamflow, and pH is a third factor related to each of the others.

Calcium and magnesium are strongly interrelated in all of the streams, along with iron. This would seem to implicate dolomite as an important input of the calcium and magnesium ions to the system. However, geologic investigations have failed to substantiate this, and

little dolomite has been identified; the principal calcium source seems to be the calcite-rich concretions which litter the area.

Zinc and cadmium show evidence of a close direct association among only the disturbed watersheds. This indicates that these two metals may be released from the coal strata in the form of sphalerite (ZnS with associated CdS) as noted by Gluskotter (36) for Illinois coals. To date, however, zinc has been found primarily in the overburden rock, and no sphalerite has been identified.

There are numerous relationships between solids loadings and other constituent concentrations, especially in the mined watersheds. The elements present as impurities in the coal and those present in the overlying strata are subjected to increased levels of exposure and weathering as a result of surface mining. The loose material in the newly consolidated spoil is given up easily to surface runoff. Some of these particulates will, of course, go into solution, but such dissolution will be limited by solubility and kinetic considerations.

The relationship between turbidity and solids concentrations present for most of the streams is somewhat deceptive. All streams except Indian Fork show significant correlation coefficients between turbidity and some or all solids measurements at the 1 percent significance level. The actual meaning of these correlations, however, is not readily apparent at first observation. For the three undisturbed streams, solids loadings are all very low, and little or no turbidity is present. Therefore, a significant coefficient is generated. For the mined basins, however, agreement between the two measurements is not so good.

At normal conditions, waters with a wide range of solids concentrations give the same turbidity reading. The significant correlations are achieved only under conditions of very high flow and high solids loadings. In these cases high turbidities will also be measured. This behavior results in an overall significant correlation which is spurious.

Strong positive correlations exist in all of the disturbed watersheds between total iron concentration and suspended solids. This predominance of iron in particulate form has been previously noted by Delfino (14, 15) in a number of watersheds. Delfino found a similar strong association between manganese concentrations and suspended solids in his Missouri River study. In the streams of the New River study, however, only Bills Branch gives evidence of this behavior. Significant positive correlations exist for zinc and suspended solids in Bills Branch and Green Branch, and for copper concentrations and suspended solids in all streams.

Total copper concentrations may be of special interest for future model development, due to the large number of other constituents with which it correlates at significant levels. In Bills Branch, for example, copper correlates with all total metal concentrations (except total cobalt concentrations, for which sufficient data was not available) at the 5 percent significance level.

Countless other inferences could be drawn from these tables, and this will certainly be an area of continued study.

VI. STORM RUNOFF STUDY

A. Introduction and Experimental Design

A second phase of the study considered the short-term variation in stream water quality over the six sample watersheds during and immediately following a major storm. The study was of a preliminary nature consisting of only a single sampling period, and as such only general trends may be discerned from it. Despite this lack of statistical significance, some very interesting behaviors can be observed. This study has since been extended to form the basis for a future research effort.

Stormwater may be defined as that runoff which enters a stream without a significant base flow component. Tschantz (43), Overton and Meadows (44), and Tung (17) have noted increased peak flows in streams of the New River area attributable to coal strip mining. The actual magnitude of this change is a function of the degree of mining disturbance, and of the magnitude and duration of the storm. The highwalls and open bench cuts of the mine sites intercept large volumes of stormwater, and subsequently route it as surface flow to the streams.

Water samples were collected from the six study streams at frequent intervals during and following the storm of March 5, 1975. In this case it was not possible to begin sampling before the onset of the storm. However, sample collection was initiated at each site prior to the peak flow, and considerably before the rain subsided.

All samples were subsequently returned to the laboratory for analysis. The water quality variables for which the samples were analyzed are shown in Table XVI, along with the methodology employed in each case. The analyses were conducted as quickly as possible, but some delays were experienced as a result of the large sample load. Due to these delays, the alkalinity data are considered particularly suspect. All atomic absorption analyses for the metals were completed within three days after the samples were returned to the lab. The samples had probably not undergone significant changes due to adsorption to the sample bottle walls.

At three of the sites (Lowe Branch, Green Branch and Indian Fork), automated samples were also collected for comparison with the simultaneous grab samples. A Sigmamotor Model # WM-2-24 peristaltic sampling pump was employed for this purpose. Site selection was based on achieving a wide spectrum of disturbance conditions, and to some extent on accessibility.

B. Results and Discussion

The results of the study are shown in Tables XVI through XXV, for each of the streams from which samples were collected manually and from each of the sites of automatic sampling.

For all of the sites studied during this March storm, the total iron concentration showed an apparent positive relationship to stream flow. This relationship was not so well defined for Anderson Creek and Lowe Branch as for the more extensively disturbed watersheds. For Bills

TABLE XVI

ANALYTICAL METHODOLOGY

Constituent	Method
Suspended Solids	Gravimetric (Standard Methods (33))
Sulfate	Hach Kit turbidometric method
Alkalinity	Titrametric Method (Standard Methods (33))
Turbidity	Hach Model 1860 turbidimeter
Fe, Mn, Ca, and Mg	Atomic Absorption Spectrophotometry (Perkin Elmer 403)

TABLE XVII

ANDERSON CREEK STORMWATER QUALITY

Time	Flow (cfs)	Fe-T (mg/l)	Ca-T (mg/l)	Mg-T (mg/l)	S Sol (mg/l)	Turb (jtu)
1345	0.47	0.95	1.50	1.40	15.0	8.0
1400	0.54	1.00	1.50	1.30		
1415	0.54	1.00	1.50	1.30	20.0	11.0
1430	0.54	1.10	1.40	1.30		
1445	0.60	1.20	1.60	1.30	45.0	15.0
1500	0.76	1.30	1.50	1.40		
1515	0.76	1.50	1.50	1.40	41.0	17.0
1530	0.84	1.30	1.60	1.30		
1545	0.84	1.20	1.50	1.30	30.0	12.0
1615	0.84	1.20	1.50	1.50		
1645	0.84	1.50	1.60	1.40	38.0	14.0
1715	0.84	1.60	1.70	1.40		
1745	0.84	1.40	1.50	1.30	16.0	11.0
1845	0.84	1.10	1.70	1.40		
1945	0.76	0.93	1.60	1.40	18.0	7.0
2045	0.76	0.93	1.50	1.40		
2145	0.68	0.95	1.40	1.30	14.0	3.0
2245	0.60	0.95	1.60	1.40		
2345	0.60	0.93	1.50	1.40	12.0	5.0
0045	0.60	0.88	1.70	1.40		
0145	0.60	0.84	1.60	1.40	2.0	4.0
0245	0.60	0.86	1.50	1.30		
0345	0.60	0.84	1.40	1.30	20.0	5.0
0445	0.60	0.75	1.40	1.30		
0545	0.60	0.75	1.30	1.30	16.0	3.0
0645	0.54	0.73	1.30	1.40		
0745	0.54	0.66	1.30	1.30	8.0	2.0

TABLE XVIII

LOWE BRANCH STORMWATER QUALITY

Time	Flow (cfs)	Fe-T (mg/l)	Ca-T (mg/l)	Mg-T (mg/l)	SO_4 (mg/l)	S Sol (mg/l)	Turb (jtu)
1415	0.65	1.02		1.5		37	18
1430	0.69	0.31			6		
1445	0.72	0.35	1.4	1.5		7	2
1500	0.80	0.66	1.4	1.6	7		
1515	0.88	0.91	1.3	1.6		44	18
1530	0.88	0.44	1.3	1.5	6		
1545	0.92	0.64	1.3	1.5		44	13
1600	0.92	0.42	1.4	1.5	8		
1615	1.01	0.33	1.5	1.6		11	2
1645	1.01	0.51	1.5	1.6	13		
1715	1.01	0.38	1.5	1.5		38	1
1745	1.01	0.46		1.6	16		
1845	1.01	0.31	1.6	1.6		5	2
1945	1.01	0.29	1.6	1.6	14	12	1
2045	1.01	0.33	1.6	1.7			
2145	1.01	0.31	1.6	1.6	10	4	1
2245	0.96	0.31	1.7	1.6			
2345	0.88	0.33	1.7	1.6	11	0	0
0045	0.88	0.31	1.7	1.6			
0145	0.88	0.33	1.7	1.6	10	14	0
0245	0.84	0.29	1.7	1.6			
0345	0.84	0.29	1.6	1.6	12	0	0
0445	0.84	0.27	1.6	1.6			
0545	0.84	0.27	1.6	1.6	9	0	0
0645	0.80	0.29	1.6	1.6			
0745	0.80	0.27	1.7	1.6	11	20	0
0845	0.80	0.24	1.6	1.6			

TABLE XIX

BOWLING BRANCH STORMWATER QUALITY

Time	Flow (cfs)	Fe-T (mg/l)	Mn-T (mg/l)	Ca-T (mg/l)	Mg-T (mg/l)	Alk (mg/l)	SO_4 (mg/l)	S Sol (mg/l)	Turb (jtu)
1430	1.95	4.50	0.04	1.3	1.4	3.77	14	70	51
1445	2.11	9.40	0.11	1.3	1.5	2.78	40		
1500	2.11	10.50	0.13	1.2	1.5		38	96	320
1515	2.25	16.10	0.20	1.1	1.7		0		
1530	2.40	16.00	0.20	1.0	1.7		35	356	520
1545	2.40	13.60	0.17	1.0	1.6		25		
1600	2.72	9.60	0.13	1.1	1.5	3.33	35	306	350
1615	2.72	6.70	0.10	1.2	1.3		12		
1630	2.72	5.00	0.07	1.2	1.5		10	142	125
1700	2.72	4.20	0.05	1.2	1.4		14		
1730	2.90	3.41	0.03	1.2	1.4		13	79	56
1800	2.90	2.80	0.02	1.2	1.4		10		
1830	2.90	1.60	0.01	1.3	1.5		9	0	16
1930	2.90	1.60	0.00	1.3	1.3		11	11	15
2030	2.90	1.40	0.00	1.4	1.4		10		
2130	2.90	1.30	0.00	1.3	1.4		11	12	8
2230	2.90	1.10	0.00	1.4	1.3		10		
2330	2.90	1.10	0.00	1.3	1.2		9	0	6
0030	2.72	0.95	0.00	1.4	1.3		10		
0130	2.72	0.87	0.00	1.3	1.2		8	14	7
0230	2.72	0.84	0.00	1.4			7		
0330	2.56	0.76	0.00	1.4	1.2			7	6
0430	2.56	0.78	0.00	1.3	1.4		10		
0530	2.40	0.78	0.00	1.4	1.3		10	15	4
0630	2.40	0.74	0.00	1.4	1.3		9		
0730	2.40	0.67	0.00	1.4	1.4			11	4
0830	2.40	0.69	0.00	1.4	1.4				

TABLE XX

BILLS BRANCH STORMWATER QUALITY

Time	Flow (cfs)	Fe-T (mg/l)	Mn-T (mg/l)	Ca-T (mg/l)	Mg-T (mg/l)	Alk (mg/l)	SO_4 (mg/l)	S Sol (mg/l)	Turb (jtu)
1500	1.48	1.80		7.5	6.0	13.17	38	100	43
1515	1.64	2.00		8.0	6.0	13.57	38		
1530	1.64	2.40	0.02	7.5	6.0	15.28	39	174	65
1545	2.00	4.10	0.05	8.5	6.0	13.97	40		
1600	3.24	6.80	0.05	10.0	7.0	15.38	32	586	400
1615	3.40	8.10	0.07	10.5	8.0	16.98	30		
1630	3.02	8.70	0.07	12.0	8.0	15.18	36	508	470
1645	2.71	8.10	0.07	12.0	9.0	14.37	41	354	380
1700	2.45	7.80	0.06	14.0	10.0	13.47	36	312	
1730	2.14	8.40	0.06	13.0	10.0	13.97	43		375
1800	1.87	7.20	0.06	14.0	10.0	12.56	46	280	260
1830	1.70	5.00		12.0	9.0	12.16	56		
1900	1.59	3.60		12.0	9.0	12.06	58	396	78
2000	1.53	2.00		12.0	8.0	12.16	59		
2100	1.30	1.60		11.0	7.0	11.86	56	33	18
2200	1.21	1.10		10.0	7.0	12.36	51		
2300	1.17	0.94		10.0	6.0	12.06	50	15	9
2400	1.13	0.85		9.3	6.0	12.26	44		
0100	1.09	0.81		8.6	6.0			13	
0200	1.09	0.77		8.6	6.0	12.26	46		7
0300	1.06	0.73		8.5	6.0	12.46	45	10	
0400	1.02	0.73		8.5	6.0	12.36	42		7
0500	1.02	0.69		8.1	6.0	12.26	41	9	
0600	1.02	0.69		8.3	6.0	12.36	42		6
0700	1.02	0.65		8.3	6.0	11.26	40	6	
0800	1.02	0.65		8.0	6.0		39		5
0900	0.98	0.61		8.0	5.0		40	10	
1000	0.98	0.61		8.0	5.0		40		

TABLE XXI

GREEN BRANCH STORMWATER QUALITY

Time	Flow (cfs)	Fe-T (mg/l)	Mn-T (mg/l)	Ca-T (mg/l)	Mg-T (mg/l)	Alk (mg/l)	SO_4 (mg/l)	S Sol (mg/l)	Turb (jtu)
1600	4.08	7.8	0.08	34	18	20.65		486	320
1615	4.76	12	0.10	34	18	13.32			
1630	5.01	15	0.11	34	19	22.53	150	960	660
1645	5.01	14	0.15	35	19	28.64	140		
1700	5.01	15	0.15	35	19	29.53	127	1006	1050
1715	4.76	16	0.16	34	19	29.30	140		
1730	4.52	16	0.15	34	19	27.86	135	778	880
1745	4.29	16	0.18	34	19	39.85	140		
1800	4.08	16	0.16		18	47.29		516	1200
1830	3.49	13	0.11	34	18	40.85			
1900	3.09	12	0.11	32	19	42.18	125	410	1050
1930	2.74	9	0.30	36	18	43.29	147		
2000	2.58	7	0.08	34	18	36.41	145	380	300
2100	2.41	4	0.04	34	18	33.08	140		
2200	2.25	2	0.02	35	18	33.41	132	47	29
2300	2.10	2	0.03	34	19	29.97	140		
2400	1.96	3		33	18	30.97	145	10	8
0100	1.96	2		33	18		145		
0200	1.83	2		33	18		145	31	18
0300	1.83	2		34	18		145		
0400	1.69	2		34	18		140	47	12
0500	1.69	2		32	18		135		
0600	1.69	2		33	18		145	0	5
0700	1.69	1		35	18		142		
0800	1.57	1		33	18		152	22	3
0900	1.45	1		34	18		140		

TABLE XXII

INDIAN FORK STORMWATER QUALITY

Time	Flow (cfs)	Fe-T (mg/l)	Mn-T (mg/l)	Ca-T (mg/l)	Mg-T (mg/l)	SO_4 (mg/l)	S Sol (mg/l)	Turb (jtu)
1430	10.3	24.5	0.12	79	28	350	240	200
1445	11.6	26.3	0.13	80	28	340		
1500	13.4	26.3	0.12	79	28	350	282	
1515	13.6	46.4	1.28	95	31	345		160
1530	14.0	27.4	0.14	81	28	350	630	
1545	15.1	26.0	0.17	78	28	320	1014	550
1600	16.0	28.0		61	28		1540	
1615	18.0	39.0	0.35	72	27	300	1020	1750
1630	19.5	50.0		68	27		1140	
1700	24.3	36.0	0.30	70	27	295		1400
1730	25.7	27.0	0.15	73	26	295	460	
1800	26.2	28.0	0.13	70	26	280		510
1830	23.5	18.0	0.11	60	25	275	256	
1930	16.3	23.0	0.91	55	23	240		230
2030	13.8	14.0	0.85	53	23	260	278	140
2130	12.2	6.9	0.08	55	22	240	102	
2230	10.3	5.8	0.07	55	22	250		80
2330	9.5	4.7	0.06	57	22	270	40	
0030	8.8	4.6	0.11	57	23	280		43
0130	8.1	4.6	0.37	58	23	280	34	
0230	7.4	4.2	0.35	58	23	295		20
0330	7.2	4.3	0.47	58	24	295	18	
0430	6.8	4.3	0.54	61	24			18
0530	6.5	4.4	0.55	62	25		0	
0630	6.2	4.6	0.56	63	25			8
0730	6.2	4.6	0.65	61	25		0	
0830	6.2	4.6	0.66	60	25			11
0930	6.0	4.6	0.66	60	25		19	
1030	5.8	4.7	0.80	61	25			11
1130	5.8	4.6	0.58	60	25		0	
1230	5.8	4.6	0.71	63	25			14
1330	5.8	4.6	0.68	63	25		13	
1430	5.6	4.7		62	25			12

TABLE XXIII

LOWE BRANCH STORMWATER QUALITY
(AUTO SAMPLES)

Time	Flow (cfs)	Fe-T (mg/l)	Mn-T (mg/l)	Ca-T (mg/l)	Mg-T (mg/l)
1415	0.65	0.22	0.03	2.5	1.8
1445	0.72	0.11	0.04	3.2	2.0
1515	0.88	0.14	0.03	2.4	1.8
1545	0.92	0.12	0.03	3.0	1.9
1615	1.01	0.96		1.8	1.6
1645	1.01	0.96		2.0	1.6
1745	1.01	0.96		1.9	1.6
1845	1.01	0.96		1.9	1.7
1945	1.01	0.23		2.0	1.7
2045	1.01	0.22		2.0	1.7
2145	1.01	0.23		1.9	1.7
2245	0.96	0.23		1.8	1.7
2345	0.88	0.23	0.01	2.2	1.7
0045	0.88	0.24	0.03	2.7	1.8
0145	0.88	0.24	0.05	3.0	1.8
0245	0.84	0.22	0.05	3.3	2.0
0345	0.84	0.24	0.07	3.8	2.2
0445	0.84	0.24	0.06	3.9	2.1
0645	0.80	0.25	0.07	3.8	2.2
0845	0.80	0.13	0.05	2.5	1.2

TABLE XXIV

GREEN BRANCH STORMWATER QUALITY
(AUTO SAMPLES)

Time	Flow (cfs)	Fe-T (mg/l)	Mn-T (mg/l)	Ca-T (mg/l)	Mg-T (mg/l)	SO_4 (mg/l)
1600	4.08	5.3	0.10	36	19	170
1615	4.76	7.5	0.12	35	19	140
1630	5.01	9.0	0.10	38	20	155
1645	5.01	12.0	0.17	36	20	135
1700	5.01	13.0	0.18	34	20	130
1715	4.76	13.0	0.17	34	20	130
1730	4.52	14.0	0.18	33	20	90
1745	4.29	13.0	0.18	34	20	75
1800	4.08	12.0	0.17	34	20	130
1830	3.49	10.0	0.15	35	19	135
1900	3.09	7.7	0.12	36	19	135
1930	2.74	6.0	0.11	36	19	145
2000	2.58	4.7	0.09	37	19	155
2100	2.41	2.6	0.06	37	19	160
2200	2.25	1.6	0.04	38	19	155
2300	2.10	1.3	0.04	38	19	165
2400	1.96	1.2	0.03	37	19	160
0100	1.96	1.0	0.03	37	19	155
0200	1.83	0.9	0.03	37	19	155
0300	1.83	0.9	0.03	37	19	150
0400	1.69	0.8	0.03	36	19	155
0500	1.69	0.6		36	19	

TABLE XXV

INDIAN FORK STORMWATER QUALITY
(AUTO SAMPLES)

Time	Flow (cfs)	Fe-T (mg/l)	Mn-T (mg/l)	Ca-T (mg/l)	Mg-T (mg/l)
1430	10.3	16	0.13	81	31
1500	13.4	18	0.16	80	31
1530	14.0	18	0.19	75	30
1600	16.0	27	0.31	69	30
1630	19.5	42	0.34	71	29
1730	25.6	21	0.16	69	27
1830	23.5	10	0.10	62	25
1930	16.3	7.4	0.11	60	24
2030	13.8	5.1	0.11	58	23
2130	12.2	4.6	0.10	62	25
0030	8.8	1.7	0.05	64	29
0130	8.1		0.02	65	31
0230	7.4	2.3	0.08	62	30
0330	7.2	1.1	0.31	61	30
0430	6.8	1.3	0.47	59	31
0530	6.5	1.2	0.35	60	32
0630	6.2	1.4	0.43	60	30
0730	6.2	1.7	0.28	62	31
0830	6.2	1.6	0.48	64	
0930	6.0	1.6	0.51	62	
1030	5.8	1.6	0.43	64	
1130	5.8	1.3	0.40		

Branch and Green Branch, the increase in [Fe] lags slightly behind the rising flow. Indian Fork, Bowling Branch, and Lowe Branch, however, experienced the maximum concentrations just before the peak flow. In each of these cases this behavior mimics that of the suspended solids, indicating that the iron is primarily in the particulate form. At Anderson Creek the total iron concentration peaked with the maximum flow, following the peak in suspended solids; in each case, however, the increase was small.

Total manganese concentrations behaved very similarly to the iron. At Anderson Creek all samples were below detectable limits by flame analysis and no trend could, therefore, be discerned. Data from Lowe, Bowling, Bills, and Green Branch all indicated a positive relationship between total manganese concentration and flow. In each of these cases the behavior of manganese closely follows that of iron and of suspended solids. At Indian Fork, however, the concentration of Mn during the high flow period was very erratic; there did appear to be an increasing trend in concentration as the flow subsided.

Calcium and magnesium concentrations experienced no strong association with flow at Anderson, Lowe, and Green. Calcium concentrations indicated an inverse relationship to streamflow at Indian Fork and Bowling Branch, with magnesium behaving similarly at Indian Fork only. This behavior could perhaps be attributed to the elevated initial concentrations from the storm runoff which preceeded the sampling period, or to an absence of calcium and magnesium in the soil and litter of these watersheds. The data from Bills Branch show a positive relationship to flow for both calcium and magnesium, with the respective concentrations lagging slightly behind the increasing flow.

As shown in these tabulations, suspended solids concentrations increased directly with the rising flow in all six watersheds. This elevation in suspended solids was much greater in magnitude in the three watersheds subjected to surface mine disturbance, and in Bowling Branch which had experienced recent intense logging activity.

Sufficient alkalinity data to discern any apparent effects of the stormwater on concentrations were available only for Bills Branch and Green Branch. In each of these cases the alkalinity experienced a slight increase at the elevated flow conditions. Data from the other sites were deemed unusable due to the long delay between sample collection and analysis.

Lowe, Bowling, and Bills Branch indicated positive relationships between sulfate concentrations and streamflow. No such association was apparent for Green Branch. Sulfate measurements for Indian Fork samples are highly suspect, since they were taken at the upper limit of the scale on the Hach kit. Subsequent to this analysis, it became apparent that measurements in this area of the scale were highly inaccurate, and dilution of the samples should be employed to get back to a more accurate region.

During the period of sample collection for this storm, the overall tendency for most constituents monitored was one of a large initial increase in concentration, followed by a period of rapid decline to a level typically below the annual mean. The readily leachable salts and detrital matter in the watersheds are rapidly picked up by the stormwater. After this initial flushing of the system, there is little

subsequent leaching activity, and stream concentrations are diluted by the runoff.

From the results of this study it is suggested that the maximum concentrations of these constituents are reached during the early stages of a storm period. Iron, sulfates, alkalinity, solids, and turbidity all experienced first-flush concentrations well above the annual mean for the weekly samples. Manganese concentrations increased with this flushing, but never exceeded the annual mean. The behavior of calcium and magnesium was somewhat more variable between the individual streams, with only Bills Branch and Indian Fork giving an indication of surface flushing. Generally, it appears that the water quality of these streams apparently reaches worst-case conditions during this early phase of a storm, when the flushing behavior is operative.

C. Comparison of Manual and Automated Sample Collection

Setting up camps at each of the six stream sites immediately before a major rainfall event is a rather formidable task. Furthermore, collecting water samples throughout the storm and for several hours after its conclusion tends to result in a sleepless and very miserable night for all concerned.

Clearly, it would be desirable to employ remote sampling units, which could be deposited at each of the sites and then retrieved the following day. However, these automated samplers are suspect to discrimination against suspended matter due to the small diameter of the tubing through which the water is pumped. This phenomenon has been explored to some extent with regard to wastewaters by Harris and Keffer

(45). No such information is available, however, concerning the collection of samples from small natural streams. Therefore, it was resolved to make a direct comparison between grab samples and simultaneous samples collected by the Sigmamotor peristaltic sampling units.

Agreement between the two groups of samples was relatively good at all sites for iron and manganese concentrations. The identical trends were indicated from each set of corresponding grab and automated samples. However, the auto samples were consistently slightly lower in absolute concentration than the grab samples for these constituents.

Calcium and magnesium measurements were in general agreement for the two sampling methods, with the exception of the Lowe Branch data. In this case, the grab sample data indicated a very steady concentration of both Ca and Mg throughout the study period, while the auto sample data indicated a marked increase in these concentrations with flow, although the values are very erratic and scattered. The data sets from the other two sites show general agreement in overall trends with the auto-collected samples being consistently higher. At Indian Fork, the two sets of Mg measurements are exactly comparable on the rising side of the hydrograph, but then show a marked divergence on the downward side.

It was determined that some discrimination against suspended solids did occur in the automated sample collection. Suspended solids measurements gave slightly lower values for the automated samples in most cases. However, it should be noted that the most severe disagreement between the two sample collection modes occurred at Lowe Branch, the site

with the lowest suspended solids concentrations; it is, of course, possible that simple analytical variation might account for some of this discrepancy.

VII. CONCLUSIONS

Some conclusions reached in the course of this study are detailed below. The list will continue to lengthen as other aspects of the study are pursued.

1. Benchmark water quality of the first-order watersheds of the New River basin is at or near pristine conditions.

2. Coal surface mining exerts a significant effect on the water quality of these streams, significantly elevating concentrations of a wide variety of pollutants. Levels of most of these pollutants do not exceed standards, but chronic detrimental effects may still result.

3. Seasonal cycles are evident for many constituents. The influence of these cycles, however, may be small in absolute magnitude compared to the effects of mining activity upon the constituent concentrations.

4. Stream flow significantly influences the levels of several constituents in both undisturbed and mined watersheds. This influence becomes progressively more pronounced as the extent of mining increases. Dissolved constituents tend to experience reduction in concentration with increased flow due to dilution effects. Concentrations of suspended material are increased due to turbulence and erosional effects. However, this relationship between flow and concentration is quite complex, and the actual effect at any given time is dependent upon the position relative to the stream hydrograph.

5. Interrelationships among the water quality constituents are numerous and complex.

6. Flushing effects during storm periods produce constituent concentrations significantly greater than those associated with average streamflow levels.

7. Sample collection should be designed to coincide with this worst-case condition during the initial stages of storm periods.

8. Remote sample collection devices may be employed for some constituents with little loss of accuracy. This should be tested, however, on a site-specific basis. Calibration procedures may be feasible for concentrations of suspended materials.

During the course of the study, the need for future research in several areas also became apparent:

1. More samples should be collected during the prepeak stages of the stream hydrographs, as this period presents the maximum pollutant concentrations.

2. Chronic effects of elevated pollutant concentrations which still comply with state and federal standards should be investigated with respect to the regional biota.

3. Continued observation may provide information on long-term effects of surface mining on water quality; particular emphasis should be placed on discerning constituent behavior as a function of time after cessation of the mining activity. Seasonal variations and other cycles should also be closely studied.

4. Development of predictive models for various constituents should be pursued aggressively in the near future.

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APPENDIX

DATA LISTING

Legend

The notation "." denotes a sampling point for which no data is available for one of the following reasons:

1. No sample taken from that site (i.e., dry stream, etc.);
2. Concentration less than the detection limits of direct flame atomic absorption analysis (Fe, Mn, Al, etc.); or
3. Analysis not performed for other reasons.

TABLE XXVI

pH

Date	Anderson Creek	Lowe Branch	Bowling Branch	Bills Branch	Green Branch	Indian Fork
7	.	6.05	.	6.05	.	.
15	.	6.00	.	6.00	.	6.60
22	6.00	6.00	.	6.20	.	6.70
27	5.90	6.00	6.00	6.00	.	6.50
34	6.54	6.50	6.58	7.05	7.13	7.19
38	6.30	6.31	6.40	6.96	7.10	7.12
45	6.20	6.31	6.50	7.00	7.05	6.90
50	6.50	6.41	6.50	6.90	7.02	7.11
57	6.26	6.30	6.31	6.90	7.11	7.00
64	6.25	6.18	6.49	6.49	7.28	6.62
78	6.29	6.32	6.45	6.70	7.08	7.00
87	6.31	6.39	6.25	6.82	7.10	6.78
93	6.37	6.40	6.35	6.75	7.15	6.25
98	6.35	6.39	6.59	7.00	7.10	5.90
107	6.31	6.35	6.48	6.71	7.30	5.82
114	6.33	6.37	6.40	6.80	7.16	5.95
121	6.30	6.35	6.43	6.82	7.18	6.16
133	6.29	6.39	6.45	6.81	7.12	6.25
142	6.31	6.37	6.39	6.91	7.15	6.23
149	6.30	6.33	6.37	6.70	7.20	5.95
158	6.28	6.30	6.32	6.45	7.31	5.80
167	6.31	6.32	6.49	6.80	7.19	7.12
176	6.30	6.30	6.40	6.61	7.19	6.93
183	.	6.20	6.51	6.89	7.25	6.61
190	.	6.26	6.38	7.10	7.59	6.95
197	.	6.20	6.41	7.01	7.41	6.30
207	.	.	.	6.88	7.33	5.70
212	.	6.21	6.31	6.81	7.39	6.15
222	.	.	.	7.42	7.39	7.52
225	.	.	.	6.97	7.25	5.15
232	.	6.24	.	6.99	7.29	6.75
240	.	.	.	7.28	7.27	5.69
248	.	.	.	6.95	7.30	5.79
253	.	.	.	6.84	7.26	6.10
260	.	.	.	7.05	7.27	6.91
267	6.35	6.40	6.49	6.54	6.79	6.80
283	5.45	6.34	6.42	6.75	6.68	6.83
288	.	6.38	6.69	7.01	7.11	7.30
297	6.56	6.52	6.61	7.24	7.48	7.62
302	6.43	6.20	6.27	7.30	7.53	7.29
310	6.20	6.25	6.45	7.09	7.42	7.22
317	5.20	5.10	5.93	6.20	6.42	7.05
324	5.92	5.70	5.73	6.53	7.10	7.15
338	5.59	5.40	5.95	6.51	6.90	6.75
344	5.83	5.45	5.80	6.62	6.82	6.98
349	6.20	6.19	6.57	6.90	7.15	7.13

TABLE XXVII

ALKALINITY (mg/l)

Date	Anderson Creek	Lowe Branch	Bowling Branch	Bills Branch	Green Branch	Indian Fork
7	.	5.00	.	7.80	.	.
15	.	4.62	.	7.65	.	18.80
22	4.53	4.40	.	9.05	.	24.05
27	4.62	4.45	4.40	6.44	.	19.90
34	4.81	4.95	4.53	7.00	21.12	19.78
38	5.10	4.73	4.48	7.25	23.84	19.00
45	4.74	4.68	4.49	7.90	23.67	20.20
50	4.96	4.89	4.73	7.12	22.81	16.83
57	5.02	5.03	4.40	6.79	23.66	14.30
64	4.42	5.61	4.41	11.06	22.64	7.26
78	5.21	5.00	4.51	7.76	18.03	12.70
87	5.00	4.80	5.15	8.98	25.12	11.80
93	5.18	6.60	4.80	12.40	21.40	9.16
98	5.40	5.42	5.39	11.21	29.17	2.00
107	7.62	8.51	5.81	11.60	27.15	4.39
114	5.58	5.40	5.00	7.20	24.25	8.42
121	6.03	6.12	5.82	9.40	27.50	5.21
133	6.48	7.00	6.81	11.21	28.19	1.80
142	6.90	6.23	6.01	10.79	27.64	5.32
149	6.93	5.93	6.97	11.34	31.53	6.91
158	7.52	7.74	7.71	13.83	37.38	3.80
167	6.05	7.07	6.60	15.02	31.07	23.00
176	6.89	6.90	6.05	11.20	31.07	5.87
183	.	5.85	6.60	11.12	32.25	4.21
190	.	6.07	6.03	13.03	35.08	6.12
197	.	5.95	6.17	11.83	32.40	5.29
207	.	.	.	14.92	32.20	4.20
212	.	6.18	6.05	11.35	33.12	5.10
222	.	.	.	13.93	30.97	10.15
225	.	.	.	11.20	32.20	5.25
232	.	6.05	.	12.40	31.90	8.20
240	.	.	.	16.25	30.85	5.60
248	.	.	.	15.43	32.55	5.45
253	.	.	.	13.05	31.20	6.00
260	.	.	.	16.38	32.60	12.05
267	7.15	6.74	9.20	12.05	29.05	12.60
283	6.90	7.15	9.05	15.00	27.44	10.75
288	.	6.40	7.15	17.04	32.05	20.34
297	8.58	8.97	8.58	20.67	34.52	31.59
302	8.78	10.33	8.00	23.60	33.93	34.15
310	10.50	11.10	9.60	20.00	32.50	30.80
317	6.30	6.90	6.00	12.00	26.00	23.40
324	8.09	10.14	6.53	16.28	32.08	30.15
338	6.96	6.66	6.27	15.68	31.36	25.97
344	6.90	7.60	6.90	16.60	31.50	27.40
349	8.50	7.10	6.30	17.70	32.00	26.70

TABLE XXVIII

ACIDITY (mg/l)

Date	Anderson Creek	Lowe Branch	Bowling Branch	Bills Branch	Green Branch	Indian Fork
7	.	2.03	.	2.03	.	.
15	.	1.97	.	2.34	.	3.02
22	1.84	2.04	.	2.44	.	2.80
27	1.85	2.20	1.97	2.38	.	3.00
34	1.90	2.01	1.62	2.41	2.82	3.03
38	2.08	1.94	1.79	2.40	2.61	3.60
45	1.92	1.87	1.60	2.58	2.84	3.40
50	1.78	1.98	1.49	2.76	2.78	2.68
57	1.81	2.01	1.79	2.91	2.51	2.93
64	1.80	2.40	1.88	2.87	2.69	3.20
78	1.78	2.03	1.96	2.88	2.83	2.98
87	1.94	2.03	1.79	2.87	3.16	3.15
93	1.76	1.97	1.81	2.89	4.70	2.43
98	1.80	2.05	1.50	2.29	3.12	3.21
107	1.82	2.00	1.62	2.34	2.40	4.20
114	2.04	2.12	1.73	2.39	3.01	3.21
121	1.95	2.18	1.46	2.31	2.47	3.30
133	4.07	2.09	2.35	2.80	2.34	4.96
142	3.60	2.75	1.89	2.76	3.05	3.87
149	3.92	4.21	2.23	2.34	12.10	7.18
158	2.41	3.20	2.45	2.11	2.83	4.31
167	2.08	2.80	2.50	2.25	3.44	2.43
176	3.23	2.75	1.82	2.42	3.44	3.54
183	.	3.41	2.25	2.65	2.70	4.18
190	.	3.23	2.17	2.29	3.15	3.07
197	.	3.31	2.13	2.38	2.91	3.91
207	.	.	.	2.27	2.86	4.18
212	.	2.76	1.97	2.64	2.94	3.76
222	.	.	.	2.05	3.18	3.24
225	.	.	.	2.50	2.85	4.19
232	.	3.04	.	3.25	2.80	4.42
240	.	.	.	5.30	2.90	7.05
248	.	.	.	4.90	4.60	4.80
253	.	.	.	6.04	5.04	4.20
260	.	.	.	5.20	3.94	4.30
267	3.40	3.90	3.45	3.60	4.82	6.20
283	4.10	4.15	3.06	2.95	3.90	5.25
288	.	4.04	2.46	6.42	4.25	4.10
297	3.51	2.92	3.12	2.54	2.92	3.59
302	5.37	4.48	3.22	6.44	4.29	8.29
310	5.10	4.50	3.50	3.30	3.90	4.10
317	3.40	3.00	2.20	5.00	6.20	4.20
324	4.30	4.50	3.50	5.40	4.30	8.40
338	3.69	3.88	6.01	3.69	5.43	7.95
344	9.40	7.70	9.40	8.60	11.90	13.50
349	5.30	5.50	7.60	9.90	10.90	10.80

TABLE XXIX

TOTAL SOLIDS (mg/1)

Date	Anderson Creek	Lowe Branch	Bowling Branch	Bills Branch	Green Branch	Indian Fork
7	.	15	.	45	.	.
15	.	15	.	50	.	305
22	25	15	.	45	.	325
27	30	10	25	70	.	530
34	15	20	40	75	2850.0	575
38	20	25	30	60	10.8	290
45	30	20	25	55	7200.0	305
50	25	15	10	95	10800.0	505
57	10	15	10	10	825.0	590
64	15	10	15	18195	95.0	375
78	20	20	20	70	2495.0	465
87	45	15	40	75	810.0	590
93	20	15	7	8110	190.0	285
98	15	25	10	75	170.0	635
107	15	20	20	700	1800.0	6300
114	20	25	25	2300	2100.0	5500
121	15	25	15	1600	1500.0	3200
133	25	15	25	1200	1700.0	4800
142	20	20	30	2400	21000.0	1200
149	30	15	20	15800	2200.0	1800
158	10	10	15	6100	2800.0	2000
167	35	25	25	2100	8400.0	2800
176	15	20	25	3400	8400.0	6600
183	.	15	15	2200	3400.0	8800
190	.	15	20	2300	2800.0	7800
197	.	10	10	1200	3500.0	9140
207	.	.	.	1760	3000.0	12500
212	.	72	40	1600	4000.0	12900
222	.	.	.	4400	14700.0	13800
225	.	.	.	960	3900.0	5140
232	.	72	.	960	2500.0	2600
240	.	.	.	760	1200.0	500
248	.	.	.	194	434.0	772
253	.	.	.	134	446.0	760
260	.	.	.	662	1126.0	1410
267	208	60	54	286	1452.0	360
283	296	94	22	86	488.0	508
288	.	96	14	46	416.0	700
297	152	110	116	234	408.0	598
302	40	44	54	358	1688.0	526
310	34	12	26	82	324.0	61
317	66	46	52	352	618.0	246
324	32	24	10	96	300.0	454
338	44	46	162	92	454.0	256
344	62	46	62	114	304.0	446
349	32	48	298	76	246.0	466

TABLE XXX

SUSPENDED SOLIDS (mg/l)

Date	Anderson Creek	Lowe Branch	Bowling Branch	Bills Branch	Green Branch	Indian Fork
7	.	5	.	3	.	.
15	.	4	.	5	.	55
22	7	7	.	20	.	44
27	4	5	6	11	.	28
34	11	6	9	11	2310	212
38	6	12	7	37	550	71
45	11	9	6	25	6160	50
50	8	7	3	37	8760	26
57	0	1	2	4	685	63
64	1	1	1	17280	11	43
78	1	3	6	42	1307	120
87	3	2	2	8	430	26
93	9	11	5	6990	62	27
98	3	2	4	51	14	38
107	4	10	6	440	200	340
114	6	9	5	1700	500	60
121	5	8	4	900	460	120
133	7	7	7	900	140	180
142	3	9	8	1600	17900	100
149	9	3	6	13260	440	300
158	2	5	5	3500	920	160
167	11	7	9	1440	5000	300
176	3	2	6	380	5000	2300
183	.	6	4	1400	200	500
190	.	3	6	1640	740	600
197	.	4	2	600	200	100
207	.	.	.	960	40	100
212	.	4	2	800	40	200
222	.	.	.	2800	10160	3500
225	.	.	.	400	40	100
232	.	2	.	760	160	20
240	.	.	.	340	20	100
248	.	.	.	91	120	100
253	.	.	.	94	20	40
260	.	.	.	452	596	256
267	58	8	8	200	972	44
283	104	4	0	14	24	2
288	.	34	10	2	14	2
297	2	28	10	44	16	6
302	24	4	4	212	1284	8
310	30	0	0	4	4	6
317	24	0	0	256	396	68
324	14	8	2	34	54	26
338	20	0	120	28	234	10
344	12	0	12	0	0	0
349	10	0	264	14	14	12

TABLE XXXI

DISSOLVED SOLIDS (mg/l)

Date	Anderson Creek	Lowe Branch	Bowling Branch	Bills Branch	Green Branch	Indian Fork
7	.	10	.	42	.	.
15	.	11	.	45	.	250
22	18	8	.	25	.	281
27	26	5	19	59	.	502
34	4	14	31	64	540	363
38	14	13	23	23	525	219
45	19	11	19	30	1040	255
50	17	8	7	58	2040	479
57	10	14	8	6	140	527
64	14	9	14	915	84	332
78	19	18	14	33	1188	345
87	42	13	38	67	380	564
93	11	4	2	1120	128	258
98	12	23	6	24	156	597
107	11	10	14	260	1600	5960
114	14	16	20	600	1600	5440
121	10	17	11	700	1100	3080
133	16	8	18	300	1560	4620
142	17	11	22	800	3100	1100
149	21	12	14	2540	1760	1500
158	8	5	10	2600	1880	1840
167	24	18	16	660	3400	2500
176	12	18	17	2020	3400	4300
183	.	9	11	800	3200	8300
190	.	12	14	660	2060	7200
197	.	6	8	600	3300	9040
207	.	.	.	800	2960	12400
212	.	68	38	800	3960	12700
222	.	.	.	1600	4540	10500
225	.	.	.	560	3860	5040
232	.	70	.	200	2340	2580
240	.	.	.	420	1180	400
248	.	.	.	103	314	672
253	.	.	.	40	426	720
260	.	.	.	210	530	1154
267	150	52	46	86	480	316
283	192	90	16	72	464	506
288	.	82	4	44	402	658
297	150	82	106	190	382	592
302	16	40	50	146	404	518
310	4	12	26	78	322	610
317	42	46	52	96	222	176
324	18	16	8	62	240	428
338	24	46	42	64	220	246
344	50	46	50	114	304	446
349	22	48	34	62	232	454

TABLE XXXII

TURBIDITY (jtu)

Date	Anderson Creek	Lowe Branch	Bowling Branch	Bills Branch	Green Branch	Indian Fork
7	.	0	.	0	.	.
15	.	0	.	0	.	10
22	0	0	.	1	.	4
27	0	0	0	0	.	2
34	0	0	0	2	1000	66
38	0	0	0	2	110	25
45	0	0	0	0	1000	9
50	0	0	0	4	1000	8
57	0	0	0	6	35	24
64	0	0	0	1000	0	45
78	0	0	0	1	1000	23
87	0	0	0	3	350	16
93	0	0	0	3	2	3
98	0	0	0	2	0	32
107	0	0	0	3	0	27
114	0	0	0	59	12	8
121	0	0	0	2	0	9
133	0	0	0	9	0	100
142	0	0	0	110	1000	10
149	0	0	0	1000	200	52
158	1	0	0	35	31	2
167	0	0	0	7	1000	1
176	0	0	0	125	1000	110
183	.	0	0	17	2	4
190	.	0	0	38	7	8
197	.	0	0	16	6	60
207	.	.	.	25	12	62
212	.	0	0	6	0	54
222	.	.	.	1000	1000	1000
225	.	.	.	2	0	6
232	.	.	.	18	1	7
240	.	.	.	4	0	50
248	.	.	.	.	1	30
253	.	.	.	.	0	11
260	.	.	.	5	10	52
267	20	0	1	105	310	20
283	18	0	0	0	20	8
288	.	1	1	12	7	10
297	9	0	0	7	3	16
302	18	1	1	130	750	23
310	6	1	1	0	0	22
317	13	3	3	195	320	2
324	7	1	1	7	22	21
338	8	2	130	9	150	13
344	13	2	160	6	7	13
349	5	1	250	7	8	22

TABLE XXXIII

CHLORIDE (mg/l)

Date	Anderson Creek	Lowe Branch	Bowling Branch	Bills Branch	Green Branch	Indian Fork
7	.	4.25	.	3.90	.	.
15	.	4.35	.	4.05	.	4.85
22	4.30	4.15	.	3.85	.	4.90
27	4.35	4.20	3.85	4.15	.	4.80
34	4.55	4.45	4.05	3.75	4.75	4.65
38	3.75	4.30	3.40	4.10	4.50	4.80
45	4.00	3.95	3.90	3.90	4.85	4.90
50	4.15	4.25	4.20	4.20	4.70	5.10
57	4.60	4.30	4.25	4.05	4.95	4.85
64	4.20	4.35	4.20	3.90	5.20	4.70
78	4.15	4.45	4.30	3.80	5.00	4.90
87	4.30	4.55	4.15	4.30	4.80	5.00
93	4.55	3.55	4.20	4.00	4.85	5.10
98	4.35	4.20	4.35	4.45	5.00	4.95
107	4.10	4.50	4.25	3.95	4.75	5.05
114	4.30	4.50	4.00	3.80	5.00	4.95
121	4.35	4.55	3.80	4.05	4.55	5.00
133	5.00	4.50	4.60	3.50	5.10	5.15
142	4.40	4.40	4.05	3.75	4.65	4.90
149	4.30	4.35	4.55	4.10	4.30	4.95
158	5.25	4.50	3.90	4.60	4.95	4.80
167	4.35	4.55	4.00	3.80	4.90	4.50
176	4.45	3.60	4.50	3.70	4.90	4.75
183	.	4.20	4.20	4.25	4.95	4.80
190	.	4.25	5.20	3.60	5.70	4.95
197	.	3.80	4.80	5.30	5.20	5.00
207	.	.	.	4.20	4.85	4.90
212	.	3.95	4.60	3.90	5.10	4.75
222	.	.	.	4.25	5.00	5.05
225	.	.	.	3.95	5.10	5.00
232	.	4.10	.	4.05	4.80	4.85
240	.	.	.	3.85	4.85	4.80
248	.	.	.	4.00	6.10	4.05
253	.	.	.	3.90	4.05	6.20
260	.	.	.	4.20	5.15	3.45
267	4.10	4.35	4.30	4.35	4.25	4.20
283	4.35	2.90	4.65	3.80	3.05	2.95
288	.	3.84	4.20	3.05	6.15	4.00
297	3.85	4.05	3.90	4.25	4.35	4.20
302	2.85	3.30	4.15	2.95	3.00	2.95
310	.	.	.	.	.	.
317	.	.	.	.	.	.
324	.	.	.	.	.	.
338	.	.	.	.	.	.
344	.	.	.	.	.	.
349	.	.	.	.	.	.

TABLE XXXIV

SULFATE (mg/l)

Date	Anderson Creek	Lowe Branch	Bowling Branch	Bills Branch	Green Branch	Indian Fork
7	.	8	.	12	.	.
15	.	9	.	15	.	210
22	5	8	.	17	.	205
27	8	11	5	14	.	185
34	7	9	7	15	80	215
38	5	8	6	20	68	190
45	6	7	7	17	95	210
50	5	10	5	16	100	220
57	7	8	6	21	66	220
64	7	11	6	20	95	210
78	6	9	7	16	135	300
87	7	10	7	11	75	350
93	5	11	9	18	85	325
98	7	9	7	17	90	475
107	6	8	5	12	88	400
114	6	10	6	17	77	350
121	7	10	6	25	85	375
133	5	9	7	23	120	700
142	7	9	5	27	105	485
149	6	10	6	22	115	650
158	6	11	10	23	130	1000
167	7	10	2	29	140	300
176	5	7	8	24	140	275
183	.	11	9	31	175	650
190	.	11	9	38	175	400
197	.	10	7	29	160	700
207	.	.	.	27	165	900
212	.	12	6	36	205	800
222	.	.	.	58	195	350
225	.	.	.	29	200	1025
232	.	16	.	41	210	600
240	.	.	.	37	205	1050
248	.	.	.	30	220	1250
253	.	.	.	35	150	1100
260	.	.	.	39	105	500
267	8	11	4	42	205	190
283	5	5	2	24	210	320
288	.	3	3	35	210	500
297	7	2	0	26	150	460
302	4	6	3	28	155	330
310	5	4	0	5	150	420
317	0	10	8	14	45	160
324	6	0	6	32	100	300
333	8	13	9	32	57	260
344	12	11	10	33	140	280
349	7	7	10	33	125	220

TABLE XXXV

TOTAL IRON (mg/l)

Date	Anderson Creek	Lowe Branch	Bowling Branch	Bills Branch	Green Branch	Indian Fork
7	.	0.06	.	0.050	.	.
15	.	0.03	.	0.120	.	1.7
22	0.16	0.08	.	0.090	.	2.1
27	0.05	0.05	.	0.130	.	1.9
34	0.13	0.09	0.128	0.400	16.00	4.7
38	0.18	0.11	0.090	0.300	3.90	3.5
45	0.18	0.08	0.077	0.130	11.30	2.6
50	0.16	0.08	0.064	0.400	41.00	2.3
57	0.13	0.12	0.051	0.300	1.10	4.7
64	0.10	0.07	0.066	8.000	0.08	7.2
78	0.11	0.08	0.130	1.000	12.00	2.2
87	0.09	0.20	0.142	0.350	11.80	2.5
93	0.13	0.35	0.137	5.000	0.23	0.8
98	0.06	0.16	0.073	0.180	0.00	.
107	0.10	0.08	0.072	0.370	0.13	7.2
114	0.36	0.46	0.102	4.700	2.00	14.0
121	0.16	0.26	0.114	3.000	1.20	14.0
133	0.16	0.19	0.125	2.600	0.30	37.0
142	0.10	0.20	0.110	5.900	27.00	9.0
149	0.24	0.30	0.075	22.000	7.00	21.0
158	0.22	0.18	0.013	5.000	2.00	15.0
167	0.07	0.36	0.180	3.000	11.00	3.0
176	0.16	0.50	0.107	8.000	11.00	7.0
183	.	0.21	0.011	2.000	0.70	14.0
190	.	0.10	0.013	3.000	0.60	6.0
197	.	0.58	0.016	1.000	0.30	12.0
207	.	.	.	2.000	0.30	17.0
212	.	0.20	.	0.300	0.40	19.0
222	.	.	.	4.000	16.00	11.0
225	.	.	.	0.500	0.50	14.0
232	.	0.19	.	0.700	0.80	6.0
240	.	.	.	0.700	0.50	15.0
248	.	.	.	1.000	0.20	23.0
253	.	.	.	0.600	0.20	19.0
260	.	.	.	0.076	19.00	54.0
267	0.27	0.50	0.600	4.700	33.00	3.3
283	0.73	.	0.150	2.500	4.30	4.6
288	.	.	0.192	0.300	0.25	2.8
297	0.60	.	0.108	0.500	0.40	6.1
302	0.60	.	0.220	6.700	0.33	7.0
310	0.50	.	0.272	0.700	0.25	6.3
317	0.80	0.20	0.300	5.400	5.10	0.9
324	1.00	0.40	0.400	3.200	2.50	6.4
338	1.00	0.25	7.100	1.000	5.80	5.0
344	1.40	0.30	9.100	1.000	1.30	4.6
349	0.80	0.20	11.000	0.900	1.00	7.9

TABLE XXXVI

DISSOLVED IRON (mg/l)

Date	Anderson Creek	Lowe Branch	Bowling Branch	Bills Branch	Green Branch	Indian Fork
7	.	.	.	.	.	.
15	.	.	.	.	.	.
22	.	.	.	.	.	.
27	.	.	.	.	.	.
34	.	.	.	.	.	.
38	.	.	.	.	.	.
45	.	.	.	.	.	.
50	.	.	.	.	.	.
57	0.13	0.11	0.040	0.090	0.0000	1.700
64	0.12	0.10	0.040	0.110	0.0000	2.600
78	0.07	0.04	0.055	0.030	0.0000	0.000
87	0.05	0.05	0.026	0.090	0.0000	0.200
93	0.06	0.13	0.028	0.070	0.0500	0.000
98	0.12	0.13	0.038	0.050	0.0000	1.400
107	0.09	0.10	0.048	0.070	0.0000	1.000
114	0.09	0.04	0.024	0.060	0.0000	0.110
121	0.13	0.15	0.023	0.040	0.0000	0.120
133	0.08	0.04	0.011	0.040	0.0000	.
142	0.11	0.04	0.012	0.030	0.2100	.
149	0.06	0.07	.	0.030	0.0300	0.050
158	0.06	0.00	0.005	0.050	0.0500	0.380
167	0.03	0.07	0.047	0.050	0.0400	0.000
176	0.08	0.00	0.031	1.400	0.0400	0.000
183	.	0.00	0.007	0.020	0.0300	0.000
190	.	0.00	0.006	0.050	0.0300	0.000
197	.	0.03	0.002	0.040	0.1000	0.360
207	.	.	.	0.080	0.0500	6.000
212	.	0.00	.	0.050	0.0400	7.000
222	.	.	.	0.200	0.0500	0.130
225	.	.	.	0.060	0.0500	3.000
232	.	0.07	.	0.100	0.3500	0.320
240	.	.	.	0.050	0.2600	4.000
248	.	.	.	0.100	0.1100	0.700
253	.	.	.	0.100	0.0600	14.000
260	.	.	.	0.070	0.0038	0.046
267	0.25	0.20	0.200	0.200	0.2000	0.146
283	0.50	.	0.250	0.100	0.0085	2.000
288	.	.	0.034	0.100	0.2000	1.100
297	0.10	.	0.097	0.065	0.1000	0.105
302	0.10	.	0.080	0.087	0.1000	0.041
310	0.20	.	0.058	0.089	0.1000	0.089
317	0.25	0.20	0.250	0.200	0.1500	0.150
324	0.20	0.20	0.150	0.105	0.1000	0.061
338	0.25	0.20	0.400	0.100	0.1000	0.500
344	0.20	0.15	0.250	0.150	0.1000	0.300
349	0.20	0.15	0.300	0.091	0.2000	0.081

TABLE XXXVII

TOTAL MANGANESE (mg/l)

Date	Anderson Creek	Lowe Branch	Bowling Branch	Bills Branch	Green Branch	Indian Fork
7	.	.	.	.	.	.
15	.	.	.	.	.	0.25
22	.	.	.	.	.	0.75
27	.	.	.	.	.	0.68
34	.	.	0.010	.	0.32	0.13
38	.	.	0.005	.	0.04	0.67
45	.	.	0.003	.	0.11	0.68
50	.	.	0.002	.	0.61	0.69
57	.	.	0.003	.	0.03	0.88
64	.	.	0.002	.	0.02	1.27
78	.	.	0.010	1.76	0.15	0.84
87	.	.	0.013	.	0.16	0.75
93	.	.	0.006	0.51	0.00	0.63
98	.	.	0.002	.	0.00	1.30
107	.	.	0.004	.	0.14	1.36
114	.	.	0.007	0.08	0.21	1.19
121	.	.	0.012	0.10	0.18	1.29
133	.	.	0.014	0.06	0.19	1.74
142	.	.	0.007	0.11	1.00	1.10
149	.	.	0.007	0.78	0.43	1.90
158	.	.	0.009	0.24	0.31	2.10
167	.	0.02	0.011	0.09	0.57	0.50
176	0.09	.	0.010	0.16	0.57	0.70
183	.	0.07	0.004	0.13	0.30	1.70
190	.	0.00	0.008	0.10	0.27	1.10
197	.	0.06	0.010	0.07	0.27	1.90
207	.	.	.	0.08	0.21	2.40
212	.	.	.	0.05	0.44	2.70
222	.	.	.	0.18	0.80	1.10
225	.	.	.	0.08	0.51	2.80
232	.	.	.	0.08	0.49	1.80
240	.	.	.	0.09	0.56	2.90
248	.	.	.	0.16	0.59	3.70
253	.	.	.	0.11	0.60	3.30
260	.	.	.	0.40	1.00	2.40
267	.	.	.	0.05	0.80	0.70
283	0.05	.	.	0.09	0.80	0.80
288	.	.	.	0.05	0.30	1.30
297	.	.	.	0.08	0.20	1.00
302	.	.	.	0.20	1.00	0.80
310	.	.	.	0.09	0.20	0.70
317	.		.	0.06	0.10	0.05
324	.	.	.	0.15	0.30	0.80
338	.	.	0.120	0.06	0.30	0.70
344	.	.	0.220	0.05	0.30	0.80
349	.	.	0.700	0.06	0.30	0.80

TABLE XXXVIII

DISSOLVED MANGANESE (mg/l)

Date	Anderson Creek	Lowe Branch	Bowling Branch	Bills Branch	Green Branch	Indian Fork
7	.	.	.	.	.	.
15	.	.	.	.	.	.
22	.	.	.	.	.	.
27	.	.	.	.	.	.
34	.	.	.	.	.	.
38	.	.	.	.	.	.
45	.	.	.	.	.	.
50	.	.	.	.	.	.
57	.	.	0.003	.	0.13	0.87
64	.	.	0.003	.	0.16	1.35
78	.	.	0.003	.	0.27	0.82
87	.	.	0.003	.	0.17	0.94
93	.	.	0.003	.	0.06	0.91
98	.	.	0.002	.	0.25	1.42
107	.	.	0.003	.	0.18	1.38
114	.	.	0.003	.	0.15	1.07
121	.	.	0.002	.	0.14	1.25
133	.	.	0.001	.	0.17	1.69
142	.	.	0.002	.	0.02	0.80
149	.	.	0.004	.	0.22	1.70
158	.	.	0.003	.	0.22	2.00
167	.	.	0.004	.	0.00	0.50
176	.	.	0.001	.	0.02	0.10
183	.	.	0.004	.	0.28	1.60
190	.	.	0.005	.	0.23	1.00
197	.	.	0.007	.	0.25	1.80
207	.	.	.	.	0.00	2.30
212	.	.	.	.	0.42	2.60
222	.	.	.	.	0.00	0.40
225	.	.	.	.	0.46	2.70
232	.	.	.	.	0.18	1.40
240	.	.	.	.	0.52	2.70
248	.	.	.	.	0.46	3.60
253	.	.	.	.	0.59	3.20
260	.	.	.	0.02	0.02	0.06
267	.	.	.	0.02	0.20	0.60
283	.	.	.	0.02	0.02	0.90
288	.	.	.	0.05	0.30	1.20
297	.	.	.	0.05	0.20	0.90
302	.	.	.	0.02	0.30	0.80
310	.	.	.	0.05	0.20	0.70
317	.	.	.	0.09	0.25	0.40
324	.	.	.	0.02	0.25	0.80
338	.	.	.	0.02	0.30	0.60
344	.	.	.	0.02	0.30	0.80
349	.	.	.	0.02	0.30	0.80

TABLE XXXIX

TOTAL CALCIUM (mg/l)

Date	Anderson Creek	Lowe Branch	Bowling Branch	Bills Branch	Green Branch	Indian Fork
7	•	1.3	•	2.2	•	•
15	•	0.8	•	2.3	•	40
22	0.8	1.2	•	2.2	•	32
27	0.9	1.2	•	2.4	•	30
34	0.9	1.0	0.80	2.3	8.9	27
38	0.9	1.2	1.10	2.5	15.0	31
45	0.9	1.2	0.80	2.6	14.0	33
50	1.0	1.3	0.80	2.4	6.4	35
57	1.0	1.3	0.80	2.6	14.0	40
64	1.0	1.3	0.76	6.5	23.0	67
78	0.4	1.2	0.74	3.2	12.0	44
87	0.9	1.2	0.70	2.1	15.0	50
93	0.9	1.2	0.74	3.4	16.0	46
98	0.9	1.2	0.90	4.0	22.0	72
107	0.8	1.2	0.75	2.5	21.0	72
114	1.2	1.2	0.80	1.6	18.0	54
121	1.0	1.4	0.82	1.9	21.0	63
133	1.2	1.5	0.90	2.9	28.0	80
142	1.2	1.5	0.85	•	18.0	58
149	1.2	1.6	1.00	1.4	20.0	89
158	1.2	1.7	0.95	3.4	32.0	95
167	1.0	1.0	0.90	3.5	25.0	32
176	1.2	1.7	1.30	3.6	25.0	38
183	•	2.0	1.20	4.6	40.0	82
190	•	1.8	1.30	3.5	36.0	56
197	•	1.9	1.40	4.6	41.0	90
207	•	•	•	2.9	33.0	120
212	•	2.1	1.60	5.6	47.0	121
222	•	•	•	9.4	31.0	46
225	•	•	•	6.4	50.0	126
232	•	1.9	•	7.6	50.0	81
240	•	•	•	6.9	50.0	128
248	•	•	•	7.2	46.0	152
253	•	•	•	7.7	53.0	148
260	•	•	•	11.0	57.0	94
267	1.0	1.4	1.00	3.0	25.0	43
283	1.2	1.5	1.20	10.0	49.0	55
288	•	1.6	1.20	7.5	55.0	73
297	1.1	1.5	1.10	7.5	50.0	61
302	1.1	1.5	1.10	7.5	32.0	58
310	1.2	1.4	1.20	5.0	45.0	65
317	1.0	1.1	1.00	5.0	24.0	27
324	1.2	1.3	1.10	6.0	38.0	54
338	1.0	1.2	0.50	5.0	32.0	45
344	1.0	1.3	0.40	5.0	32.0	50
349	1.1	1.3	0.50	6.0	35.0	60

TABLE XL

DISSOLVED CALCIUM (mg/l)

Date	Anderson Creek	Lowe Branch	Bowling Branch	Bills Branch	Green Branch	Indian Fork
7	.	.	.	.	.	.
15	.	.	.	.	.	.
22	.	.	.	.	.	.
27	.	.	.	.	.	.
34	.	.	.	.	.	.
38	.	.	.	.	.	.
45	.	.	.	.	.	.
50	.	.	.	.	.	.
57	1.0	1.2	0.80	2.6	16.0	43
64	1.0	1.3	0.75	3.7	23.0	70
78	0.4	1.2	0.76	3.2	17.0	43
87	1.0	1.2	0.76	2.1	18.0	50
93	1.0	1.3	0.76	3.4	14.0	49
98	0.9	1.3	0.78	4.0	22.0	72
107	0.9	1.3	0.76	2.6	21.0	73
114	1.3	1.3	0.83	2.5	19.0	56
121	1.1	1.4	0.80	2.9	21.0	66
133	1.2	1.5	0.85	3.6	28.0	87
142	1.2	1.5	0.86	.	27.0	63
149	1.2	1.6	0.95	4.3	27.0	95
158	1.3	1.8	0.95	5.0	35.0	94
167	1.1	1.3	0.95	4.5	36.0	33
176	1.4	1.8	1.20	5.0	36.0	44
183	.	2.0	1.20	5.5	40.0	82
190	.	1.9	1.30	4.5	37.0	55
197	.	2.0	1.40	.	41.0	86
207	.	.	.	4.5	26.0	114
212	.	2.1	1.60	5.9	47.0	120
222	.	.	.	.	43.0	53
225	.	.	.	6.4	52.0	121
232	.	2.0	.	7.8	50.0	79
240	.	.	.	7.0	50.0	125
248	.	.	.	7.4	45.0	144
253	.	.	.	7.8	51.0	140
260	.	.	.	14.0	69.0	100
267	1.1	1.4	1.00	5.0	43.0	40
283	1.2	1.5	1.20	6.0	49.0	55
288	.	1.6	1.20	7.5	7.5	73
297	1.2	1.5	1.10	7.5	50.0	61
302	1.2	1.5	1.10	12.0	50.0	58
310	1.2	1.4	1.20	6.0	45.0	65
317	1.1	1.3	1.10	5.0	24.0	27
324	1.3	1.4	1.10	7.5	38.0	54
338	1.2	1.3	1.00	5.0	32.0	45
344	1.2	1.4	1.10	6.0	32.0	50
349	1.1	1.3	1.00	6.0	35.0	60

TABLE XLI

TOTAL MAGNESIUM (mg/l)

Date	Anderson Creek	Lowe Branch	Bowling Branch	Bills Branch	Green Branch	Indian Fork
7	.	1.1	.	1.4	.	.
15	.	0.4	.	1.5	.	18
22	0.8	1.0	.	1.3	.	15
27	0.8	1.0	.	1.4	.	14
34	0.8	0.8	1.0	1.4	6.1	12
38	0.8	1.0	0.5	1.4	8.0	13
45	0.8	1.0	1.0	1.4	7.7	14
50	0.8	1.1	1.0	1.5	5.0	15
57	0.8	1.1	1.0	1.4	6.5	17
64	0.8	1.1	1.0	5.0	12.0	26
78	1.1	1.2	0.9	2.0	8.4	19
87	0.9	1.2	0.9	1.4	9.5	21
93	0.9	1.3	0.9	2.8	9.3	14
98	1.0	1.3	1.0	2.3	12.0	31
107	0.9	1.3	1.1	1.6	12.0	31
114	1.3	1.4	1.1	2.1	11.0	24
121	1.1	1.5	1.2	2.2	12.0	28
133	1.1	1.6	1.1	2.5	15.0	38
142	1.1	1.5	1.2	2.9	16.0	26
149	1.2	1.7	1.4	5.3	16.0	39
158	1.2	1.7	1.4	3.9	13.0	42
167	1.0	1.4	1.3	3.3	18.0	14
176	1.5	1.9	1.6	4.2	18.0	18
183	.	2.0	1.6	4.1	21.0	37
190	.	1.8	1.6	3.4	19.0	24
197	.	2.1	1.7	3.8	19.0	40
207	.	.	.	2.8	15.0	50
212	.	2.1	1.8	4.2	21.0	54
222	.	.	.	7.5	18.0	21
225	.	.	.	4.6	23.0	54
232	.	2.0	.	6.0	23.0	36
240	.	.	.	5.0	22.0	56
248	.	.	.	5.1	22.0	66
253	.	.	.	5.4	23.0	66
260	.	.	.	10.0	20.0	50
267	1.3	1.7	1.1	5.7	19.0	16
283	1.5	2.0	1.8	6.5	19.0	22
288	.	2.0	1.8	7.5	23.0	35
297	1.3	.	1.2	.	.	20
302	1.4	1.7	1.2	9.5	19.0	18
310	1.3	1.7	1.2	6.5	18.5	20
317	1.1	1.3	1.0	4.0	18.5	13
324	1.3	1.5	1.1	7.5	18.0	18
338	1.3	1.4	1.5	5.5	16.0	16
344	1.3	1.4	1.5	6.0	16.0	17
349	1.2	1.4	2.5	5.7	15.0	18

TABLE XLII

DISSOLVED MAGNESIUM (mg/l)

Date	Anderson Creek	Lowe Branch	Bowling Branch	Bills Branch	Green Branch	Indian Fork
7	.	.	.	.	.	.
15	.	.	.	.	.	.
22	.	.	.	.	.	.
27	.	.	.	.	.	.
34	.	.	.	.	.	.
38	.	.	.	.	.	.
45	.	.	.	.	.	.
50	.	.	.	.	.	.
57	0.8	1.1	1.1	1.5	7.9	17
64	0.8	1.1	1.0	2.0	12.0	27
78	1.1	1.2	0.9	2.0	9.4	18
87	1.0	1.2	0.9	1.4	9.8	21
93	0.9	1.3	1.0	1.9	8.1	20
98	0.9	1.3	1.0	2.3	12.0	30
107	0.9	1.3	1.1	1.7	12.0	30
114	1.3	1.3	1.1	1.5	10.0	23
121	1.0	1.4	1.1	1.9	12.0	27
133	1.1	1.6	1.3	2.3	15.0	37
142	1.1	1.5	1.3	2.7	14.0	25
149	1.2	1.7	1.4	2.3	15.0	38
158	1.2	1.7	1.4	3.2	18.0	39
167	1.0	1.4	1.3	3.1	18.0	14
176	1.3	1.8	1.6	3.8	18.0	17
183	.	2.0	1.6	3.8	20.0	35
190	.	1.8	1.6	3.2	17.0	23
197	.	1.9	1.7	3.7	19.0	37
207	.	.	.	3.0	11.0	48
212	.	2.0	1.8	4.1	21.0	52
222	.	.	.	7.1	18.0	20
225	.	.	.	4.5	23.0	51
232	.	2.0	.	5.8	22.0	34
240	.	.	.	5.0	22.0	53
248	.	.	.	4.9	21.0	63
253	.	.	.	5.4	23.0	64
260	.	.	.	10.0	20.0	50
267	1.3	1.7	1.1	5.7	19.0	16
283	1.3	2.0	1.8	6.0	19.0	22
288	.	2.0	1.8	7.5	23.0	35
297	1.3	.	1.2	.	.	20
302	1.4	1.7	1.2	9.0	19.0	18
310	1.3	1.7	1.2	6.5	18.5	20
317	1.2	1.3	1.0	4.0	18.5	13
324	1.2	1.5	1.1	7.3	18.0	18
338	1.0	1.4	1.1	5.3	16.0	16
344	1.0	1.4	1.0	6.0	16.0	17
349	1.0	1.4	1.0	5.7	15.0	18

TABLE XLIII

TOTAL ALUMINUM (mg/l)

Date	Anderson Creek	Lowe Branch	Bowling Branch	Bills Branch	Green Branch	Indian Fork
7	.	.	.	.	.	.
15	.	.	.	.	.	.
22	.	.	.	.	.	.
27	.	.	.	.	.	.
34	.	.	0.525	.	.	.
38	.	.	0.330	.	.	.
45	.	.	0.315	.	.	.
50	.	.	0.280	.	.	.
57	.	.	0.320	.	.	.
64	.	.	0.250	.	.	.
78	.	.	0.365	.	54.0	1.5
87	.	.	0.375	.	13.5	.
93	.	.	0.690	.	1.0	.
98	.	.	0.410	0.0	.	0.7
107	.	.	0.360	0.0	.	0.9
114	.	.	0.670	.	2.7	1.0
121	.	.	0.690	6.5	2.0	.
133	.	.	0.640	7.0	1.5	2.6
142	.	.	0.540	11.0	52.0	1.0
149	.	.	0.480	23.6	12.0	.
158	.	.	0.400	5.5	5.0	0.8
167	.	.	0.730	5.0	130.0	1.5
176	.	.	0.660	16.0	24.0	9.2
183	.	.	.	4.0	.	1.3
190	.	.	.	9.5	4.9	1.8
197	.	.	.	3.4	2.0	.
207	.	.	.	5.5	1.3	0.6
212	.	.	.	.	2.3	1.1
222	.	.	.	16.6	53.0	20.0
225	.	.	.	17.0	1.0	0.8
232	.	.	.	4.5	1.0	0.8
240	.	.	.	1.2	.	.
248	.	.	.	0.9	.	.
253	.	.	.	0.0	.	.
260	.	.	.	22.0	23.5	.
267	.	.	.	5.7	50.0	.
283	.	.	.	3.1	8.0	.
288	.	.	.	0.0	.	.
297	.	.	.	0.8	.	.
302	.	.	.	6.6	40.0	.
310	.	.	.	0.6	.	.
317	.	.	.	6.5	4.5	.
324	.	.	.	2.3	3.5	.
338	.	.	.	1.1	11.5	.
344	.	.	.	.	2.0	.
349	.	.	.	1.1	1.3	.

TABLE XLIV

TOTAL CADMIUM (mg/l)

Date	Anderson Creek	Lowe Branch	Bowling Branch	Bills Branch	Green Branch	Indian Fork
7	.	0.0000	.	0.0000	.	.
15	.	0.0000	.	0.0000	.	0.0005
22	0.0000	0.0000	.	0.0000	.	0.0004
27	0.0000	0.0000	0.0000	0.0000	.	0.0005
34	0.0000	0.0000	0.0000	0.0000	0.0005	0.0003
38	0.0000	0.0000	0.0000	0.0000	0.0002	0.0002
45	0.0000	0.0000	0.0000	0.0000	.	0.0002
50	0.0000	0.0000	0.0000	0.0000	0.0018	0.0003
57	0.0000	0.0000	0.0000	0.0000	.	.
64	0.0001	0.0001	0.0000	0.0068	0.0001	0.0004
78	.	0.0000	0.0000	0.0001	0.0004	0.0002
87	0.0002	0.0001	0.0000	0.0002	0.0004	0.0003
93	0.0002	0.0018	0.0000	0.0043	0.0001	0.0004
98	0.0002	0.0001	0.0000	0.0002	0.0001	0.0005
107	0.0001	0.0001	0.0000	0.0005	0.0002	0.0004
114	0.0001	0.0000	0.0000	0.0006	0.0003	0.0005
121	0.0002	0.0001	0.0000	0.0005	0.0001	0.0004
133	0.0001	0.0001	0.0006	0.0009	0.0001	0.0007
142	0.0005	0.0002	0.0006	0.0009	0.0009	0.0008
149	0.0002	0.0001	0.0000	0.0007	0.0002	0.0007
158	0.0002	0.0002	0.0000	0.0015	0.0004	0.0006
167	0.0002	0.0001	0.0000	0.0003	0.0006	0.0006
176	0.0005	0.0002	0.0000	0.0003	0.0004	0.0004
183	.	0.0002	0.0000	0.0003	0.0002	0.0005
190	.	0.0001	0.0000	0.0006	0.0008	0.0004
197	.	0.0003	0.0000	0.0002	0.0001	0.0004
207	.	.	.	0.0003	0.0002	0.0005
212	.	0.0003	.	0.0002	0.0001	0.0005
222	.	.	.	0.0002	0.0005	0.0005
225	.	.	.	0.0001	0.0001	0.0007
232	.	0.0003	.	0.0001	0.0002	0.0006
240	.	.	.	0.0003	0.0001	0.0007
248	.	.	.	0.0002	0.0002	0.0010
253	.	.	.	0.0004	0.0002	0.0006
260	.	.	.	0.5200	0.0004	0.0006
267	0.0002	0.0003	.	0.4000	0.0004	0.0006
283	0.0004	0.0005	.	1.1800	0.0003	0.0004
288	.	0.0005	.	0.1900	0.0002	0.0006
297	0.0004	0.0004	.	0.4800	0.0002	0.0005
302	0.0002	0.0001	.	0.3000	0.0005	0.0005
310	.	0.0002	.	0.3700	.	.
317	.	0.0001	.	.	.	.
324	.	.	.	.	.	.
338	.	.	.	.	.	.
344	.	.	.	.	.	.
349	.	.	.	.	.	.

TABLE XLV

DISSOLVED CADMIUM (mg/l)

Date	Anderson Creek	Lowe Branch	Bowling Branch	Bills Branch	Green Branch	Indian Fork
7	.	.	.	.	.	.
15	.	.	.	.	.	.
22	.	.	.	.	.	.
27	.	.	.	.	.	.
34	.	.	.	.	.	.
38	.	.	.	.	.	.
45	.	.	.	.	.	.
50	.	.	.	.	.	.
57	0.0000	0.0000	0.0000	.	.	.
64	0.0001	0.0001	0.0000	0.0001	0.0001	0.0004
78	.	0.0001	0.0000	0.0001	0.0002	0.0001
87	0.0002	0.0002	0.0000	0.0001	0.0003	0.0003
93	0.0002	0.0001	0.0000	0.0003	0.0002	0.0003
98	0.0001	0.0008	0.0000	0.0004	0.0001	0.0007
107	0.0001	0.0001	0.0000	0.0003	0.0001	0.0003
114	0.0001	0.0001	0.0000	0.0005	0.0002	0.0003
121	0.0002	0.0001	0.0000	0.0005	0.0001	0.0002
133	0.0001	0.0001	0.0006	0.0003	0.0001	0.0008
142	0.0005	0.0003	0.0000	0.0004	0.0002	0.0004
149	0.0003	0.0016	0.0000	0.0001	0.0002	0.0009
158	0.0003	0.0003	0.0000	0.0003	0.0003	0.0014
167	0.0009	0.0039	0.0000	0.0002	0.0008	0.0007
176	0.0003	0.0001	0.0000	0.0002	0.0004	0.0005
183	.	0.0001	0.0000	0.0003	0.0003	0.0004
190	.	0.0004	0.0000	0.0001	0.0001	0.0004
197	.	0.0004	0.0000	0.0006	0.0002	0.0010
207	.	.	.	0.0008	0.0004	0.0005
212	.	0.0003	.	0.0002	0.0002	0.0004
222	.	.	.	0.0032	0.0002	0.0011
225	.	.	.	0.0002	0.0003	0.0002
232	.	0.0001	.	0.0002	0.0002	0.0014
240	.	.	.	0.0001	0.0003	0.0006
248	.	.	.	0.0003	0.0003	0.0014
253	.	.	.	0.0004	0.0003	0.0006
260	.	.	.	0.0046	0.0016	0.0005
267	0.0005	0.0009	.	0.0083	0.0004	0.0013
283	0.0032	0.0005	.	0.8000	0.0001	0.0007
288	.	0.0010	.	0.2600	0.0003	0.0060
297	.	0.0001	.	0.2700	0.0003	0.0003
302	0.0002	0.0001	.	0.2700	0.0002	0.0002
310	.	0.0001	.	.	.	.
317	.	0.0005	.	.	.	.
324	.	.	.	.	.	.
338	.	.	.	.	.	.
344	.	.	.	.	.	.
349	.	.	.	.	.	.

TABLE XLVI

TOTAL CHROMIUM (mg/1)

Date	Anderson Creek	Lowe Branch	Bowling Branch	Bills Branch	Green Branch	Indian Fork
7	.	0	.	0.0000	.	.
15	.	0	.	0.0000	.	0.0030
22	0.0000	0	.	0.0000	.	0.0012
27	0.0000	0	0.0000	0.0000	.	0.0008
34	0.0000	0	0.0000	0.0000	.	0.0104
33	0.0000	0	0.0000	0.0000	.	0.0035
45	0.0000	0	0.0000	0.0000	0.0114	0.0006
50	0.0000	0	0.0000	0.0000	0.1600	0.0012
57	0.0000	0	0.0000	0.0000	0.0104	0.0024
64	0.0000	0	0.0010	0.0000	0.8000	0.0004
78	0.0020	.	0.0020	.	.	.
87	0.0022	.	0.0020	0.0054	0.0590	.
93	0.0062	.	0.0020	0.8400	.	.
98	0.0016	.	0.0010	0.0110	.	.
107	0.0060	.	0.0010	0.0070	.	.
114	0.0017	.	0.0020	0.0250	.	.
121	.	.	0.0020	0.0270	.	.
133	.	.	0.0015	0.0130	.	.
142	.	.	0.0180	0.0650	.	.
149	.	.	0.0010	0.0750	.	.
158	.	.	0.0040	0.0140	.	.
167	.	.	0.0020	0.0036	.	.
176	.	.	0.0020	0.0170	.	.
183	.	.	0.0005	0.0065	.	.
190	.	.	0.0010	0.0100	.	.
197	.	.	0.0003	0.0040	.	.
207	.	.	.	0.0070	.	.
212	.	.	0.0010	0.0014	.	.
222	.	.	.	0.0170	.	.
225	.	.	.	0.0010	.	.
232	.	.	.	0.0030	.	.
240	.	.	.	0.0014	.	.
248	.	.	.	0.0038	.	.
253	.	.	.	0.0016	.	.
260	.	.	.	.	.	.
267	.	.	.	.	.	.
283	.	.	.	.	.	.
288	.	.	.	.	.	0.0000
297	.	.	.	.	.	.
302	.	.	.	.	.	.
310	.	.	.	.	.	.
317	.	.	.	.	.	.
324	.	.	.	.	.	.
333	.	.	.	.	.	.
344	.	.	.	.	.	.
349	.	.	.	.	.	.

TABLE XLVII

DISSOLVED CHROMIUM (mg/l)

Date	Anderson Creek	Lowe Branch	Bowling Branch	Bills Branch	Green Branch	Indian Fork
7	.	.	.	.	.	.
15	.	.	.	.	.	.
22	.	.	.	.	.	.
27	.	.	.	.	.	.
34	.	.	.	.	.	.
38	.	.	.	.	.	.
45	.	.	.	.	.	.
50	.	.	.	.	.	.
57	0.0000	0	0.0000	0.0000	0	0
64	0.0000	0	0.0000	0.0000	0	0
78	0.0000	.	0.0000	.	.	.
87	0.0000	.	0.0000	0.0000	0	.
93	0.0007	.	0.0000	0.0025	.	.
98	0.0000	.	0.0000	0.0000	.	.
107	0.0004	.	0.0000	0.0000	.	.
114	0.0000	.	0.0000	0.0000	.	.
121	.	.	0.0000	0.0000	.	.
133	.	.	0.0000	0.0000	.	.
142	.	.	0.0000	0.0000	.	.
149	.	.	0.0001	0.0000	.	.
158	.	.	0.0020	0.0015	.	.
167	.	.	0.0000	0.0000	.	.
176	.	.	0.0000	0.0000	.	.
183	.	.	0.0005	0.0000	.	.
190	.	.	0.0001	0.0000	.	.
197	.	.	0.0004	0.0000	.	.
207	.	.	.	0.0010	.	.
212	.	.	.	0.0010	.	.
222	.	.	.	0.0024	.	.
225	.	.	.	0.0000	.	.
232	.	.	.	0.0000	.	.
240	.	.	.	0.0000	.	.
248	.	.	.	0.0000	.	.
253	.	.	.	0.0000	.	.
260	.	.	.	.	.	.
267	.	.	.	.	.	.
283	.	.	.	.	.	.
288	.	.	.	.	.	.
297	.	.	.	.	.	.
302	.	.	.	.	.	.
310	.	.	.	.	.	.
317	.	.	.	.	.	.
324	.	.	.	.	.	.
338	.	.	.	.	.	.
344	.	.	.	.	.	.
349	.	.	.	.	.	.

TABLE XLVIII

TOTAL COPPER (mg/l)

Date	Anderson Creek	Lowe Branch	Bowling Branch	Bills Branch	Green Branch	Indian Fork
7	.	0.0000	.	0.0000	.	.
15	.	0.0000	.	0.0000	.	0.0020
22	0.0000	0.0000	.	0.0000	.	0.0030
27	0.0000	0.0000	0.000	0.0000	.	0.0010
34	0.0000	0.0000	0.000	0.0000	0.0060	0.0080
38	0.0000	0.0000	0.000	0.0000	0.0070	0.0040
45	0.0000	0.0000	0.000	0.0000	0.0170	0.0022
50	0.0000	0.0000	0.000	0.0000	0.0190	0.0020
57	0.0000	0.0000	0.000	0.0000	0.0040	0.0035
64	0.0019	0.0045	0.000	0.3232	0.0045	0.0147
78	0.0024	0.0040	0.000	0.0218	0.1700	0.0464
87	0.0036	0.0484	0.000	0.0078	0.0692	0.0214
93	0.0021	.	0.000	0.0137	0.0101	0.0101
98	0.0012	0.0100	0.000	0.0086	0.0008	0.0141
107	0.0007	0.0041	0.000	0.0092	0.0021	0.0081
114	0.0050	0.0074	0.000	0.0196	0.0077	0.0117
121	0.0048	0.0047	0.000	0.0232	0.0065	0.0187
133	0.0051	0.0065	0.000	0.0227	0.0041	0.0250
142	0.0053	0.0082	0.000	0.0580	0.1810	0.0183
149	0.0048	0.0055	0.000	0.1950	0.0125	0.0186
158	0.0074	0.0035	0.001	0.0376	0.0115	0.0095
167	0.0022	0.0029	0.000	0.0151	0.0664	0.0155
176	0.0154	0.0035	0.000	0.0356	0.0664	0.0544
183	.	0.0056	0.000	0.0151	0.0045	0.0137
190	.	0.0041	0.000	0.0219	0.0095	0.0195
197	.	0.0143	0.000	0.0120	0.0067	0.0099
207	.	.	.	0.0146	0.0095	0.0110
212	.	0.0101	0.000	0.0102	0.0084	0.0130
222	.	.	.	0.0424	0.0145	0.0245
225	.	.	.	0.0160	0.0093	0.0130
232	.	0.0053	.	0.0171	0.0084	0.0235
240	.	.	.	0.0130	0.0085	0.0172
243	.	.	.	0.0142	0.0058	0.0320
253	.	.	.	0.0085	0.0062	0.0135
260	.	.	.	0.0836	0.0103	0.0688
267	0.0149	0.0046	.	0.0352	0.1120	0.0196
283	0.0448	0.0026	.	0.0340	0.0128	0.0107
288	.	0.0039	.	0.0063	.	0.0080
297	0.0085	0.0020	.	0.0102	0.0040	0.0075
302	0.0055	0.0014	.	0.0388	0.1330	0.0125
310	0.0060	0.0021	.	0.0057	0.0076	0.0065
317	0.0067	0.0022	.	0.0276	0.0506	0.0140
324	0.0053	0.0030	.	0.0106	0.0130	0.0064
338	.	0.0041	.	0.0069	0.0212	.
344	.	0.0035	.	.	0.0096	.
349	.	0.0020	.	.	0.0075	.

TABLE XLIX

DISSOLVED COPPER (mg/1)

Date	Anderson Creek	Lowe Branch	Bowling Branch	Bills Branch	Green Branch	Indian Fork
7	.	.	.	.	.	.
15	.	.	.	.	.	.
22	.	.	.	.	.	.
27	.	.	.	.	.	.
34	.	.	.	.	.	.
38	.	.	.	.	.	.
45	.	.	.	.	.	.
50	.	.	.	.	.	.
57	0.0000	0.0000	0	0.0000	0.0000	0.0000
64	0.0038	0.0068	0	0.0108	0.0018	0.0100
78	0.0051	0.0052	0	0.0038	0.0072	0.0056
87	0.0034	0.0054	0	0.0024	0.0057	0.0027
93	0.0050	.	0	0.0167	0.0033	0.0040
98	0.0031	0.0070	0	0.0044	0.0039	0.0067
107	0.0021	0.0052	0	0.0054	0.0005	0.0028
114	0.0042	0.0055	0	0.0072	0.0031	0.0032
121	0.0054	0.0045	0	0.0059	0.0017	0.0037
133	0.0044	0.0055	0	0.0061	0.0020	0.0098
142	0.0054	0.0056	0	0.0064	0.0088	0.0035
149	0.0045	0.0193	0	0.0054	0.0073	0.0038
158	0.0072	0.0043	0	0.0064	0.0033	0.0060
167	0.0042	0.0051	0	0.0037	0.0061	0.0052
176	0.0045	0.0039	0	0.0082	0.0061	0.0130
183	.	0.0046	0	0.0053	0.0041	0.0040
190	.	0.0065	0	0.0045	0.0032	0.0077
197	.	0.0078	0	0.0069	0.0049	0.0092
207	.	.	.	0.0073	0.0055	0.0060
212	.	0.0054	0	0.0079	0.0084	0.0129
222	.	.	.	0.0135	0.0103	0.0155
225	.	.	.	0.0090	0.0082	0.0186
232	.	0.0029	.	0.0056	0.0058	0.0060
240	.	.	.	0.0050	0.0045	0.0340
248	.	.	.	0.0060	0.0062	0.0304
253	.	.	.	0.0038	0.0058	0.0120
260	.	.	.	0.0115	0.0073	0.0040
267	0.0072	0.0058	.	0.0112	0.0006	0.0065
283	0.0187	0.0042	.	0.0099	0.0055	0.0153
288	.	0.0057	.	0.0058	.	0.0110
297	.	0.0023	.	0.0053	0.0049	0.0063
302	0.0070	0.0030	.	0.0109	0.0093	0.0050
310	0.0082	0.0019	.	0.0058	0.0071	0.0130
317	0.0081	0.0060	.	0.0082	0.0127	0.0057
324	0.0085	0.0034	.	0.0045	0.0057	0.0048
338	.	0.0034	.	0.0066	0.0127	.
344	.	0.0032	.	.	0.0073	.
349	.	0.0031	.	.	0.0060	.

TABLE L

TOTAL LEAD (mg/1)

Date	Anderson Creek	Lowe Branch	Bowling Branch	Bills Branch	Green Branch	Indian Fork
7	.	0.00	.	0.000	.	.
15	.	0.00	.	0.000	.	0.000
22	0.000	0.00	.	0.000	.	0.000
27	0.000	0.00	0.0000	0.000	.	0.000
34	0.000	0.00	0.0000	0.000	0.050	0.000
38	0.000	0.00	0.0000	0.000	0.003	0.000
45	0.000	0.00	0.0000	0.000	0.010	0.000
50	0.000	0.00	0.0000	0.000	0.007	0.000
57	0.000	0.00	0.0000	0.000	0.000	0.000
64	0.000	0.00	0.0000	0.282	0.000	0.000
78	0.000	0.00	0.0000	0.000	0.028	0.000
87	0.000	0.00	0.0000	0.000	0.006	0.000
93	0.005	0.00	0.0000	0.246	0.000	0.000
98	0.000	0.00	0.0000	0.000	0.000	0.000
107	0.000	0.00	0.0000	0.000	0.000	0.000
114	0.001	0.00	0.0000	0.004	0.000	0.000
121	0.000	0.00	0.0000	0.002	0.000	0.000
133	0.000	0.00	0.0000	0.000	0.000	0.000
142	0.032	0.04	0.0570	0.040	0.055	0.013
149	0.000	0.00	0.0005	0.021	0.005	0.000
158	0.002	0.00	0.0025	0.008	0.000	0.000
167	0.002	0.00	0.0000	0.000	0.006	0.000
176	.	0.00	0.0000	0.005	0.006	.
183	.	.	.	.	.	.
190	.	.	.	.	.	.
197	.	.	.	.	.	.
207	.	.	.	.	.	.
212	.	.	.	.	.	.
222	.	.	.	.	.	.
225	.	.	.	.	.	.
232	.	.	.	.	.	.
240	.	.	.	.	.	.
248	.	.	.	.	.	.
253	.	.	.	.	.	.
260	.	.	.	.	.	.
267	.	.	.	.	.	.
283	.	.	.	.	.	.
288	.	.	.	.	.	.
297	.	.	.	.	.	.
302	.	.	.	.	.	.
310	.	.	.	.	.	.
317	.	.	.	.	.	.
324	.	.	.	.	.	.
338	.	.	.	.	.	.
344	.	.	.	.	.	.
349	.	.	.	.	.	.

TABLE LI

DISSOLVED LEAD (mg/l)

Date	Anderson Creek	Lowe Branch	Bowling Branch	Bills Branch	Green Branch	Indian Fork
7	.	.	.	.	.	.
15	.	.	.	.	.	.
22	.	.	.	.	.	.
27	.	.	.	.	.	.
34	.	.	.	.	.	.
38	.	.	.	.	.	.
45	.	.	.	.	.	.
50	.	.	.	.	.	.
57	0.000	0	0.0000	0.000	0	0
64	0.000	0	0.0000	0.000	0	0
78	0.000	0	0.0000	0.000	0	0
87	0.000	0	0.0000	0.000	0	0
93	0.000	0	0.0000	0.000	0	0
98	0.000	0	0.0000	0.000	0	0
107	0.000	0	0.0000	0.000	0	0
114	0.000	0	0.0000	0.000	0	0
121	0.000	0	0.0000	0.000	0	0
133	0.000	0	0.0000	0.000	0	0
142	0.000	0	0.0000	0.000	0	0
149	0.000	0	0.0000	0.000	0	0
158	0.002	0	0.0035	0.003	0	0
167	0.000	0	0.0000	0.000	0	0
176	.	0	0.0000	.	0	.
183	.	.	.	.	.	.
190	.	.	.	.	.	.
197	.	.	.	.	.	.
207	.	.	.	.	.	.
212	.	.	.	.	.	.
222	.	.	.	.	.	.
225	.	.	.	.	.	.
232	.	.	.	.	.	.
240	.	.	.	.	.	.
248	.	.	.	.	.	.
253	.	.	.	.	.	.
260	.	.	.	.	.	.
267	.	.	.	.	.	.
283	.	.	.	.	.	.
288	.	.	.	.	.	.
297	.	.	.	.	.	.
302	.	.	.	.	.	.
310	.	.	.	.	.	.
317	.	.	.	.	.	.
324	.	.	.	.	.	.
338	.	.	.	.	.	.
344	.	.	.	.	.	.
349	.	.	.	.	.	.

TABLE LII

TOTAL NICKEL (mg/l)

Date	Anderson Creek	Lowe Branch	Bowling Branch	Bills Branch	Green Branch	Indian Fork
7	.	0.000	.	0.000	.	.
15	.	0.000	.	0.000	.	0.044
22	0.000	0.000	.	0.000	.	0.046
27	0.000	0.000	.	0.000	.	0.042
34	0.003	0.000	0.0000	0.000	0.142	0.031
38	0.004	0.000	0.0000	0.000	0.028	0.031
45	0.000	0.006	0.0000	0.000	0.050	0.025
50	0.000	0.000	0.0000	0.000	0.200	0.024
57	0.000	0.000	0.0000	0.000	0.028	0.042
64	0.000	0.000	0.0000	0.000	0.000	0.062
78	0.000	0.000	0.0000	0.000	0.120	0.038
87	0.003	0.000	0.0000	0.006	0.046	0.026
93	0.000	0.000	0.0000	0.000	0.000	0.013
98	0.000	0.000	0.0000	0.000	0.012	0.049
107	0.000	0.000	0.0000	0.000	0.000	0.049
114	0.008	0.000	0.0000	0.013	0.012	0.038
121	0.000	0.025	0.0000	0.005	0.012	0.044
133	0.011	0.008	0.0045	0.019	0.009	0.110
142	0.000	0.000	0.0192	0.009	0.118	0.030
149	0.009	0.003	0.0000	0.000	0.028	0.065
158	.	0.006	0.0198	0.012	0.008	0.056
167	.	.	0.0000	0.014	.	0.000
176	.	.	0.0073	.	.	0.000
183	.	.	0.0000	0.015	.	0.044
190	.	.	0.0044	0.025	.	.
197	.	.	.	0.000	.	.
207	.	.	.	0.016	.	.
212	.	.	.	0.000	.	.
222	.	.	.	0.050	.	.
225	.	.	.	0.005	.	.
232	.	.	.	0.010	.	.
240	.	.	.	0.000	.	.
248	.	.	.	.	.	.
253	.	.	.	.	.	.
260	.	.	.	.	.	.
267	.	.	.	.	.	.
283	.	.	.	.	.	.
288	.	.	.	.	.	.
297	.	.	.	.	.	.
302	.	.	.	.	.	.
310	.	.	.	.	.	.
317	.	.	.	.	.	.
324	.	.	.	.	.	.
338	.	.	.	.	.	.
344	.	.	.	.	.	.
349	.	.	.	.	.	.

TABLE LIII

DISSOLVED NICKEL (mg/l)

Date	Anderson Creek	Lowe Branch	Bowling Branch	Bills Branch	Green Branch	Indian Fork
7	.	.	.	.	.	.
15	.	.	.	.	.	.
22	.	.	.	.	.	.
27	.	.	.	.	.	.
34	.	.	.	.	.	.
38	.	.	.	.	.	.
45	.	.	.	.	.	.
50	.	.	.	.	.	.
57	0	0.000	0	0.000	0.006	0.036
64	0	0.000	0	0.000	0.000	0.055
78	0	0.000	0	0.000	0.000	0.049
87	0	0.000	0	0.000	0.012	0.038
93	0	0.000	0	0.000	0.000	0.034
98	0	0.000	0	0.000	0.000	0.060
107	0	0.000	0	0.000	0.000	0.046
114	0	0.000	0	0.000	0.006	0.026
121	0	0.012	0	0.000	0.004	0.034
133	0	0.000	0	0.000	0.000	0.046
142	0	0.000	0	0.000	0.000	0.000
149	0	0.007	0	0.003	0.000	0.046
158	.	0.005	0	0.000	0.000	0.044
167	.	.	0	0.000	.	0.000
176	.	.	0	.	.	0.000
183	.	.	0	0.000	.	0.076
190	.	.	0	0.000	.	.
197	.	.	.	0.000	.	.
207	.	.	.	0.000	.	.
212	.	.	.	0.000	.	.
222	.	.	.	0.005	.	.
225	.	.	.	0.000	.	.
232	.	.	.	0.000	.	.
240	.	.	.	0.000	.	.
248	.	.	.	.	.	.
253	.	.	.	.	.	.
260	.	.	.	.	.	.
267	.	.	.	.	.	.
283	.	.	.	.	.	.
288	.	.	.	.	.	.
297	.	.	.	.	.	.
302	.	.	.	.	.	.
310	.	.	.	.	.	.
317	.	.	.	.	.	.
324	.	.	.	.	.	.
338	.	.	.	.	.	.
344	.	.	.	.	.	.
349	.	.	.	.	.	.

TABLE LIV

TOTAL ZINC (mg/l)

Date	Anderson Creek	Lowe Branch	Bowling Branch	Bills Branch	Green Branch	Indian Fork
1	.	.	.	.	.	.
15	.	.	.	.	.	0.020
22	0.0035	.	.	.	.	0.010
27	0.0015	.	.	.	.	0.008
34	0.0080	.	0.0032	0.006	0.160	0.030
38	0.0060	.	0.0002	.	0.020	0.020
45	0.0080	.	0.0038	.	0.050	0.010
50	0.0110	.	0.0002	.	0.500	0.020
57	0.0071	.	0.0002	.	0.012	0.040
64	0.0026	.	0.0001	.	.	0.070
78	0.0042	.	0.0007	0.006	0.130	0.030
87	0.0070	0.0012	0.0006	0.004	0.125	0.030
93	0.0320	.	0.0012	.	.	0.010
98	0.0035	.	0.0002	.	.	0.090
107	0.0050	.	0.0005	.	0.010	0.060
114	0.0022	.	0.0004	0.030	0.010	0.060
121	0.0060	.	0.0024	0.020	0.010	0.070
133	0.0055	.	0.0018	0.020	0.006	0.130
142	0.0220	0.0180	0.0106	0.050	0.210	0.070
149	0.0095	.	0.0002	0.120	0.050	0.100
158	0.0140	.	0.0017	0.030	0.020	0.080
167	0.0032	.	0.0007	0.010	0.080	0.020
176	0.0360	.	0.0002	0.040	0.080	0.050
183	.	.	0.0008	0.010	0.008	0.060
190	.	.	0.0015	0.020	0.010	0.040
197	.	0.0050	0.0054	0.012	0.010	0.060
207	.	.	.	0.017	0.010	0.080
212	.	.	.	0.008	0.010	0.090
222	.	.	.	0.040	0.150	0.070
225	.	.	.	.	0.008	0.080
232	.	.	.	0.010	0.008	0.040
240	.	.	.	0.009	0.004	0.080
248	.	.	.	0.010	0.004	0.110
253	.	.	.	.	0.004	0.100
260	.	.	.	0.070	0.080	0.080
267	.	.	.	.	.	.
283	.	.	.	.	.	.
288	.	.	.	.	.	.
297	.	.	.	.	.	.
302	.	.	.	.	.	.
310	.	.	.	.	.	.
317	.	.	.	.	.	.
324	.	.	.	.	.	.
336	.	.	.	.	.	.
344	.	.	.	.	.	.
349	.	.	.	.	.	.

TABLE LV

DISSOLVED ZINC (mg/l)

Date	Anderson Creek	Lowe Branch	Bowling Branch	Bills Branch	Green Branch	Indian Fork
7	.	.	.	.	.	.
15	.	.	.	.	.	.
22	.	.	.	.	.	.
27	.	.	.	.	.	.
34	.	.	.	.	.	.
38	.	.	.	.	.	.
45	.	.	.	.	.	.
50	.	.	.	.	.	.
57	0.0120	.	0.0004	.	.	0.040
64	0.0050	.	0.0001	.	.	0.050
78	0.0045	.	0.0010	.	.	0.007
87	0.0036	0.0005	0.0003	0.0002	0.0008	0.020
93	0.0250	.	0.0001	.	.	0.030
98	0.0045	.	0.0001	.	.	0.070
107	0.0020	.	0.0003	.	.	0.050
114	0.0060	.	0.0003	.	.	0.020
121	0.0038	.	0.0002	.	.	0.030
133	0.0055	.	0.0007	.	.	0.070
142	0.0100	.	0.0001	.	.	0.005
149	0.0095	.	0.0006	.	.	0.040
158	0.0075	.	0.0012	.	0.0100	0.050
167	0.0062	.	0.0002	.	.	0.008
176	0.0065	.	0.0016	.	.	0.008
183	.	.	0.0008	.	.	0.020
190	.	.	0.0003	.	.	0.010
197	.	.	0.0008	.	.	0.040
207	.	.	.	.	.	0.060
212	.	.	.	.	.	0.070
222	.	.	.	.	.	0.010
225	.	.	.	.	.	0.070
232	.	.	.	.	.	0.010
240	.	.	.	.	.	0.070
248	.	.	.	.	.	0.100
253	.	.	.	.	.	0.090
260	.	.	.	.	.	.
267	.	.	.	.	.	.
283	.	.	.	.	.	.
288	.	.	.	.	.	.
297	.	.	.	.	.	.
302	.	.	.	.	.	.
310	.	.	.	.	.	.
317	.	.	.	.	.	.
324	.	.	.	.	.	.
338	.	.	.	.	.	.
344	.	.	.	.	.	.
349	.	.	.	.	.	.

TABLE LVI

TOTAL COBALT (mg/l)

Date	Anderson Creek	Lowe Branch	Bowling Branch	Bills Branch	Green Branch	Indian Fork
7	.	0	.	0	.	.
15	.	0	.	0	.	0.017
22	0	0	.	0	.	0.016
27	0	0	0	0	.	0.011
34	0	0	0	0	.	0.018
38	0	0	0	0	0.025	0.014
45	0	0	0	0	0.050	0.012
50	0	0	0	0	.	0.013
57	.	.	0	.	.	.
64	.	.	0	.	.	.
78	.	.	0	.	.	.
87	0	0	0	0	0.046	0.047
93	.	.	0	.	.	.
98	.	.	0	.	.	.
107	.	.	0	.	.	.
114	.	.	0	.	.	.
121	.	.	0	.	.	.
133	.	.	0	.	.	.
142	.	.	0	.	.	.
149	.	.	0	.	.	.
158	.	.	0	.	.	.
167	.	.	0	.	.	.
176	.	.	0	.	.	.
183	.	.	0	.	.	.
190	.	.	0	.	.	.
197	.	.	0	.	.	.
207	.	.	.	.	.	.
212	.	.	.	.	.	.
222	.	.	.	.	.	.
225	.	.	.	.	.	.
232	.	.	.	.	.	.
240	.	.	.	.	.	.
248	.	.	.	.	.	.
253	.	.	.	.	.	.
260	.	.	.	.	.	.
267	.	.	.	.	.	.
283	.	.	.	.	.	.
288	.	.	.	.	.	.
297	.	.	.	.	.	.
302	.	.	.	.	.	.
310	.	.	.	.	.	.
317	.	.	.	.	.	.
324	.	.	.	.	.	.
338	.	.	.	.	.	.
344	.	.	.	.	.	.
349	.	.	.	.	.	.

TABLE LVII

DISSOLVED COBALT (mg/l)

Date	Anderson Creek	Lowe Branch	Bowling Branch	Bills Branch	Green Branch	Indian Fork
7	.	.	.	.	.	.
15	.	.	.	.	.	.
22	.	.	.	.	.	.
27	.	.	.	.	.	.
34	.	.	.	.	.	.
38	.	.	.	.	.	.
45	.	.	.	.	.	.
50	.	.	.	.	.	.
57	.	.	0	.	.	.
64	.	.	0	.	0	.
78	.	.	0	.	.	.
87	0	0	0	0	0	0.038
93	.	.	0	.	.	.
98	.	.	0	.	.	.
107	.	.	0	.	.	.
114	.	.	0	.	.	.
121	.	.	0	.	.	.
133	.	.	0	.	.	.
142	.	.	0	.	.	.
149	.	.	0	.	.	.
158	.	.	0	.	.	.
167	.	.	0	.	.	.
176	.	.	0	.	.	.
183	.	.	0	.	.	.
190	.	.	0	.	.	.
197	.	.	0	.	.	.
207	.	.	.	.	.	.
212	.	.	.	.	.	.
222	.	.	.	.	.	.
225	.	.	.	.	.	.
232	.	.	.	.	.	.
240	.	.	.	.	.	.
248	.	.	.	.	.	.
253	.	.	.	.	.	.
260	.	.	.	.	.	.
267	.	.	.	.	.	.
283	.	.	.	.	.	.
288	.	.	.	.	.	.
297	.	.	.	.	.	.
302	.	.	.	.	.	.
310	.	.	.	.	.	.
317	.	.	.	.	.	.
324	.	.	.	.	.	.
338	.	.	.	.	.	.
344	.	.	.	.	.	.
349	.	.	.	.	.	.

TABLE LVIII

WATER TEMPERATURE (°C)

Date	Anderson Creek	Lowe Branch	Bowling Branch	Bills Branch	Green Branch	Indian Fork
7	.	.	.	.	.	.
15	.	4.0	.	3.5	.	4.0
22	6.0	6.5	.	5.5	.	6.5
27	7.2	7.8	6.5	6.5	.	6.0
34	8.0	8.0	7.5	8.0	8.2	7.0
38	5.1	6.0	5.0	3.8	4.2	4.0
45	7.0	7.2	6.6	6.2	7.8	7.2
50	7.4	5.5	7.2	6.9	6.5	6.2
57	6.0	6.9	6.0	6.3	7.0	7.2
64	5.4	6.5	5.3	6.0	19.5	10.5
78	8.0	8.5	8.0	7.5	8.0	8.2
87	11.8	12.5	13.2	13.0	15.0	14.8
93	7.8	8.3	9.5	8.2	9.3	9.0
98	8.7	9.0	9.0	8.6	9.3	9.4
107	12.1	12.0	12.4	13.0	13.8	16.4
114	15.2	15.0	15.0	15.4	16.1	15.4
121	16.0	15.4	17.0	16.1	18.1	18.4
133	15.2	15.9	17.9	18.4	18.0	18.5
142	17.8	18.2	19.0	20.0	20.5	21.6
149	18.2	18.8	19.1	18.0	19.7	20.1
158	18.5	19.4	23.6	21.9	21.7	22.0
167	20.1	21.3	21.0	21.5	22.1	21.8
176	21.0	22.4	22.1	21.4	22.1	21.5
183	.	21.0	22.8	23.0	22.9	22.2
190	.	22.1	26.4	21.4	23.0	22.3
197	.	20.8	22.0	21.6	22.0	22.1
207	.	.	.	21.4	21.6	21.6
212	.	21.0	21.3	22.8	21.9	21.2
222	.	.	.	20.2	20.8	20.1
225	.	.	.	22.9	22.1	21.6
232	.	22.4	.	23.4	22.3	22.1
240	.	.	.	24.4	24.0	24.2
248	.	.	.	22.9	22.9	22.0
253	.	.	.	17.2	18.7	19.4
260	.	.	.	16.1	16.0	15.6
267	15.6	15.0	15.5	15.0	4.8	15.0
283	15.0	15.1	17.8	16.0	16.0	15.5
288	.	16.2	16.2	17.4	17.9	18.0
297	13.8	15.0	11.8	13.5	13.8	12.2
302	15.0	14.9	14.3	14.9	15.2	15.0
310	14.8	14.8	13.8	14.2	14.1	18.7
317	9.4	9.6	9.8	7.5	7.5	7.7
324	11.4	10.9	10.4	11.4	11.4	11.5
338	7.5	7.0	6.7	7.1	7.7	6.1
344	2.2	5.8	5.3	4.6	4.3	3.7
349	11.2	11.1	10.8	11.0	11.7	11.0

TABLE LIX

STREAMFLOW (cfs)

Date	Anderson Creek	Lowe Branch	Bowling Branch	Bills Branch	Green Branch	Indian Fork
7	.	.	.	.	.	.
15	.	.	.	.	.	8.20
22	.	.	.	.	.	6.20
27	.	.	.	.	.	7.40
34	.	.	.	7.40	.	16.00
38	.	.	.	5.60	.	12.00
45	.	.	.	5.00	.	.
50	.	.	.	.	.	4.90
57	.	.	.	3.60	.	4.40
64	.	.	.	0.85	.	1.60
78	.	.	.	.	.	34.00
87	.	.	.	1.70	.	11.00
93	.	.	.	1.50	.	11.00
98	.	.	.	0.76	.	5.90
107	.	.	.	.	.	5.30
114	.	.	.	0.99	.	7.70
121	.	0.98	.	0.65	.	6.10
133	.	0.31	.	0.36	.	2.80
142	.	0.79	.	.	.	.
149	.	0.60	.	.	.	.
158	.	0.16	.	.	.	.
167	.	0.39	.	.	.	23.00
176	.	0.03	.	.	.	12.00
183	.	0.02	.	0.62	.	3.70
190	.	0.09	.	0.90	.	6.10
197	.	0.01	.	0.27	.	2.60
207	.	.	.	0.07	.	1.90
212	.	0.03	.	0.09	.	1.90
222	.	.	.	0.42	.	8.40
225	.	.	.	0.05	.	1.30
232	.	0.11	.	0.17	.	.
240	.	.	.	0.04	.	.
248	.	.	.	0.02	.	0.76
253	.	.	.	0.02	.	0.80
260	.	.	.	0.36	.	4.60
267	.	1.90	.	5.00	.	.
283	.	0.18	.	0.71	.	.
288	.	0.04	.	0.46	.	1.80
297	.	0.16	.	0.39	.	.
302	.	0.25	.	0.66	.	.
310	.	0.15	.	0.29	.	.
317	.	8.50	.	7.90	.	.
324	.	0.78	.	2.70	.	.
338	.	1.20	.	1.40	.	14.00
344	.	1.10	.	1.30	.	13.00
349	.	0.90	.	1.60	.	17.00

VITA

Donald Eugene Dunning, Jr. was born in Cairo, Illinois, on February 26, 1954. He later moved to Oak Ridge, Tennessee, and graduated from Oak Ridge High School in 1972. He entered the University of Tennessee in June 1972, and in December 1974 received a Bachelor of Arts degree in biology. The following January he began graduate study in environmental engineering, as a graduate research assistant. He received the Master of Science degree from that program in March 1977. He has been employed as an environmental consultant at Oak Ridge National Laboratory since March 1976.