3-1986

Water quality in mined and unmined watersheds in East Tennessee

Charles W. Becker

To the Graduate Council:

I am submitting herewith a thesis written by Charles W. Becker entitled "Water quality in mined and unmined watersheds in East Tennessee." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Forestry.

Frank W. Woods, Major Professor

We have read this thesis and recommend its acceptance:

Garland Wells, Cliff Amundsen

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

168
80

To the Graduate Council:

I am submitting herewith a thesis written by Charles W. Becker entitled "Water Quality in Mined and Unmined Watersheds in East Tennessee." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fullfillment of the requirements for the degree of Master of Science, with a major in Forestry.

Frank W. Woods

Frank W. Woods, Major Professor

We have read this thesis
and recommend its acceptance:

Clifford C. Amundsen

G. R. Wells

Accepted for the Council:

C W Minkel

Vice Provost
and Dean of The Graduate School

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of te requirements for a Master's degree at The University of Tennessee, Knoxville, I agree that the Library shall make it available to borrowers under rules of the Library. Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of the source is made.

Permission for extensive quotation from or reproduction of this thesis may be granted by my major professor, or in his absence, by the Head of Interlibrary Services when, in the opinion of either, the proposed use of the material is for scholarly purposes. Any copying or use of the material in this thesis for financial gain shall not be allowed without my written permission.

Signature Charles W. Becker

Date March 19, 1986

WATER QUALITY IN MINED AND UNMINED WATERSHEDS IN EAST TENNESSEE

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Charles W. Becker

June 1986

ACKNOWLEDGEMENTS

The assistance and support of many people were necessary for the completion of this thesis and I wish to thank the following for their contributions. Dr. Frank Woods, my major professor, for his guidance and support during all phases of my work. Dr. Garland Wells and Dr. Cliff Amundsen for serving on my committee and reviewing my work. Gene Johnston for his assistance with the field work and data collection. Northeastern Forest Experiment Station in Berea, Kentucky for their physical, technical and financial help. Dr. William Sanders for his help with the statistical analyses of the data. The many graduate students and faculty within the Department of Forestry, Wildlife and Fisheries for their help and constant encouragement. And finally, to my family for their love, support and contiuous faith in me.

ABSTRACT

In late 1980 and early 1981 a stream flow monitering station was installed on each of six small watersheds to evaluate the effects of surface mining on water quality. Three of the watersheds were in the Cumberland Mountains and three were on the Cumberland Plateau of east Tennessee. Both geographic regions had a recently mined, old mined and unmined watershed. Stream flow and concentration levels for 12 water quality parameters, collected every four weeks from 1981 through 1984, were evaluated. Geology, soils and land cover data were also studied.

Analyses were made to determine sesonality of stream water quality, differences due to watershed conditions and changes in stream water quality over the study period. Results showed that there were seasonal variations in water quality and that flow rates were associated with these differences. Significant differences in water quality were found between newly mined and unmined watersheds, with newly mined watersheds generally having higher levels of minerals and greater turbidity. Differences were also found between old mined and unmined watersheds. The Cumberland Mountains unmined watershed had greater concentrations than the old mined one for most of the constituents tested, especially total dissolved solids, lead, magnesium, sodium and calcium. This was apparently due to a road running through the unmined watershed. The two newly mined watersheds showed a significant change in water quality over the study period; the plateau one decreased in stream concentration levels, where as the mountain watershed levels increased. Two other watersheds showed only marginal changes in water quality.

Stream water quality, as defined by EPA, was adversely affected by surface mining. Age of the mined area was associated with water quality, the older the mined area the better the water quality.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

FIGURE		PAGE

CHAPTER 1

INTRODUCTION AND OBJECTIVES

The practice of surface mining began about 1800 in the United States. The first operations were very small and consisted of manual removal of exposed or thinly covered coal deposits. Later, draft animals were used to remove the overlying materials on deeper coal beds, generally with limited environmental impact (Matlick 1965).

The development of steam and internal combustion engines allowed for the design and construction of mining machinery which could remove large volumes and great depths of soil and rock. After World War II, machines capable of removing entire mountaintops were developed and the environmental impact of mining often became severe. Entire drainages were altered and unreclaimed lands were left barren, unstable and highly prone to surface erosion and mass movement. The exposed spoil materials were sometimes highly toxic and as they weathered, rain leached out many of the harmful elements, causing water contamination. Thousands of miles of streams in the Appalachian region have been affected in this manner (Seitz 1981).

By 1950, the increased visibility of watershed damage from surface mining prompted the establishment of monitoring stations, for collection of water samples and measurement of flow rates (Dyer 1982). Most of the early stations were on large watersheds supporting a wide variety of land uses, making it very difficult to attribute water problems specifically to surface mining. In this study, monitoring stations were established on small watershed streams in an effort to minimize this problem.

This study had two objectives. The first was to compare unmined, old mined and newly mined watersheds in two geographical regions to determine if there were differences in their water quality, based on EPA national drinking water standards. The second was to determine if there were changes in stream water quality on the study areas over a four year period.

CHAPTER 2

METHODS AND MATERIALS

Watershed Criteria

In late 1980 and early 1981, a stream flow monitoring station was installed at the mouth of each of six watersheds in the coal regions of eastern Tennessee. Each site selected represented an "old mined", "newly mined" or "unmined condition". The criteria used for this selection were the same as that used in an earlier project (Dyer 1982), from which this study evolved. Generally, all of the watersheds chosen were to be between 50 and 250 acres in size and contain a perennial, first-order stream. Specifically, criteria for the three watershed conditions were as followed.

Unmined Watersheds

These watersheds were to be unmined, with no roads or cuts that exposed bare ground, and were not to have been farmed, disturbed or developed in any way. Old revegetated logging roads and skid trails were allowed. Completely forested watersheds were selected if at all possible, but some with a mixture of grassland or pasture were used when necessary. The unmined areas were to be similar in aspect and located as close as possible to the mined watersheds.

Old Mined Watersheds

These watersheds should have had 10 to 100 percent of their area disturbed by surface mining before January 1972 (Tennessee Surface Mining Law was enacted in 1972), with no surface mining or reclamation occurring after that date. When possible, watersheds were selected where only one seam of coal had been mined.

Newly Mined Watersheds

These watersheds were to have had no mining until after January 1972. From 10 to 100 percent of the area was to be disturbed by surface mining and active mines were permitted. Old mines that were worked before 1972 were also permitted, provided that all areas previously mined were reworked after January 1972. When possible, watersheds with only one coal seam or those that had only one seam mined were to be selected.

Site selection and verification was conducted by the Northeastern Forest Experiment Station in Berea, Kentucky through interviews with local residents, checking public records, reports and use of aerial photos. The watersheds were then identified and marked on USGS Seven and one-half minute topographic maps. The name given to each site was that of the closest community or stream to the study area.

Monitoring Equipment Used

A trapezoidal venturi flume stream flow gauge with stilling well was constructed by the Northeastern Forest Experiment Station of Berea, KY at the mouth of each of the six watersheds (Figure 1). Where possible, the flume was constructed on bedrock. Depth of flow in the flume was converted to stream discharge rate, in cubic feet per second, using a conversion table from the Rocky Mountain Forest and Range Experiment

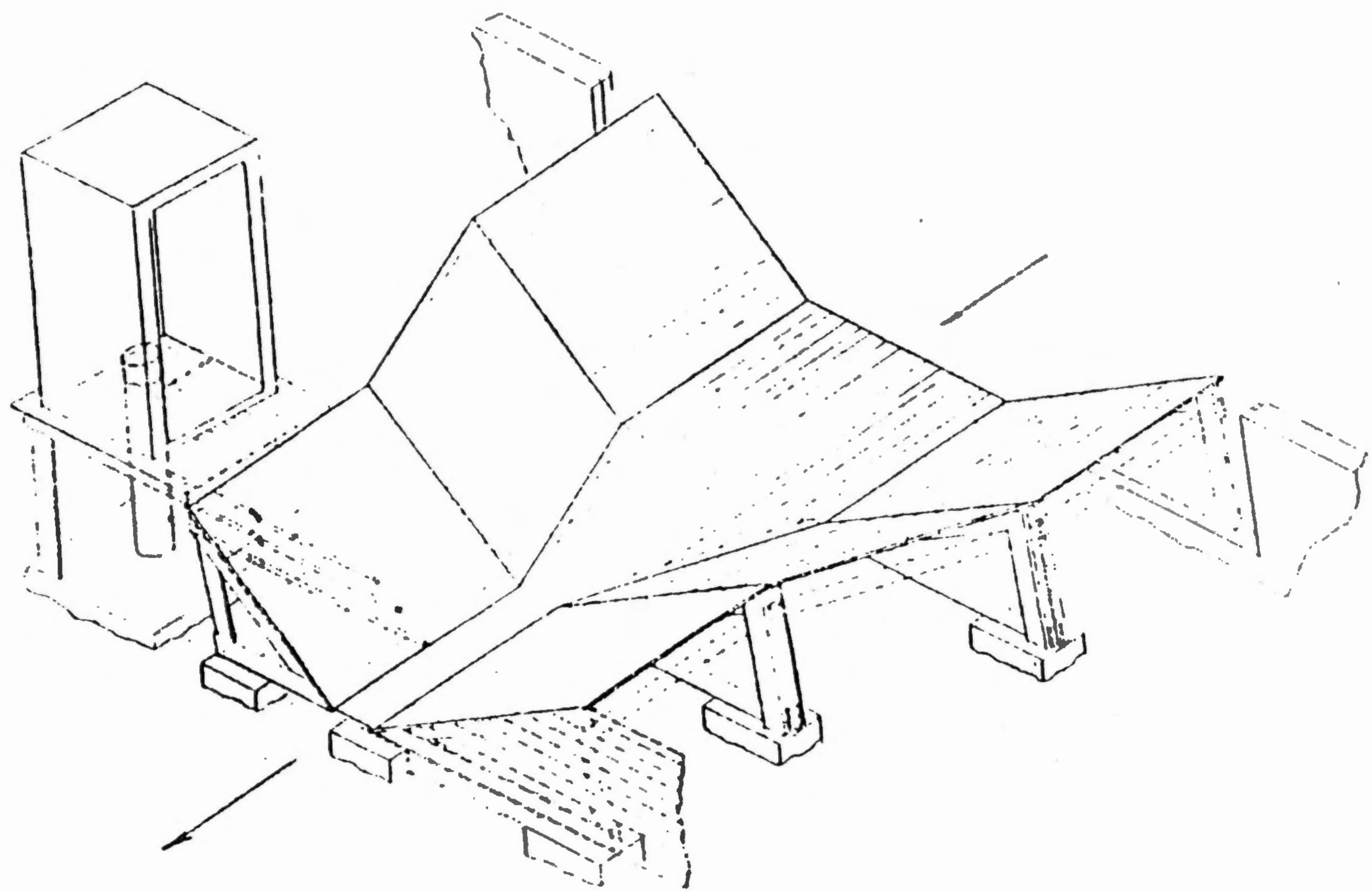


Figure 1. Trapizoidal venturi flume with stilling well (from US Northeast Forest Experiment Station, Berea, KY).

Station, Flagstaff, AZ. Water level (stage) was measured by using a float in the stilling well which was connected to a battery powered Model 7000 Series Stevens Digital Recorder. Water stage was recorded at five or ten minute intervals on punched paper strip charts. Water level recording equipment was housed in a fiberglass shelter with a solar panel mounted on top to recharge the recorder battery.

Servicing Equipment and Collecting Water Samples

After all equipment was operational, each site was visited approximately every four weeks. Gauges and recorders were checked and adjustments were made if they were not functioning correctly. Information on each of the sites were collected on field data sheets. The strip charts were also checked and replaced as needed.

Water samples were collected at each site during the visit, but only if water was flowing through the flume. Four samples were collected at each site: two unfiltered, one filtered and one filtered-acidified. Two samples were filtered with a type HA Millipore filter, one of which was acidified with 50 percent nitric acid. Data on stream and air temperature, weather conditions, stream water condition and time of sampling were also collected. After all sites were visited, the water samples, charts and data sheets were sent to the Northeastern Forest Experiment Sation in Berea, Kentucky, for processing.

Water samples were analyzed for 33 elements and properties. Procedures used follow Dyer (1982). All data were compiled and stored at the offices of the U.S. Forest Service at Berea, Kentucky.

In 1985, addition reclamation work was performed on the newly mined

Davis Creek watershed. This work allowed easy acess to the stream above the lower stripmine. Additional water samples were collected, starting in June of 1985 to determine water quality differences above and below the stripmine.

Statistical Tests

Four different statistical tests were used to determine various influences on water quality within the study areas. Water quality and stream flow data were analyzed using two computer programs from the Statistical Analysis System (SAS) Institute Inc., Cary, North Carolina. Twelve of the properties analyzed in the water samples (sulfate, iron, total dissolved solids (TDS), turbidity, lead, zinc, pH, manganese, magnesium, sodium, nickel and calcium) were used for most of the analyses performed.

The first analysis utilized SAS's Proc X11 program, from the Econometrics and Time Series program package (SAS 1984), to determine if fluctuations in water quality were random or seasonal. Stream flow, along with four of the tested water properties with high variability (sulfate, iron, TDS and calcium) were used in this examination.

The second test analyzed the relationship of stream flow, date and watershed to water quality using SAS's General Linear Model (Proc GLM) (SAS 1985). Results from this test were used in the final two analyses.

One of the primary objectives of this study was to compare water quality differences among watersheds with different mining conditions. The third test compared the water quality of the newly mined and old mined watersheds to that of the unmined for each region. The "Estimate" option in Proc GLM (SAS 1985) was used to directly compare stream water properties of the various watersheds, on a given date, for significant differences.

The final analysis compared water quality differences within the same watersheds over a four year period. The Proc GLM "Estimate" option was again used; this time water property levels for 1981 were compared to those in 1984 for significant differences.

Environmental Protection Agency's drinking water standards (U.S. Dept. of H.E.W., Public Health Service 1962, EPA Office of Water Supply 1976 and EPA 1980) were used to evaluate the seriousness of the water quality impacts due to mining.

CHAPTER 3

STUDY AREAS

The six study areas were divided into two groups of three, with one set being located on the Cumberland Plateau and the other in the Cumberland Mountains. Each group contained an unmined, old mined and newly mined watershed. The watersheds were from 88 to 259 acres in size and all contained small streams. Historically, the study areas were covered with deciduous forests and ocassional pines (Springer and Elder 1980). Various land uses have altered this condition and now there is much variability in the land cover.

Climate

East Tennessee has a warm, continental climate characterized by warm, humid summers and mild winters. The average yearly temperature for the study areas is around 14 degrees Centigrade. Winter temperatures average four degrees C. with normal daily minima of minus two. Summer temperatures average 25 degrees C. with normal daily maxima of 30 degrees C. The average growing season is between 180 and 220 days (Gale Research Co. 1978).

Precipitation averages 50 to 55 inches annually and is distributed evenly throughout the year, although there is a greater frequency of large scale storms in the winter and early spring. Thunderstorms and showers sometimes produce high rates of precipitation during midsummer. Snow averages 10 to 15 inches a year. Winds average five to seven miles per hour, usually from a west to southwesterly direction (Gale Research Co. 1978).

Geology and Stratigraphy

The rocks of Tennessee's coal region are largely Pennsylvanian. Their stratigraphy consists of layers of sandstone, shale, coal and very thin limestone. Two major divisions are recognized in the stratigraphic sequence (Luther 1959). The lower part consists of three groups which contain thick sandstone and conglomerate separated by approximately equal amounts of shale. The upper part consists of six groups containing larger, more prominent shale layers found only in the Cumberland Mountains. Details of geology and stratigraphy are given in Appendix A.

Soils

All soils in the study areas have similar characteristics. They are acidic with pH levels ranging from below four to 5.5. and are low in natural fertility and organic matter. Greatest differences in soil types are found between the Cumberland Plateau watersheds and the Cumberland Mountains watersheds (Springer and Elder 1980, Moneymaker 1981 and Elder et al 1958). A brief description of each soil type in the two geographic regions is found in Appendix C.

Watershed Conditions

USGS-TVA 7.5 minute topographic maps were used to delineate the areas and to determine elevation and aspect. Some study areas were in regions where detailed soils or surface geology information was not available. In these cases information was extrapolated from adjacent areas. The watersheds selected for this study did not meet all of the criteria stated for their watershed condition classification. This was due to a variety of reasons: changes in land uses since classification, sparse area information, time constraints and best available site. Deviations from the set criteria will be mentioned in the description of each watershed. Detailed descriptions of the study areas, along with land cover, surface geology and soils maps, are found in Appendix C. A summary of each follows.

Cumberland Plateau

Suzanne Creek, Unmined, Brayton Quad, Bledsoe County: Located approximately five and one half miles west of the junction of Bledsoe, Rhea and Hamilton counties (Figure 2), this watershed is around 132 acres in size with an eastern aspect. The elevation from confluence to ridgetop is about 160 feet. It is mainly covered with hardwood forests but, includes unpaved roads, cultivated fields, old fields, pastures and homesites. The stream is intermittent and during the summer may be dry for two to three months.

Denny Cove, Newly Mined, White City Quad, Marion County: Located approximately seven miles north of Jasper, Tennessee (Figure 3), it is about 88 acres in size and has a western aspect. Elevation from the confluence to ridgetop is 220 feet. Approximately 25 percent of the watershed was disturbed by surface mining activities between 1975 and 1979 (Dyer 1982); the remainder is predominantly hardwood forest.

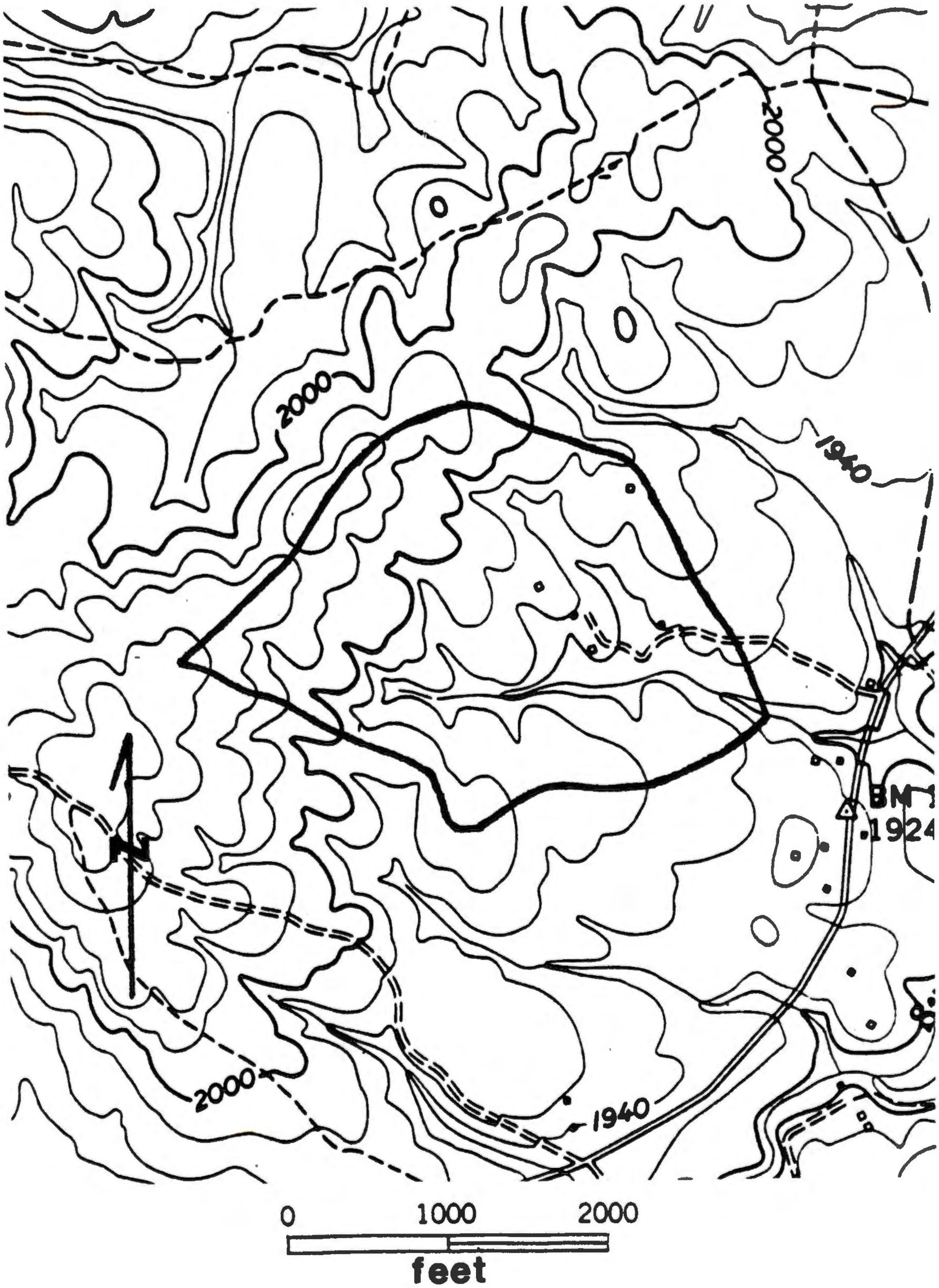


Figure 2. Suzanne Creek study area, Brayton Quadrangle, Tennessee.

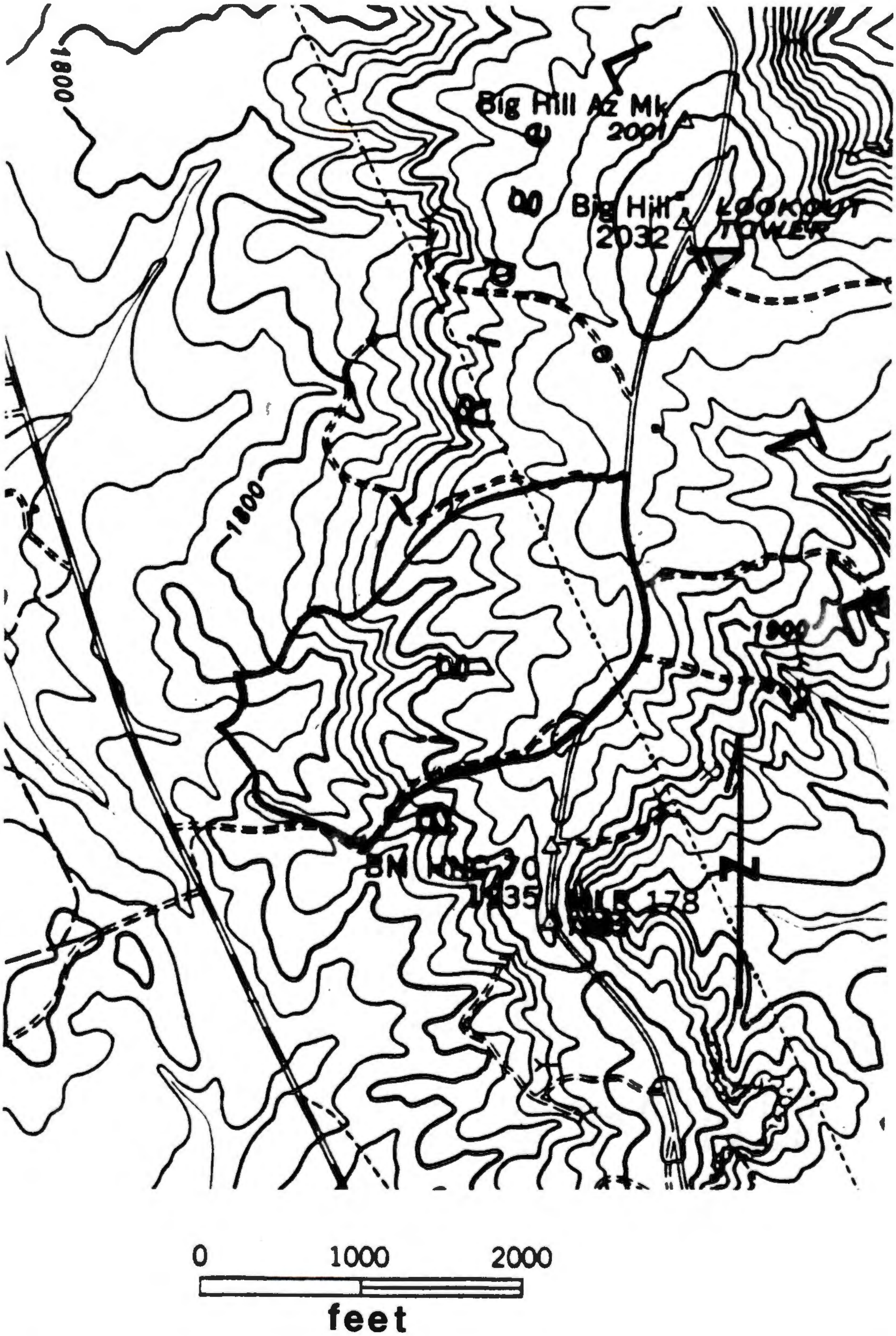


Figure 3. Denny Cove study area, White City Quadrangle, Tennessee.

The mined area is almost completely revegetated and appears stable. The flume was constructed just below a small, shallow pond. A swamp is located directly above the pond.

Corn Branch, Old Mined, Tracy City Quad, Grundy County: Located approximately five miles north of Tracy City, Tennessee (Figure 4), it is about 140 acres in size and has a southwestern aspect. Elevation from confluence to ridgetop is 120 feet. Approximately 30 percent of the area was disturbed by surface mining before 1972 (Dyer 1982) and now contains a variety of land cover ranging from bare ground to pine forests. The rest of the watershed is a mixture of forest, hayfields, grasslands and homesites. The stream is intermittent in the summer.

Cumberland Mountains

Lake City, Unmined, Lake City Quad, Anderson County: Located just southwest of Lake City, Tennessee (Figure 5), it is around 88 acres in size and has an eastern aspect. Elevation from the confluence to the ridgetop is about 1220 feet. It is almost completely forested except for a few houses and a road. Materials from the road wash into the stream and at least one area has household trash of all types in and adjacent to the stream due to dumping from the road above. This stream flows continuously and usually supports algal growth in the flume.

Davis Creek, Newly Mined, La Follette Quad, Campbell County: Located approximately seven miles northeast of La Follette, Tennessee (Figure 6), it is approximately 259 acres in size and has a western aspect. The elevation from confluence to ridgetop is about 610 feet. This watershed

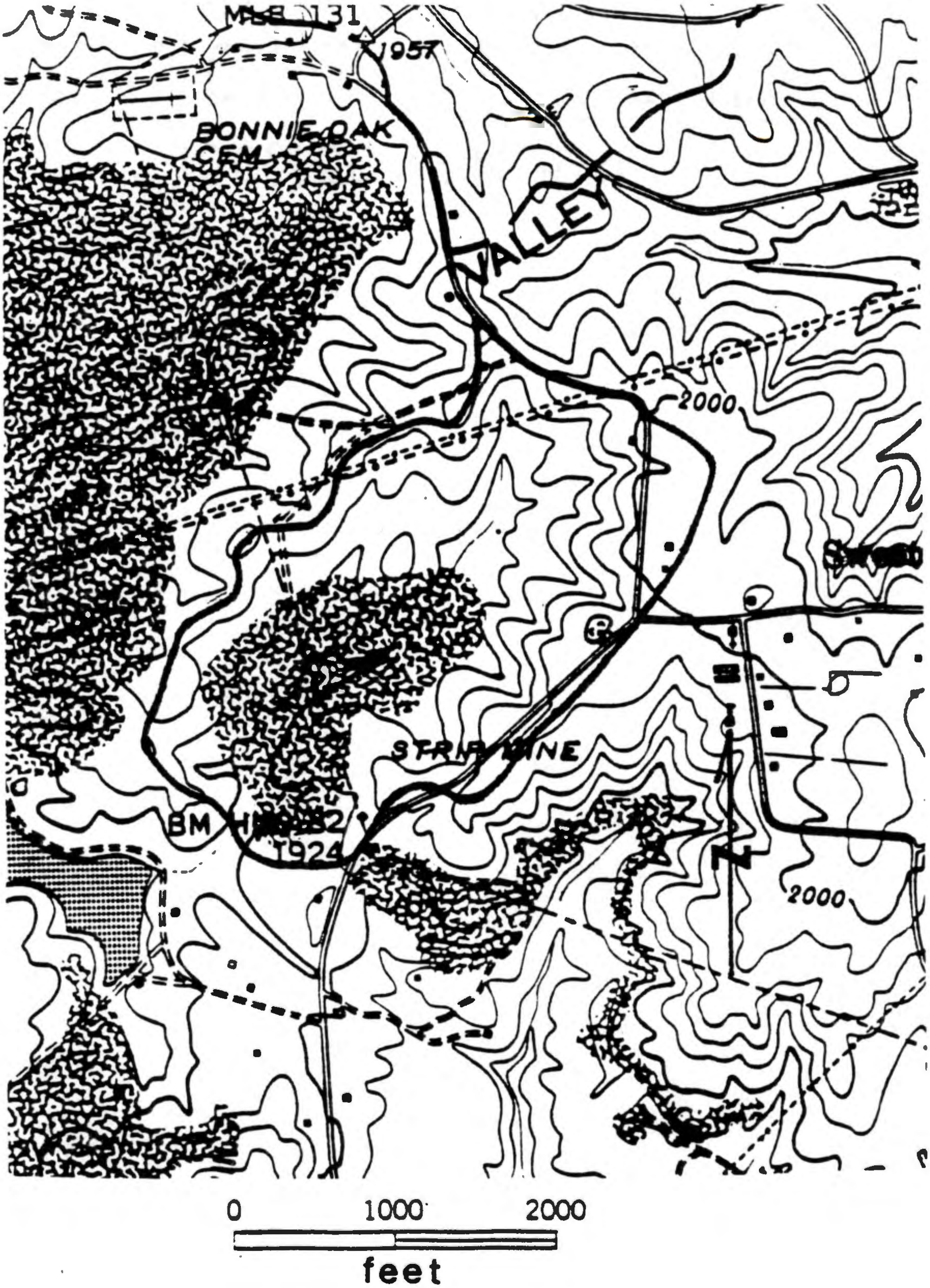


Figure 4. Corn Branch study area, Tracy City Quadrangle, Tennessee.

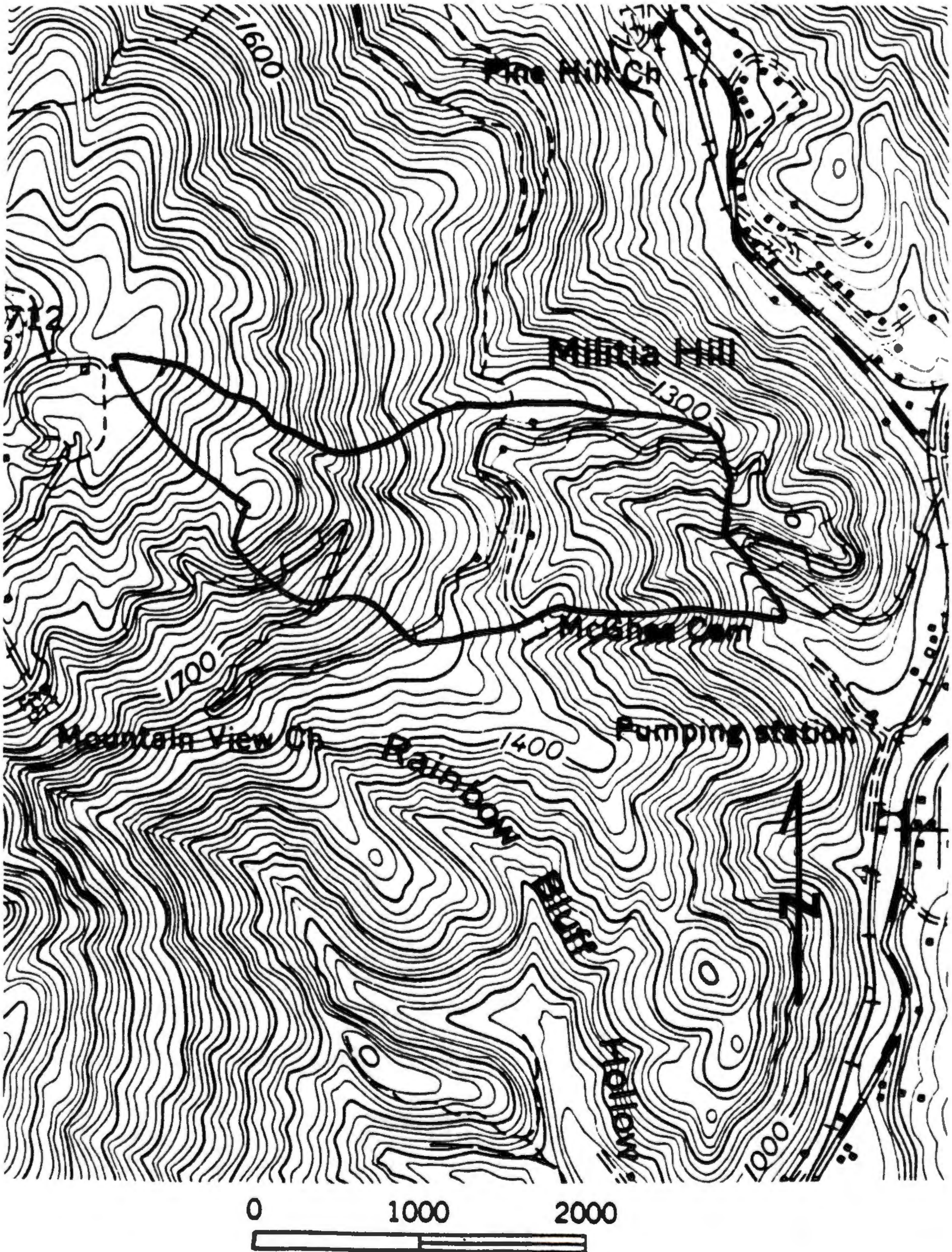


Figure 5. Lake City study area, Lake City Quadrangle, Tennessee.

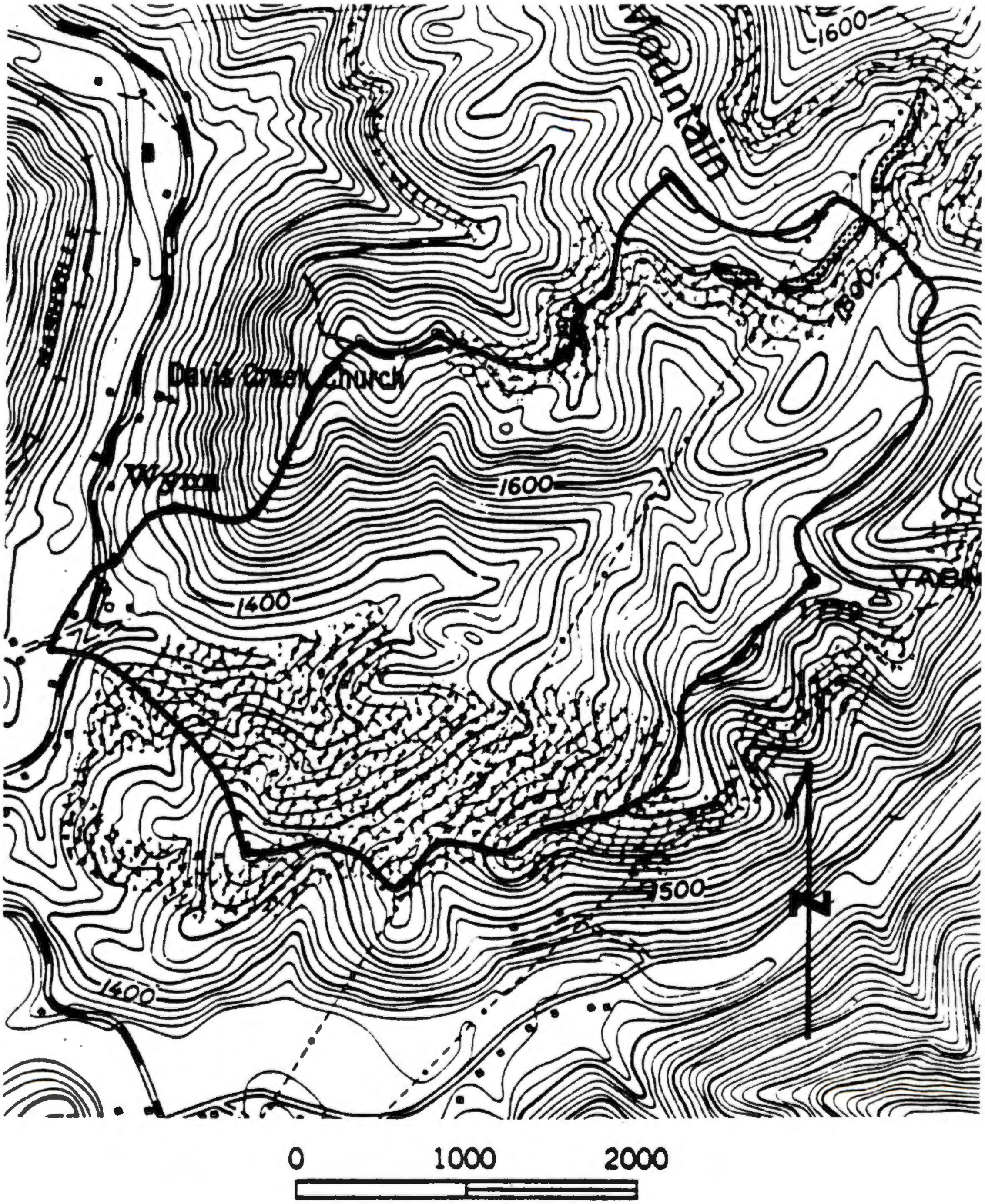


Figure 6. Davis Creek study area, LaFollette Quadrangle, Tennessee.

is approximately two to three times the size of the other areas studied and also has the largest area disturbed by mining. Approximately 35 percent of the area has been disturbed by surface mining since 1972, with the most recent operation completed in late 1981. At least three coal seams were mined from this watershed. The disturbed area is largely covered with grasses and scattered small trees. The area still has erosion problems and some limited reclamation work is being done at times.

With the exception of a few homes near the mouth of the watershed, the unmined area is hardwood forest that contains many new dirt roads, some of which drain into the stream. The stream flows continuously with the stream bed and water both reddish in color below the lowest stripmine.

<u>Crooked Fork, Old Mined, Petros Quad, Morgan County:</u> Located approximately one mile south of Petros, Tennessee (Figure 7), this watershed is about 121 acres in size and has a western aspect. Elevation from the confluence to the ridgetop is about 1120 feet. It is almost completly covered with hardwood forest and less than 10 percent has been disturbed by surface mining (Dyer 1982). More than one seam of coal has been mined in this watershed. The very top of the watershed has been disturbed after January 1972, however most of the drainage from this area has been diverted to an adjacent watershed by means of a ditch. The disturbed areas are vegetated. The stream flows only during winter and other wet periods.

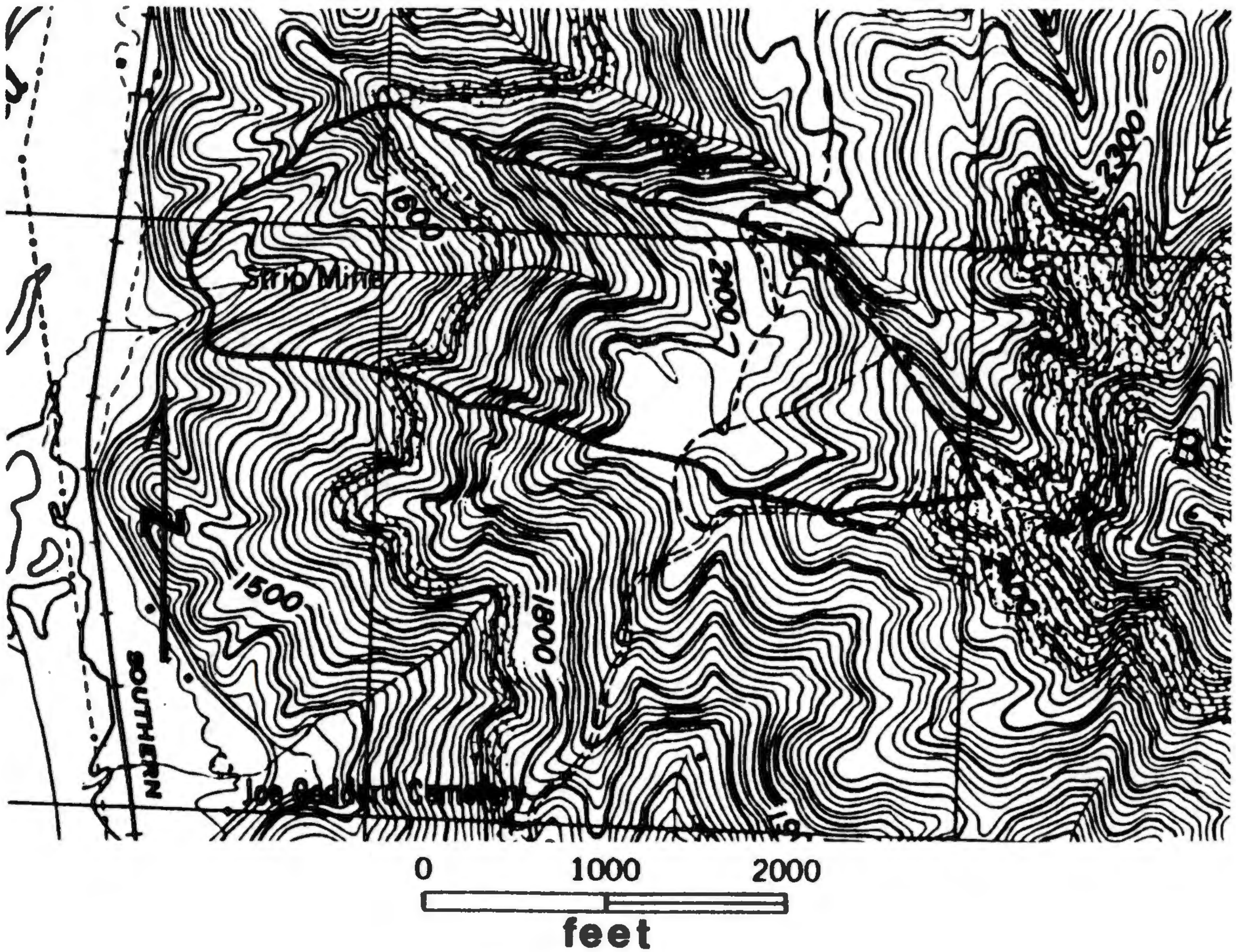


Figure 7. Crooked Fork study area, Petros Quadrangle, Tennessee.

CHAPTER 4

RESULTS

Of the 33 different water quality properties analyzed from water samples, twelve were selected for consideration in this study: sulfate, iron, total dissolved solids (TDS), pH, lead, turbidity, zinc, manganese, magnesium, sodium, nickel and calcium. The data were edited for these 12 and for stream flow.

Tests were first made to determine whether observed water quality fluctuations were random or seasonal. Four of the stream water components with large variability (SO_4, Fe, TDS and Ca) along with stream flow were selected and their values were averaged quarterly from 1981 through 1984. These data were analyzed using the stable seasonality test within SAS's Proc X11 program. A summary of the results appears in Table 1.

Since this program does not allow missing values, the two watersheds with intermittent streams were excluded. These streams were considered to have seasonal fluctuations since they flowed during the winter and dried up each summer, during the study period.

The next step was to determine possible influences on stream water quality in the study areas. Three independent variables (water flow, watershed and date) were used, separately and in combination, to determine if they were correlated with the water quality constituents. Date was used to evaluate what affects time of year or seasonal weather conditions might have on water quality. SAS's Proc GLM (General Linear Model) program was used to determine the effects of the independent factors on water quality. Table 2 contains the summarized results for each

Table 1

Seasonal Fluctuations in Water Quality

Watershed	SO4	Fe	TDS	Ca	CFS
		Cumberland Plateau			
Newly Mined	NS	***	NS	NS	NS
Old Mined	***	***	***	***	NS
Unmined	---	---	---	---	---
		Cumberland Mountains			
Newly Mined	***	***	***	***	***
Old Mined	---	---	---	---	---
Unmined	***	***	***	***	***

*** significant at the 99 percent level
NS not significant
--- insufficient data

Table 2

Relationship of Flow, Date and Watershed to Water Quality

Element[1]	CFS	Date	Watershed	CFS*Watershed	Date*Watershed
SO4	***	***	***	***	***
Fe	**	***	***	***	***
TDS	***	NS	***	***	***
pH	**	***	***	***	**
Ca	***	***	***	***	***
Pb	*	NS	*	**	**
Turb.	NS	NS	*	*	*
Mn	***	NS	***	***	***
Mg	***	NS	***	***	***
Zn	NS	NS	NS	*	NS
Na	***	***	***	***	***
Ni	***	NS	NS	NS	*

1 as logarithm of concentration
*** significant at the 99% level
** significant at the 95% level
* significant at the 90% level
NS not significant

of the correlationships tested. Type I and III sum of squares tests, along with their corresponding F values, were used to evaluate these relationships.

With the exception of "Date" a significant relationship existed between most water quality constituents and their various independent factors. The high number of correlations with "CFS" and "Watershed" indicate that concentration levels were related to flow rates and that each watershed had an independent concentration regime. This assumption was further strengthened by the results obtained from the interaction of flow and watershed (CFS*Watershed) as an independent factor (Table 2). Concentration levels also appeared to be highly related to the interaction of date and watershed (Date*Watershed), while date alone was significant in less than half of the cases. This indicated that date itself may not generally influence stream water quality. From the results in Table 2 it was concluded that flow rates are important factors influencing water quality fluctuations in streams. Also, concentration levels appeared to be dependent on specific watershed conditions.

The "Estimate" option in the Proc GLM program was used to compare the same water quality parameters under different mining conditions. From the results of the previous test, mean stream flow of each watershed was used in the comparisons (Table 3).

The greatest difference found was between the newly mined and unmined watersheds in the Cumberland Mountains group. The newly mined site had the largest disturbed area and also had the stream flowing through this disturbed section, which probably accounts for the large differences ($p = .01$).

Table 3

Concentration Differences Between Watersheds for 1981 and 1984

(milligrams per liter)

Water Property	unmined -vs- "newly" mined (-) (+)		unmined -vs- old mined (-) (+)	
	1981 ave.	1984 ave.	1981 ave.	1984 ave.
		Cumberland Plateau		
SO4	159.00***	97.10***	11.80***	7.20***
Fe	0.94***	0.11**	0.15***	0.06***
TDS	214.00***	130.00***	27.00***	15.00***
pH!	0.00	-0.90***	0.50***	0.50**
Pb	0.04***	0.03**	0.01*	0.00
Turb.	38.00***	10.00**	8.00**	7.00***
Zn	0.01	0.01	0.01	-0.01**
Mn	10.10***	4.46***	0.19***	0.07***
Mg	14.44***	12.97***	3.69***	2.44***
Na	2.02***	1.27***	0.69***	0.36***
Ni	0.03!!	0.02!!	0.01!!	0.01!!
Ca	24.12***	15.33***	2.64***	1.04***
		Cumberland Mountains		
SO4	982.00***	1388.00***	-3.20	2.20**
Fe	11.20***	20.90***	0.00	-0.01
TDS	1182.00***	1772.00***	-133.00***	-123.00***
pH!	-2.80***	-3.40***	1.40***	1.50***
Pb	0.08***	0.29***	-0.04***	-0.01
Turb.	127.00***	164.00***	3.00	-17.00**
Zn	0.40***	0.37***	0.00	-0.03
Mn	20.07***	26.87***	-0.01	0.00
Mg	103.50***	179.50***	-2.62***	-2.17***
Na	5.91***	39.60***	-37.20***	-31.90***
Ni	0.33***	0.48***	0.00	0.00**
Ca	117.20***	180.00***	-16.53***	-16.22***

*** significant at the 99 percent level
** significant at the 95 percent level
* significant at the 95 percent level
! units are in log(1/(H+))
!! values were zero for unmined, could not compute significance

The significance of the concentration differences between the newly mined and unmined, and the old mined and unmined watersheds, in the Cumberland Plateau region, was about the same. However, differences in concentrations were much greater between newly mined and unmined watersheds. This would be expected considering the more recent exposure of unweathered materials, which would increase the probability of leaching by surface and subsurface water flow.

The last comparison of watershed conditions was between the old mined and unmined watersheds in the Cumberland Mountains region. The significant differences between these two areas were smaller than in the other comparisons, indicating that this old mined watershed was closer to the unmined condition than the other ones. In fact, the unmined area had significantly greater concentrations of many elements, which appeared to contradict what would be expected; however, drainage from a road discharged into to the stream.

The comparison of watershed conditions showed significant differences between the watersheds for many water quality components, indicating that surface mining can have a demonstrable impact on the water quality.

A close examination of Table 3 reveals large differences between 1981 and 1984 comparisons. Proc GLM "Estimate" statements were set up for each watershed to compare 1981 water constituent levels with 1984 levels for significant changes. The same months were compared to account for seasonal differences. Results showed that both "newly" mined watersheds had significant changes in most water quality indicators over time (Table 4). One increased in concentrations (Cumberland

Table 4

Significance and Direction of Change in Water Quality Concentrations

From 1981 To 1984

Water Property[1]	"Newly" Mined	Old Mined	Unmined
	Cumberland Plateau		
SO4	- ***	- ***	- *
Fe	- ***	NS	NS
TDS	- ***	- **	+ **
pH	- ***	NS	NS
Pb	NS	NS	NS
Turb.	- ***	NS	NS
Zn	NS	NS	+ **
Mn	- ***	NS	+ ***
Mg	NS	- *	NS
Na	- ***	- ***	NS
Ni	- *	NS	ID
Ca	- *	NS	+ ***
	Cumberland Mountains		
SO4	+ **	NS	- ***
Fe	+ **	NS	NS
TDS	+ ***	NS	NS
pH	- ***	NS	NS
Pb	+ ***	NS	NS
Turb.	NS	NS	NS
Zn	NS	NS	NS
Mn	NS	NS	- **
Mg	+ ***	NS	NS
Na	+ ***	- **	NS
Ni	NS	NS	- *
Ca	+ ***	NS	NS

1 as logarithm of concentration

+ increased over time
- decreased over time
*** significant at the 99 percent level
** significant at the 95 percent level
* significant at the 90 Percent level
NS not significant
ID insuffficent data

Mountains) while the other decreased (Cumberland Plateau). The other watersheds changed over time, but most of the analyses showed no significant differences.

In June of 1985 additional water sampling was begun in the stream above the the lower surface mine at the Cumberland Mountains newly mined watershed (Davis Creek). Although data were collected after the study period and a statistical analysis was not made, the results are quite apparent (Table 5). Levels of all constituents increased greatly below the disturbed area indicating that mining activities had a drastic affect on water quality.

Table 5

Water Quality Above and Below Davis Creek Strip Mine: 1985

Property	Units	June Above	June Below	July Above	July Below	August Above	August Below	September Above	September Below	October Above	October Below
SO4	mg/l	45.80	1494.20	59.80	2043.80	38.60	1377.40	52.90	1933.20	50.40	1977.80
Fe	mg/l	0.05	33.56	0.10	33.41	0.02	7.68	0.08	28.45	0.01	31.06
TDS	mg/l	86.00	2127.00	108.00	2727.00	66.00	1803.00	91.00	2570.00	95.00	2675.00
pH	log(1/H+)	7.30	3.80	7.60	3.70	7.30	7.30	7.70	4.40	7.70	3.70
Pb	mg/l	0.00	0.52	0.00	0.39	0.00	0.49	0.00	0.37	0.00	0.35
Turb.	JTU*	39.00	308.00	45.00	637.00	65.00	127.00	20.00	290.00	20.00	423.00
Zn	mg/l	0.01	0.32	0.09	0.36	0.01	0.33	0.01	0.43	0.02	0.39
Mn	mg/l	0.02	38.65	0.13	41.16	0.04	14.47	0.03	34.33	0.00	41.43
Mg	mg/l	7.61	211.01	8.59	233.50	6.14	144.46	7.55	218.83	8.22	233.43
Na	mg/l	8.02	85.23	10.82	92.74	2.91	85.00	6.98	97.33	8.79	97.01
Ni	mg/l	0.00	0.44	0.01	0.57	0.00	0.36	0.00	0.54	0.00	0.57
Ca	mg/l	7.13	244.29	9.20	261.60	5.59	150.17	7.23	237.44	8.01	273.27

* Jackson Turbidity Units (JTU)

CHAPTER 5

DISCUSSION

The effects of surface mining on water quality have been studied by many investigators (i.e. Dyer 1981, 1982, Minear and Tschantz 1976). In most cases mining has been determined to have a detrimental impact on water quality. For the study reported here, watershed condition criteria were set in advance to better evaluate the differences in water quality between watersheds. EPA Primary Drinking Water standards were used as a basis to determine the degree of impact on water quality. All graphs are displayed as logarithmic values due to the large differences in concentration levels beteen watersheds. These graphs are meant only to show relative differences. A brief discussion on each of the water quality properties used and their concentrations in each of the study areas follow.

SO_4 (Sulfate): Sulfate causes a laxative affect at concentrations greater than 600 mg/liter. The taste of beverages is impaired when concentrations reach 300 to 400 mg/liter and magnesium exacerbates both effects. Transient users of water can be affected by much lower concentrations, usually around 250 mg/liter which is the suggested limit (US Dept H.E.W., Public Health Ser. 1962 and EPA Office of Water Supply 1976).

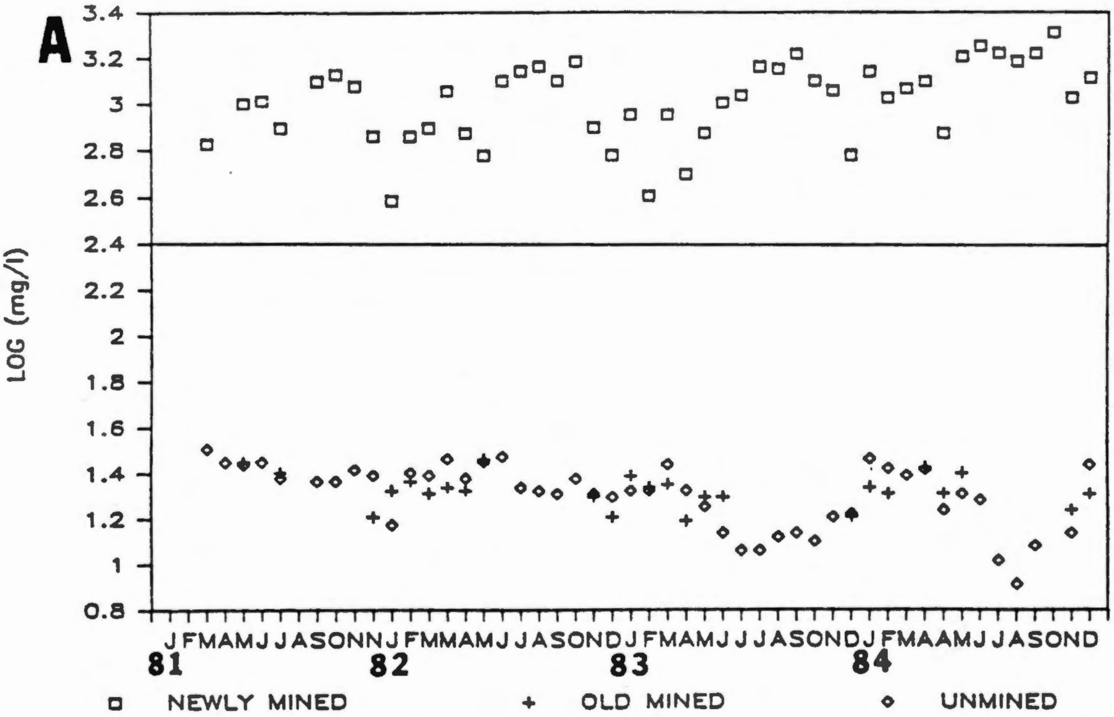
Sulfate has been studied extensively with regard to mining activities, due mainly to its relationship to stream acidity. Sulfate concentrations usually depend on the amount of exposed framboidal pyrite in the disturbed areas (Schaller and Sutton 1978). As pyrite weathers, sulfur and iron compounds dissolve into an extremely acid solution, causing lower pH levels and solubilizing many normally-bound elements.

Sulfate exceeded standards on only one of the study areas, Davis Creek, which was the most recently mined watershed. Concentrations averaged over four times the recommended limit and increased throughout the study period (Figure 8 A). The other newly mined watershed, Denny Cove, had the second highest concentrations of sulfate and showed a significant decrease in levels over time (Figure 8 B). Although well below the set standard, Crooked Fork (old mined) and Lake City (unmined) also showed significant reductions in sulfate concentrations during the study period. The other two watersheds had levels of sulfate below those recognized as problems to water quality.

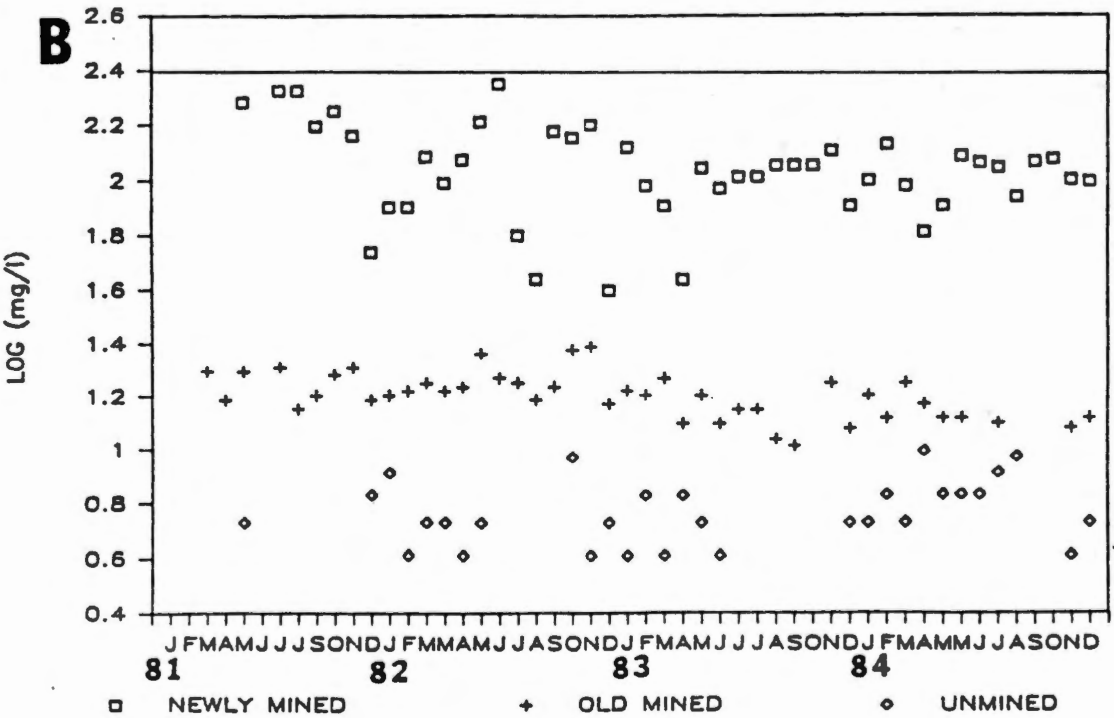
Iron: Iron is objectionable because it is detectable to taste between 1.8 and 3.4 mg/liter, with staining of cloth occurring around 0.3 mg/liter. Iron should not exceed 0.3 mg/liter (US Dept. H.E.W., Public Health Service 1972).

Iron, like sulfate, is usually associated with pyrite weathering. The rust colored stream bottoms of many mined areas are due to high iron levels. The two newly mined watersheds both had amounts well in excess of the standards in 1981, but as with sulfate levels, Davis Creek concentrations increased and Denny Cove levels decreased. By 1984, Denny Cove had iron levels comparable to the unmined watersheds. Davis Creek levels increased to approximately 70 times accepted standards during the study. The other four watersheds were below the limits and showed no significant change over time.

Figure 8. Periodic sulfate levels from 1981 through 1984. A. Cumberland Mountains streams: newly mined (Davis Creek), old mined (Crooked Fork) and unmined (Lake City). B. Cumberland Plateau streams: newly mined (Denny Cove), old mined (Corn Branch) and unmined (Suzanne Creek). Solid line (———) indicates EPA's acceptable level.


A
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
LOG (mg/l)
J FMAMJ J ASONNJ FMMAMJ J ASONDJ FMAMJ J JASONDJ FMAAMJ JASOND
81
82
83
84
NEWLY MINED
OLD MINED
UNMINED

SULFATE


B
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
LOG (mg/l)
J FMAMJ J J SONDJ FMMAMJ J ASONDJ FMAMJ J J ASONDJ FMAMMJ J ASOND
81
82
83
84
NEWLY MINED
OLD MINED
UNMINED

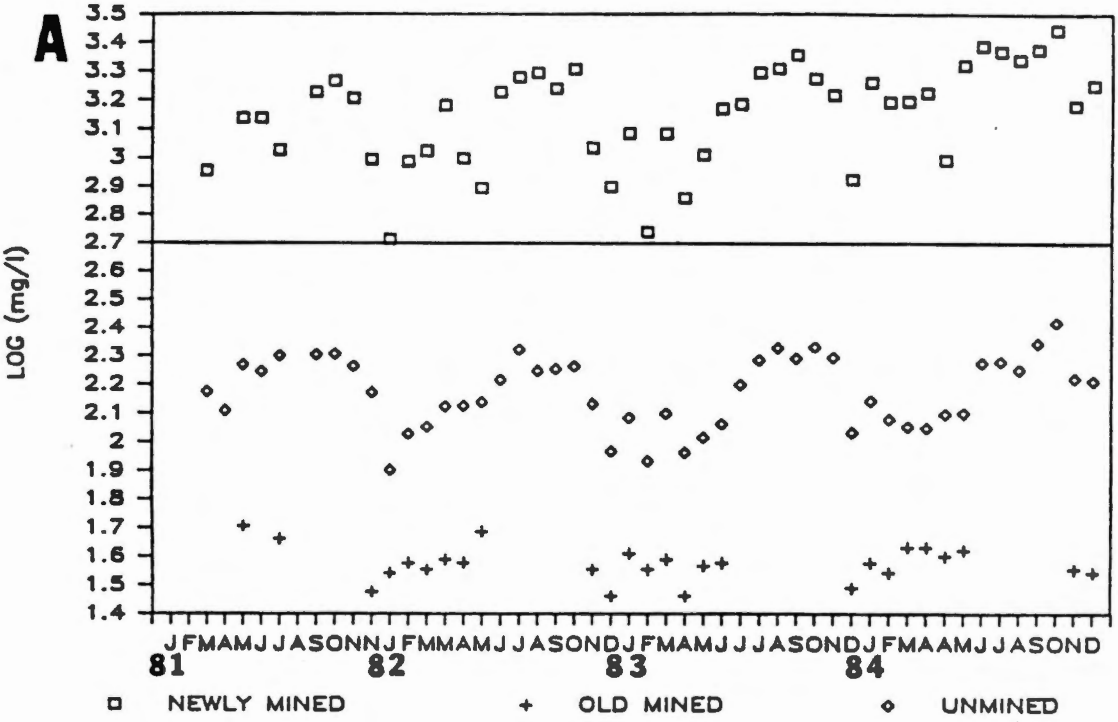
Total Dissolved Solids (TDS): Taste and odor of water can be affected by TDS and in cases of high sulfate levels, a laxative effect can occur. Although people can become accustomed to high concentrations, it is recommended that alternative water sources be used when TDS exceeds 500 mg/liter (US Dept. of H.E.W., Public Health Service 1962).

With the exception of Davis Creek, TDS levels did not exceed defined problem levels (Figure 9). The Davis Creek stream averaged over three times the suggested standard and is still increasing. Denny Cove showed a very significant decrease in TDS during the study period, indicating fast recovery of the mined area. Lake City, which was unmined, had concentration levels comparable to Denny Cove, probably due to drainage from a road or erosion of the stream bed due to the steepness of the watershed. A significant decrease in concentration was noted for Corn Branch and an increase for Suzanne Creek.

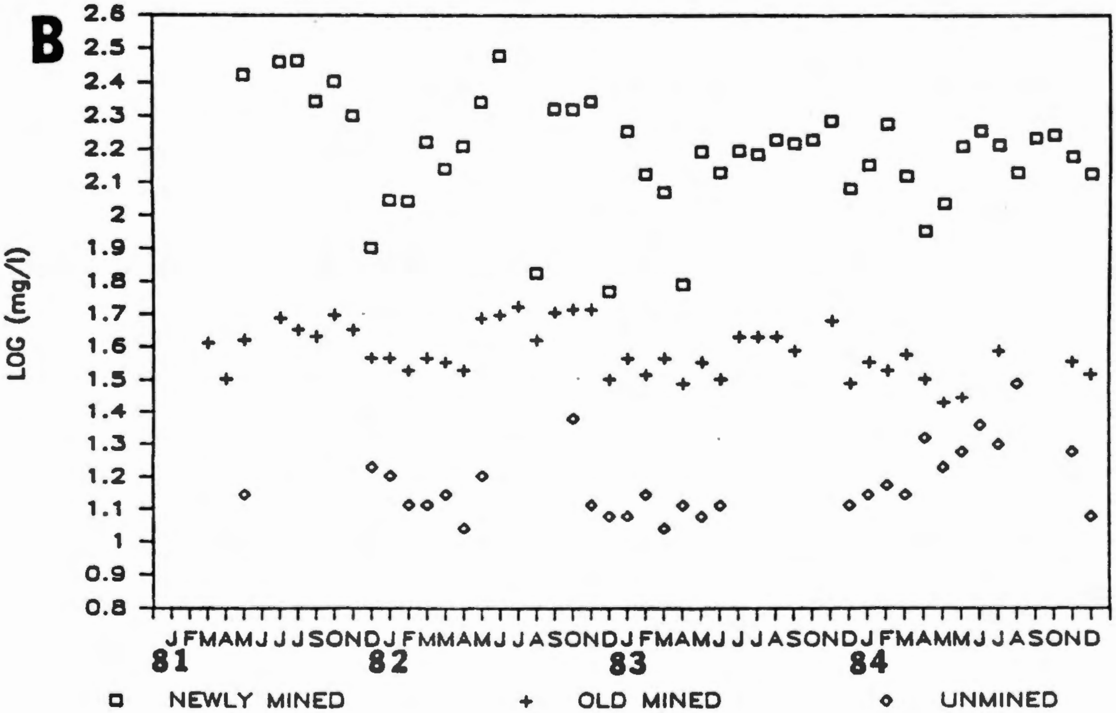
pH: Acidity and alkalinity have long been used as indicators of water quality due to the solubility of various substances at different values. Extremes can be fatal to aquatic life and may render water unfit for human consumption. For domestic water supplies values should be between five and nine (U.S. Environmental Protection Agency 1976). In the Appalachian coal region, acid runoff is one of the major problems associated with mining. By comparing water pHs, a quick estimate of mining influence on water quality can be obtained.

The pH values of the study areas were of concern in only one watershed, Davis Creek. Values there have continually dropped throughout the study period, to about four by the end of 1984, and have probably contributed to increased amounts of dissolved minerals in the stream.

Figure 9. Periodic total dissolved solid (TDS) levels from 1981 through 1984. A. Cumberland Mountain streams: newly mined (Davis Creek), old mined (Crooked Fork) and unmined (Lake City). B. Cumberland Plateau streams: newly mined (Denny Cove), old mined (Corn Branch) and unmined (Suzanne Creek). Solid line (———) indicates EPA's acceptable level.



TOTAL DISSOLVED SOLIDS



Denny Cove also showed a significant decrease from 1981 to 1984, from about 6.3 to 5.6, but this was not considered a runoff problem, since rainwater saturated with carbon dioxide has a pH of about 5.5.

Lake City watershed was unusual in that the stream had a high pH compared with the other areas, averaging above 8.2. Being an unmined watershed two possibilities may explain this. Either the stream flows through an alkaline stratum, which is unlikely according to geologic maps, or washings from the gravelled road are increasing the pH of the stream.

Lead: Lead is very toxic and can cause permanent brain damage to young children. Water standard limits are 0.05 mg/liter on the average but should never exceed four mg/liter (US Dept of H.E.W., Public Health Service 1962).

Lead is a problem in only one watershed, Davis Creek. From the beginning of the study it has exceeded the average concentration standard and continued to increase throughout the study. Two watersheds, Denny Cove and Lake City, were below the average concentration standard but not greatly so. The other three study areas were well within quality standards.

Turbidity: This is a measure of water clarity. As turbidity increases, the amount of light that can pass through water decreases. Water should contain less than five turbidity units and preferably no more than one (EPA Office of Water Supply 1976). As turbidity increases, chlorine disinfection of water becomes increasingly difficult (U.S. Environmental Protection Agency 1976).

All six watersheds exceed water quality standards for turbidity levels. Suzanne Creek had the lowest levels with an average of approximately seven turbidity units. Denny Cove showed a highly significant reduction in turbidity over the study period and had levels comparable to the old mined watersheds by the end of the period. Davis Creek, had the highest levels with averages greater than 100 turbidity units. Lake City water had relatively high turbidity, which was probably due to road wash or steepness of the watershed. The two old mined watersheds, Corn Branch and Crooked Fork, had levels three to four times that of the stated criterion.

Zinc: For fresh water aquatic life, the average should not exceed 46 micrograms/litre and should never exceed approximately 600 micrograms/liter. For human consumption, zinc should not exceed five mg/liter (Environmental Protection Agency 1980).

Zinc concentrations on the six study areas were all below acceptable drinking water standards. However, concentrations at Davis Creek exceeded standards for fresh water aquatic life. Suzanne Creek showed a significant increase in zinc levels over the study but they were still below the standards.

Manganese: Domestic complaints occur when manganese exceeds 0.15 mg/liter. It causes a brownish color in laundry and impairs the taste of beverages. Concentrations of iron and manganese combined should not exceed 0.3 mg/liter and alternative water sources should be used if manganese exceeds 0.05 mg/liter (US Dept. of H.E.W., Public Health Service 1962).

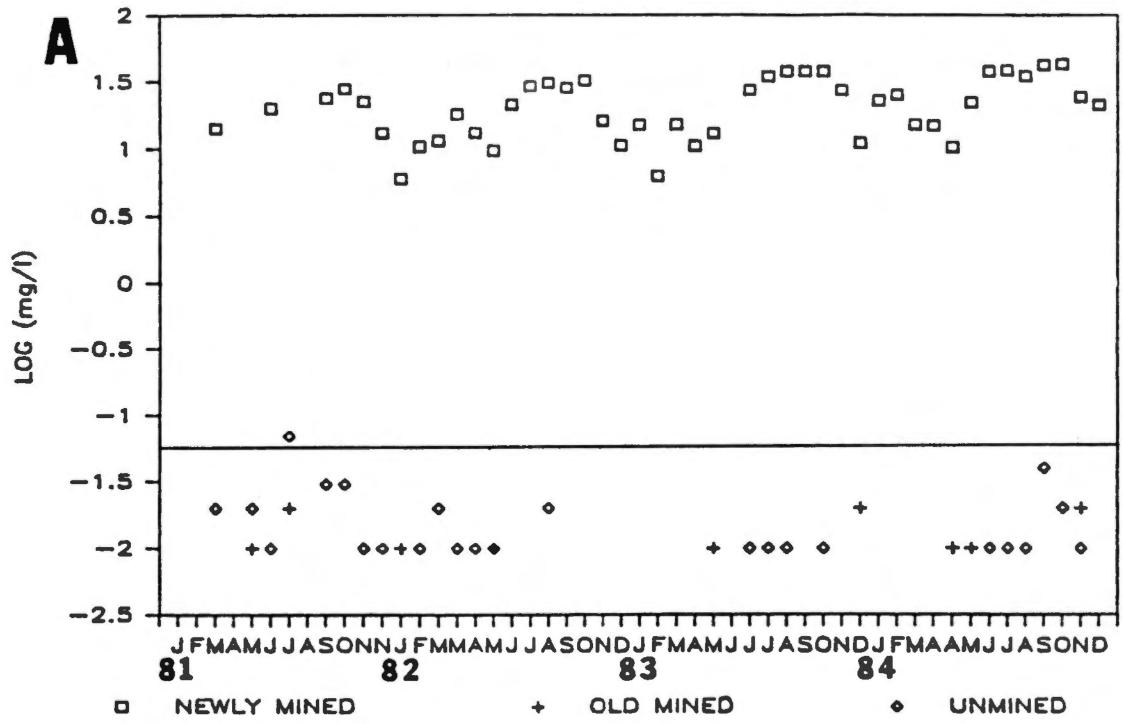
Davis Creek (newly mined) had the highest concentrations, more than 100 times greater than set standards, followed by Denny Cove (newly mined) (approximately 100 times greater), then Corn Branch (old mined) (approximately three times greater) (Figure 10). The newest mine had the greatest levels and the oldest the least. Denny Cove had a highly significant decline in concentration over time. The other three watersheds were below the standards and showed little change during the study.

Magnesium: Although water quality standards were not determined, magnesium concentrations showed large variations between study areas and over time (Figure 11). Davis Creek had the highest concentrations and also had a highly significant increase during the study period. Denny Cove had the next highest levels, followed by Lake City, Corn Branch, Crooked Fork and Suzanne Creek, all of which were stable.

Sodium: High sodium levels are associated with high blood pressure and other cardiovascular diseases. Over 40 percent of domestic water supplies exceed 20 mg/litre of sodium which is considered a safe limit for all people (EPA Office of Water Supply 1976).

Davis Creek and Lake City, had sodium concentration above the set standards (Figure 12). Davis Creek concentrations were three to four times greater and there was a highly significant increase in levels during the study period. Lake City had a fairly constant sodium level of about twice the water quality standard. The high levels of sodium in this unmined watershed are unexplained unless they are due to the roads or homesites. Denny Cove, Corn Branch and Crooked Fork all show significant reductions in concentration levels during the study period.

Figure 10. Periodic manganese levels from 1981 through 1984. A. Cumberland Mountains streams: newly mined (Davis Creek), old mined (Crooked Fork) and unmined (Lake City). B. Cumberland Plateau streams: newly mined (Denny Cove), old mined (Corn Branch) and unmined (Suzanne Creek). Solid line (———) indicates EPA's acceptable level.


A
LOG (mg/l)
2
1.5
1
0.5
0
−0.5
−1
−1.5
−2
−2.5
J FMAMJ J ASONNJ FMMAMJ J ASONDJ FMAMJ J J ASONDJ FMAAMJ J ASOND
81
82
83
84
NEWLY MINED
OLD MINED
UNMINED

MANGANESE

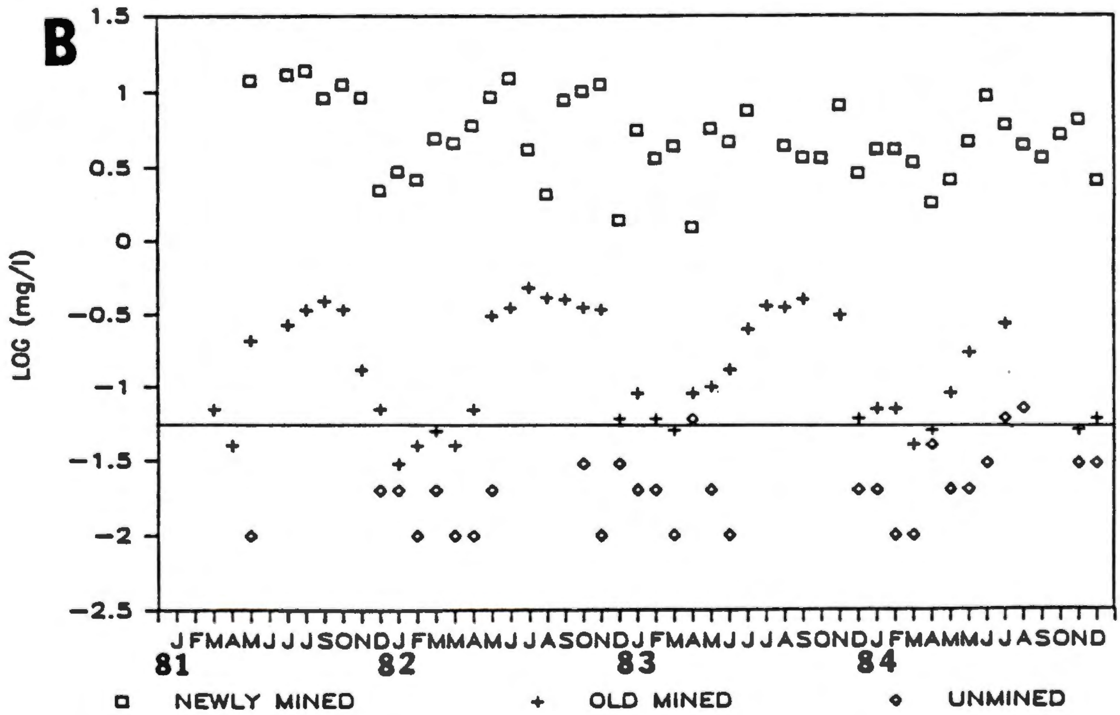
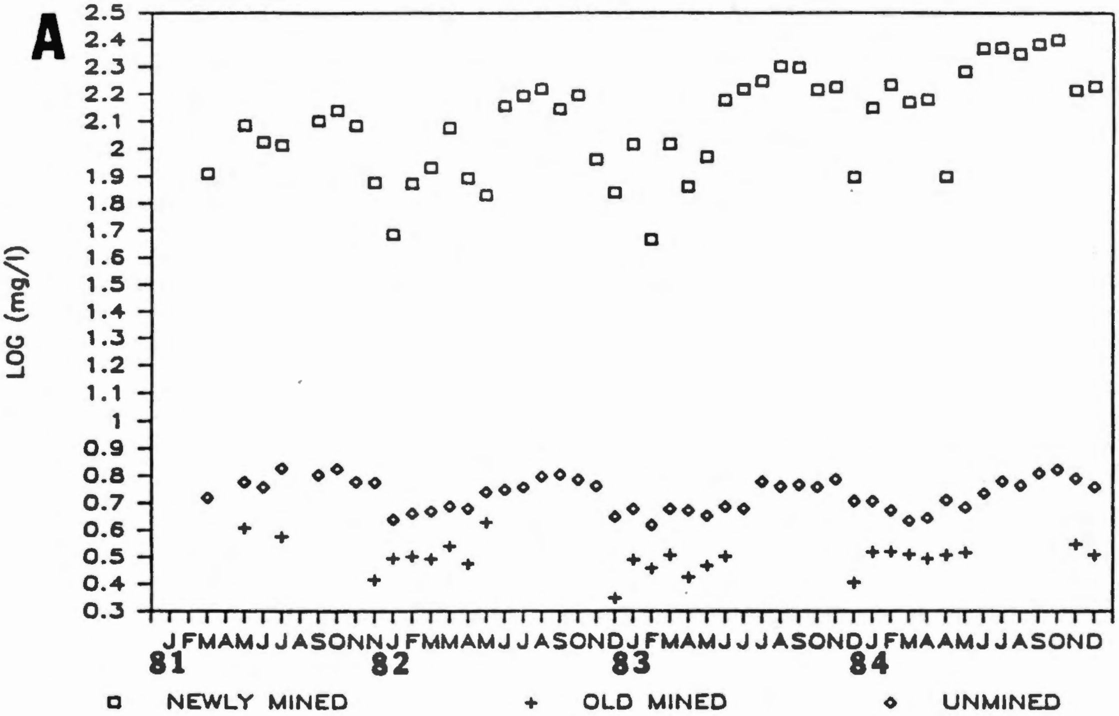

B
LOG (mg/l)
1.5
1
0.5
0
−0.5
−1
−1.5
−2
−2.5
J FMAMJ J J SONDJ FMMAMJ J ASONDJ FMAMJ J J ASONDJ FMAMMJ J ASOND
81
82
83
84
NEWLY MINED
OLD MINED
UNMINED

Figure 11. Periodic magnesium levels from 1981 through 1984. A. Cumberland Mountains streams: newly mined (Davis Creek), old mined (Crooked Fork) and unmined (Lake City). B. Cumberland Plateau streams: newly mined (Denny Cove), old mined (Corn Branch) and unmined (Suzanne Creek).


A
LOG (mg/l)
J FMAMJ J ASONNJ FMMAMJ J ASONDJ FMAMJ J JASONDJ FMAAMJ J ASOND
81
82
83
84
NEWLY MINED
OLD MINED
UNMINED

MAGNESIUM

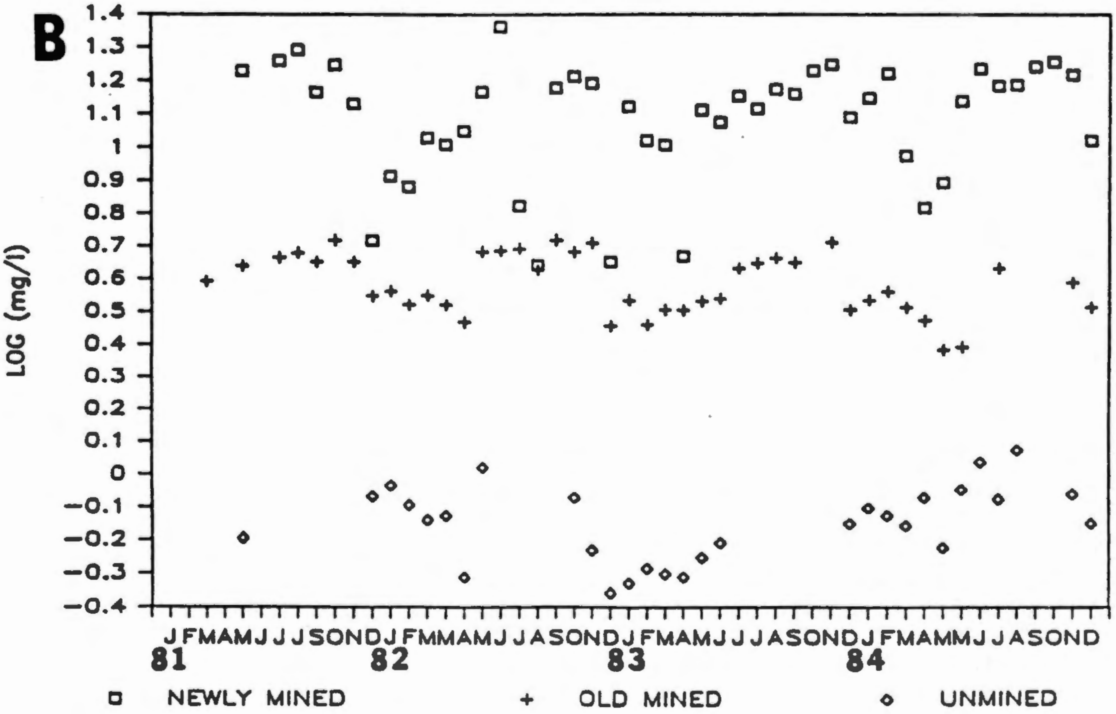
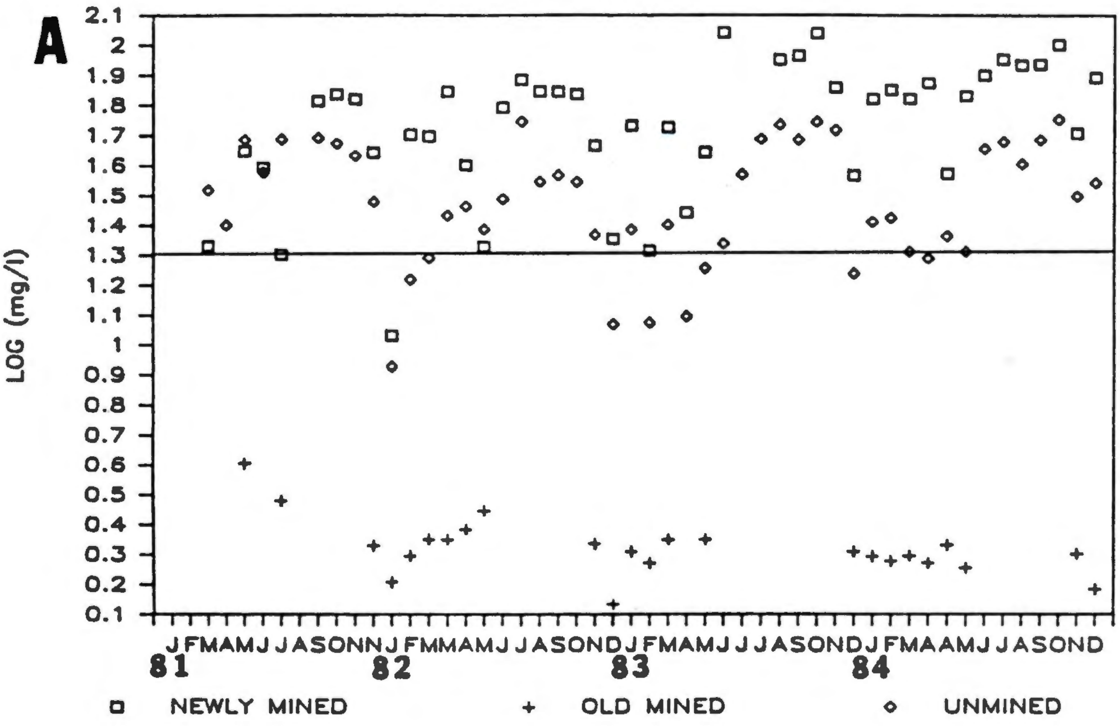
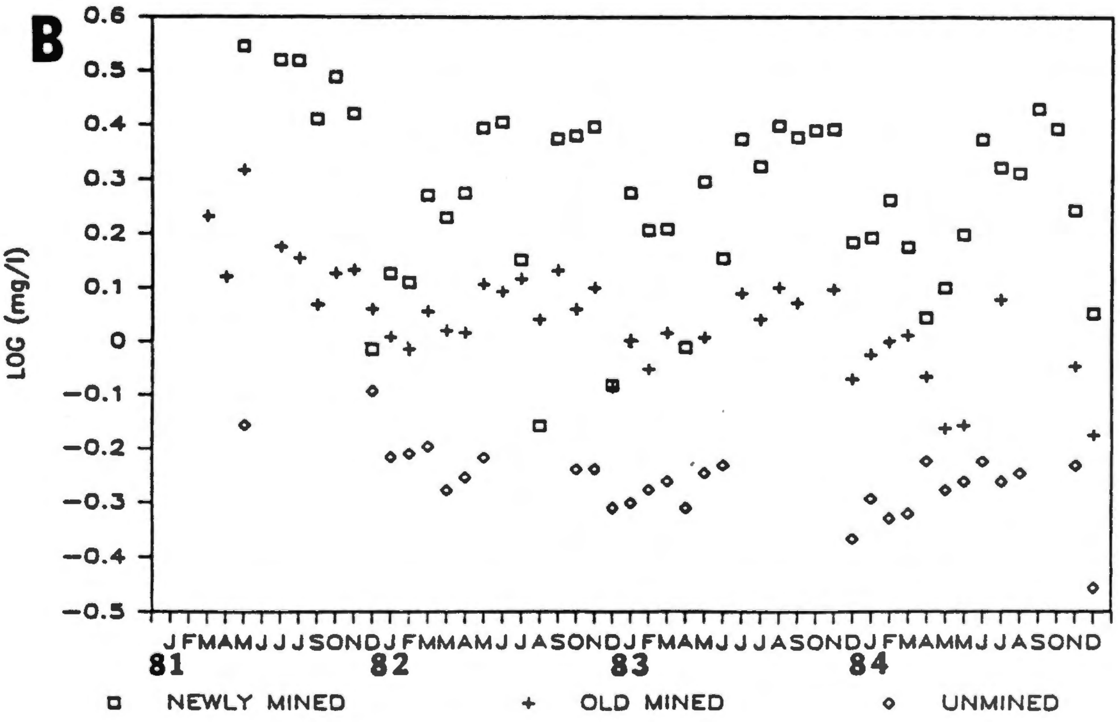

B
LOG (mg/l)
J FMAMJ J J SONDJ FMMAMJ J ASONDJ FMAMJ J J ASONDJ FMAMMJ J ASOND
81
82
83
84
NEWLY MINED
OLD MINED
UNMINED

Figure 12. Periodic sodium levels from 1981 through 1984. A. Cumberland Mountains streams: newly mined (Davis Creek), old mined (Crooked Fork) and unmined (Lake City). B. Cumberland Plateau streams: newly mined (Denny Cove), old mined (Corn Branch) and unmined (Suzanne Creek). Solid line (———) indicates EPA's acceptable level.


A
LOG (mg/l)
J F M A M J J A S O N N J F M M A M J J A S O N D J F M A M J J J A S O N D J F M A A M J J A S O N D
81
82
83
84
NEWLY MINED
OLD MINED
UNMINED

SODIUM


B
LOG (mg/l)
J F M A M J J J S O N D J F M M A M J J A S O N D J F M A M J J J A S O N D J F M A M M J J A S O N D
81
82
83
84
NEWLY MINED
OLD MINED
UNMINED

Nickel: Nickel is very toxic to humans, causing capillary and renal damage as well as pulmonary and nervous system disorders. Potable water should not exceed 13.4 micrograms/litre, while sources used strictly for harvest of edible aquatic organisms should not exceed 100 micrograms/litre (Environmental Protection Agency 1980).

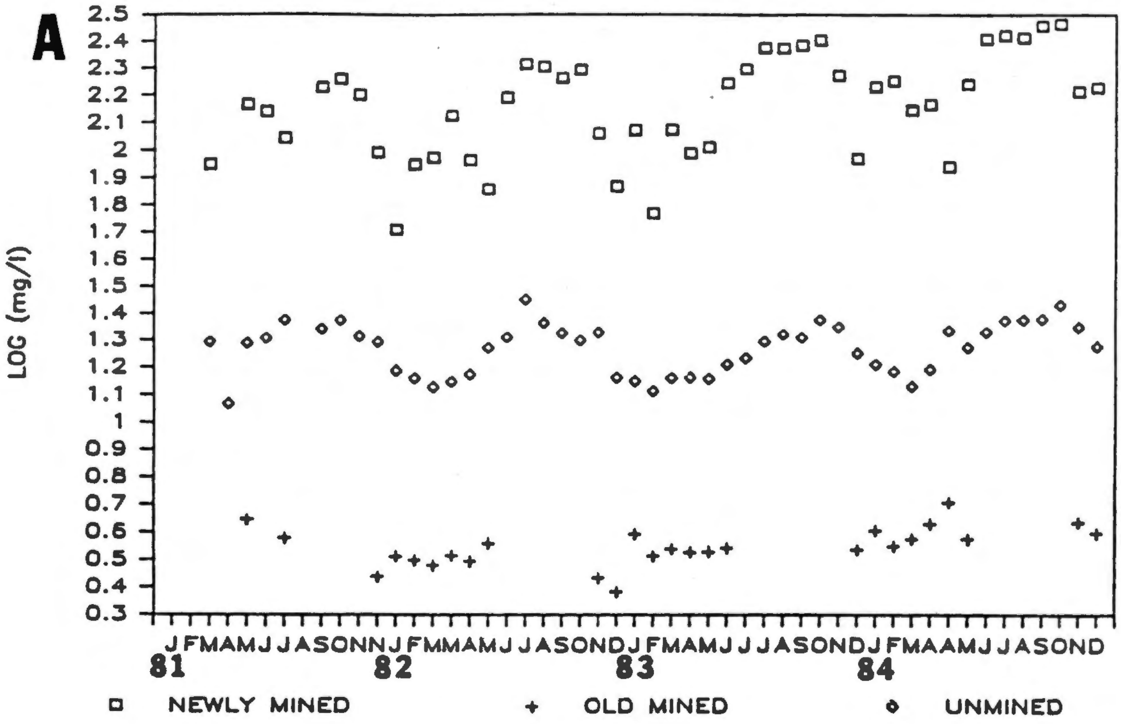
Water quality standards for nickel were very close to the analytical limits of our equipment. Therefore, some of the streams concentration levels maybe either nearer or further from the limit than they appear. The two newly mined watersheds were definitely above the potable water standard and Davis Creek exceeded even the more liberal edible aquatic organism standard by three to four times. The other four watersheds appeared to be below the stated limits.

Calcium: Although water quality standards are not available, calcium concentrations varied greatly between the study areas and over time (Figure 13). Davis Creek had the highest concentrations and showed a highly significant increase during the study period. Denny Cove was second highest in 1981, but by 1984 was comparable to Lake City. The higher than expected levels at Lake City are probably due to washings from the road. Suzanne Creek showed a highly significant increase in calcium levels over the period, probably due to farming activities. The other three watersheds had low concentrations that were fairly stable during the study period.

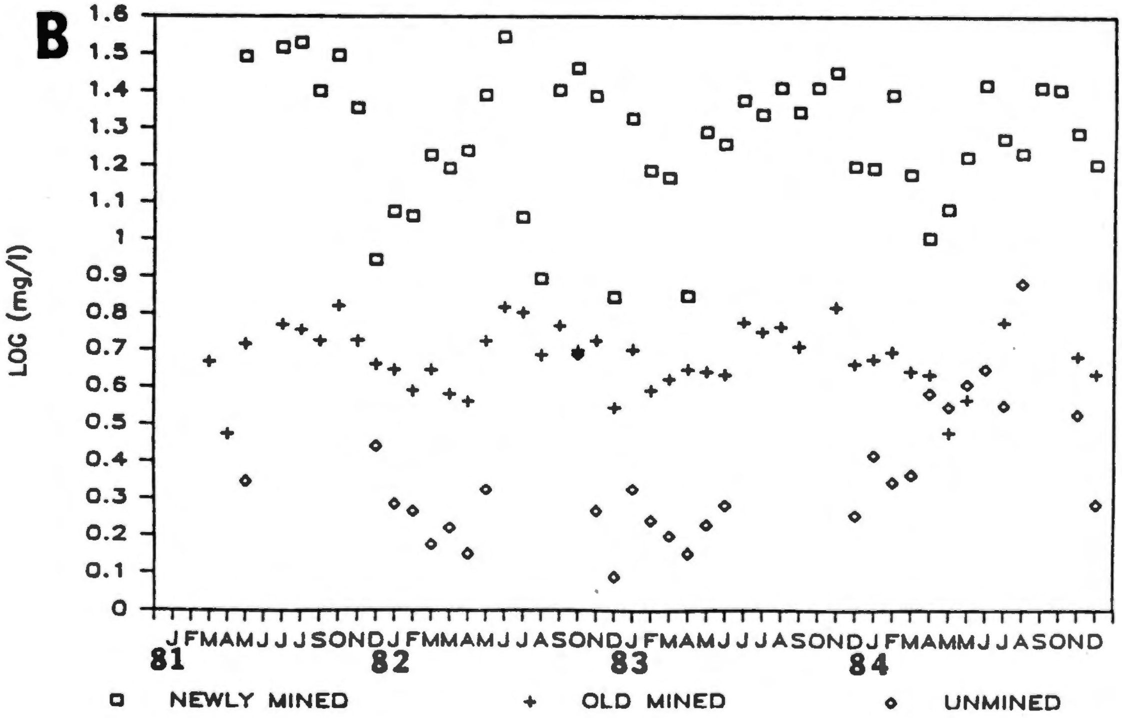
Evaluation of Mining Conditions on Water Quality

Newly mined watersheds showed significantly higher levels for practically all the water quality constituents tested as compared to unmined

Figure 13. Periodic calcium levels from 1981 through 1984. A. Cumberland Mountains streams: newly mined (Davis Creek), old mined (Crooked Fork) and unmined (Lake City). B. Cumberland Plateau streams: newly mined (Denny Cove), old mined (Corn Branch) and unmined (Suzanne Creek).


A
LOG (mg/l)
J FMAMJ J ASONNJ FMMAMJ J ASONDJ FMAMJ J JASONDJ FMAAMJ J ASOND
81
82
83
84
NEWLY MINED
OLD MINED
UNMINED

CALCIUM


B
LOG (mg/l)
J FMAMJ J J SONDJ FMMAMJ J ASONDJ FMAMJ J J ASONDJ FMAMMJ J ASOND
81
82
83
84
NEWLY MINED
OLD MINED
UNMINED

control areas (Table 3). Davis Creek exceeded the water quality criteria for every property that had a standard and continues to decrease in water quality, indicating that this stream is unfit for human use. Since mining operations in this area were not completed until late 1981, the continuing increase may be due to the newness of the disturbed area. Freshly exposed materials weather and are leached, which can cause an increase in stream water constituent levels for the first few years after mining has ceased. The high concentration levels and low pH may also be influenced by the highly acid shale strata that are associated with some of the coal mined.

Denny Cove exceeded water quality standards for iron, TDS, manganese and nickel. Concentration levels declined significantly in nine of the 12 constituents tested, so that by the end of the study some of the levels were nearly the same as those of old and unmined watersheds. Fast recovery of this watershed was probably due to good reclamation practices that enabled rapid site stabilization. The disturbed area is almost completely vegetated, has moderate slopes and if recovery continues at the same rate, the stream water quality will probably return to unmined levels in the next few years.

The old mined watershed, Corn Branch, had significantly higher levels for most of the water quality properties tested than the unmined control, Suzanne Creek. However, only two, turbidity and manganese, were above water quality standards. With the exception of some tree planting, no reclamation measures were taken on this area and there are exposed areas that will take years to revegetate, in spite of the fact that the disturbed area appears to be stabilized. Four of 12 properties

The water quality differences between the old mined area, Crooked Fork, and the unmined site, Lake City, of the Cumberland Mountains were the smallest of the comparisons made (Table 3). However, unlike the other comparisons made, the unmined area had the higher constituent levels. Concentrations of TDS, lead, magnesium, sodium and calcium were significantly higher in the unmined area. This indicated that a land disturbance affecting the stream existed in the unmined area, probably a road. Maps of the two areas showed that the road in the unmined watershed covered more area than the strip mine in the old mined watershed. The small area disturbed by the old stripmine has allowed Crooked Fork to heal in approximately 15 years. The recent mine at the tip of this watershed appears to have had little, if any, influence on stream water quality. Most of the drainage from this site is channeled through a ditch into an adjacent watershed, and in addition, there is a large undisturbed buffer area between it and where the stream surfaces.

Summary and Recommendations for Future Work

This study was carried out to determine the effects of surface mining conditions on stream water quality of six small watersheds in east Tennessee. Analyses of water quality properties showed that, based on EPA water quality standards, strip mining can have a detrimental affect. Seasonal fluctuations of tested water quality property levels and stream flow were evident in most of the watersheds studied, indicating that water quality in the streams changed throughout the year. Length of time after mining was related to water quality, the older the mined area the better the quality, indicating that the areas are recovering.

This study showed that surface mining had a negative impact on water quality. However, it is not coal (which is usually only slightly acidic) itself that causes the problem, but the highly acidic strata commonly associated with it. Any excavation that exposes acid materials, such as road construction, can have the same deleterious effects.

One of the reasons for using small watersheds was to be able to relate water quality to surface mining without having to consider other watershed conditions. However, some of the watersheds did not meet the criteria set up for their selection. The influence of roads was an overriding factor in at least one watershed and others had homesites and cultivated fields that may have contributed to changes in water quality.

In this study, the number of different factors influencing the watersheds, such as watershed size, size of mined area, geology, soils, roads, mine operators, and other watershed uses, made it difficult to isolate the effects of mining on water quality. Some considerations would help correct this problem. One would be to increase the sample size. The second would be long term monitoring to evaluate changes in watersheds over time, preferably starting before mining is initiated. The third would be to use watersheds that have perennial streams both above and below mined areas; this would help correct the problem of variation between watersheds and would mitigate the period of time necessary for stream calibration. The final one would be to include other related factors into the analysis, such as the size of the watersheds, size and location of the disturbed areas within the watersheds and the disturbing factors (ie. mining, road building, etc.), to evaluate their affects on water quality and flow rate.

BIBLIOGRAPHY

BIBLIOGRAPHY

Appalachian Regional Commission. 1969. Acid Mine Drainage in Appalachia. Appalachian Regional Commission, Washington D.C.

Berman, E. 1980. Toxic Metals and Their Analysis. Heyden and Son Ltd. Cambridge University Press, Cambridge G.B.

Buckner, E., T. Simpson, R. Howard and D. Byerly. unpublished. Available Information on Surface Mine Plantings in East Tennessee. Dept. of Forestry, Wildlife, and Fisheries, University of Tennessee, Knoxville.

Claytor, G.C. 1979. An Evaluation of Geochemical Parameters of the Overburden and the Water Quality Associated with Strip Mining of the Sewanee Seam in the Southern Coalfield of East Tennessee. MS Thesis. University of Tennessee, Knoxville, TN.

Dunning, D.E. 1977. Water Quality Characterization and Some Relationships to Coal Surface Mining in Six Primary East Tennessee Watersheds. MS Thesis. University of Tennessee, Knoxville, TN.

Dyer, Kenneth L. 1982. Stream water Quality in the Coal Region of Tennessee. USDA Northeastern Forest Experiment Station. General Technical Report NE-77.

Elder, J.A., E.K. Yates, and I.B. Epley. 1958. Soil Survey of Marion County, Tennessee. USDA Soil Conservation Service.

Englund, K.J. 1968. Geology and Coal Resources of the Elk Valley Area, Tennessee and Kentucky. USGS Professional Paper 572. US Government Printing Office. Washington, D.C.

EPA Office of Water Supply. 1976. National Interim Primary Drinking Water Regulations. EPA-570/9-76-003. U.S. Government Printing Office. Washington, D.C.

Environmental Protection Agency. 1980. Part V: Water Quality Criteria Doucuments; Availability. Federal Register Vol. 45, No. 231, Nov. 28. pp 79318-79378.

Friberg, L., G.F. Nordberg and V.B. Vouk (Editors). 1979. Handbook on the Toxicology of Metals. Elseveir/North-Holland Biomedical Press, Amsterdam Netherlands.

Gale Research Company. 1978. Climates of the States, Volume Two. Book Tower. Detroit, Michigan. p. 910-928.

Gosselin, R.E., H.C. Hodges, R.P. Smith and M.N. Gleason. 1976. Clinical Toxicology of Commercial Products, Acute Poisoning. Williams and Wilkins Co. Baltimore, Md.

Hershey, R.E. 1982. Geologic Map and Mineral Resources Summary of the Altamont Quadrangle, Tennessee. Tennessee Dept. of Conservation, Division of Geology. Nashville, TN.

Hershey, R.E. 1979a. Geologic Map and Mineral Resources Summary of the Mount Airy Quadrangle, Tennessee. Tennessee Dept. of Conservation, Division of Geology. Nashville, TN.

Hershey, R.E. 1979b. Geologic Map and Mineral Resources Summary of the Whitwell Quadrangle, Tennessee. Tennessee Dept. of Conservation, Division of Geology. Nashville, TN.

Hershey, R.E. 1975. Geologic Map and Mineral Resources Summary of the Fork Mountain Quadrangle, Tennessee. Tennessee Dept. of Conservation, Division of Geology. Nashville, TN.

Hubbard, E.H., B.L. Matzek, M.E. Austin, S.R. Bacon, and K.V. Goodman. 1938. Soil Survey of Cumberland County, Tennessee. USDA Soil Conservation Service.

Luther, Edward T. 1959. The Coal Reserves of Tennessee. Department of Conservation and Commerce, Division of Geology. Nashville, Tennessee.

Matlick, J.O. (Chairman). 1965. Strip Mining in Kentucky. Kentucky Dept. of Natural Resources, Strip Mining and Reclamation Commission. Kentucky.

Moneymaker, R.H. 1981. Soil Survey of Anderson County, Tennessee. USDA Soil Conservation Service.

Morgan County Soil Conservation Service, Tennessee. Unpublished. From Private Soil Survey.

Rowe, J.E. (Editor). 1979. Coal Surface Mining: Impacts of Reclamation. Westview Press, Boulder, Colorado.

SAS Institute, Inc. 1984. SAS/ETS User's Guide. SAS Institute, Inc. Cary, North Carolina.

SAS Institute, Inc. 1985. SAS User's Guide: Statistics. SAS Institute, Inc. Cary, North Carolina.

Schaller, F.W. and P. Sutton (Editors). 1978. Reclamation of Drastically Disturbed Lands. Am. Soc. of Agronomy, Crop Sci. Soc. of Am. and Soil Sci. Soc. of Am. Madison, WI.

* Seitz, W.D. (Chairman). 1981. Surface Mining. Committee on Soil as a Resource in Relation to Surface Mining for Coal. National Academy Press. Washington, D.C.

Springer, M.E., and J.A. Elder. 1980. Soils of Tennessee. Bulletin 596. University of Tennessee Agricultural Experiment Station, Knoxville and USDA Soil Concervation Service.

Sunshine, Erving (editor). 1979. Handbook of Analytical Toxicology, Section A: General Data. Volume One. CRC Press. Boca Raton, Florida.

Swingle, G.D. 1959. Geologic Map of the Lake City Quadrangle, Tennessee. Tennesse Department of Conservation, Division of Geology. Nashville, TN.

USDA Soil Conservation Service. Unpublished. Soil Survey of Campbell County, Tennessee.

U.S. Dept. of H.E.W.,Public Health Service. 1962. Public Health Service Drinking Water Standards. PHS Publication #956. U.S. Government Printing Office. Washington, D.C.

U.S. Environmental Protection Angency. 1976. U.S. EPA Quality Criteria for Water. U.S. EPA, Washington D.C.

Venugopal, B. and T.D. Luckey. 1978. Metal Toxicity in Mammals - 2, Chemical Toxicity of Metals and Metalloids. Plenum Press, New York.

APPENDICES

APPENDIX A

GEOLOGY AND STRATIGRAPHY OF THE STUDY AREAS

Cumberland Plateau

The surface geology of all three watersheds is dominated by the Crab Orchard Mountain Group. Of the five strata within this group, only the three lowest ones are present in the study areas. A brief description of each follows.

Newton Sandstone (0 to 110 feet thick): Fine to medium grained sandstone, generally cross-bedded, with high angle crossbeds in thick sets. It is friable and may be conglomeratic and micaceous in places. It contains shale and siltstone interlaminated with sandstone, and subordinate amounts of thin- and thick-bedded ripple sandstone with some sandstone in massive channel fills (Luther 1959).

Whitwell Shale (60 to 200 feet thick, ave. less than 100): Silty shale and siltstone that sometimes contain thin beds of very fine-grained sandstone, with two coal seams. Richland coal, found near the base, is covered with a thin layer of sandstone (sometimes conglomeratic in nature). Sewanee coal, found near the middle, has been mined extensively in the plateau region (Luther 1959). This pH of the coal is about five and it is often covered by extremely acid black shale with a pH around 2.8 (Buckner et al. unpublished).

Sewanee Conglomerate (0 to 160 feet thick, ave. 80): Sandstone and conglomeratic sandstone that is fine- to coarse-grained with quartz pebbles up to one-half inch long. It is generally cross-bedded with high angle crossbeds in thick sets. There are many massive channel fills and it is partly ferruginous or calcareous (Luther 1959).

Cumberland Mountains

The surface geology of these watersheds include four groups of strata (the Red Oak Mountain, Graves Gap, Indian Bluff, and Slatestone groups) and a variety of coal seams. This large variety is due to the steepness of the watersheds; elevation changes within the watersheds range from 610 to 1230 feet. A brief description of each group and its strata follows.

RED OAK MOUNTAIN GROUP: This group contains seven strata alternating between shale and sandstone. Only the bottom shale interval which is 80 to 190 feet thick is found in the study areas. The Big Mary coal seam is in the lower part and the Beech Grove seam is near the top (Luther 1959).

GRAVES GAP GROUP (200 to 365 feet thick): This group contains six stratigraphic units: Windrock coal at the top, followed by a shale interval; Roach Creek sandstone, another shale interval; Armes Gap sandstone and the lowest shale interval. Each unit will be described (Luther 1959).

Windrock Coal: Less than 28 inches in the study areas. It has a pH between 3.5 and 5.5 (Buckner et al. unpublished) and is underlaid by a distinctive flinty underclay.

First Shale Interval: Between five and 90 feet thick, it may contain Craig coal near its base. Where the coal is found, a thin sandstone layer is between it and the Windrock coal.

Roach Creek Sandstone: Usually between 20 and 80 feet thick, it is variable and may range from well developed to absent.

Middle Shale Interval: Usually between 60 and 130 feet thick, it contains two minor coal seams, the Upper Pioneer coal found near the middle and Lower Pioneer coal found near the base. A thin sandstone is usually found between the two coals.

Armes Gap Sandstone: Sandstone ranging from zero to 70 feet thick, it can be massive and heavy-bedded or thin-bedded and shaly.

Lowest Shale Interval: Shale between 105 and 200 feet thick which may contain two coals, Norman Pond, when present, found near the middle of the stratum and Jordan, near the base.

INDIAN BLUFF GROUP (200 to 470 feet thick): Contains eight stratigraphic units, alternating between sandstone and shale. The top one is Pioneer sandstone, followed by shale, Indian Fork sandstone, another shale layer, Stockstill sandstone, a third shale interval, Seeber Flats sandstone, and finally the lowest shale interval. All sandstones in this group range in thickness from zero to 80 feet, with Pioneer sandstone the least variable. They can be massive, thin-bedded or nonexistent. Most seem to be fine-grained (Luther 1959).

First Shale Interval: Top shale layer ranging between 25 and 80 feet thick, averaging 35, and contains the thin noncommercial Indian Fork coal near its base.

Second Shale Interval: Between 25 and 100 feet thick, averaging 50, it contains the thin Stockstill coal seam.

Third Shale Interval: From 40 to 120 feet thick, averaging 80. The

Joyner coal seam is found in this stratum and it has been mined in some of the study watersheds.

Lowest Shale Interval: Between 40 and 120 feet thick and averages 75.

SLATESTONE GROUP (300 to 720 feet thick, ave. 600): This is the lowest of the upper shaly sequence of Pennsylvanian beds. This group contains nine stratigraphic units. A description of each unit follows, starting with the upper most (Luther 1959).

Jellico Coal: Occupies the top stratum and is less than 42 inches thick in the study areas. It has a pH between 3.5 and 5.5, and is covered by a very acid shale (Buckner et al. unpublished).

Newcomb Sandstone: Rather thin, irregular, and discontinuous, it ranges from zero to 60 feet, averaging 20.

First Shale Interval: Ranges in thickness from 40 to 120 feet and averages about 90. Terry Creek coal is sometimes found near the base.

Sand Gap Sandstone: A massive, thick sandstone found over much of the area. It is locally absent, but it may be as much as 100 feet thick.

Second Shale Interval: Between 40 and 170 feet thick and averages about 100. The Blue Gem coal seam is near the top of this unit. A thin, but persistent, sandstone underlies the coal in most areas.

Petros Sandstones: Consists of the Upper Petros and Lower Petros sandstones. They are separated by a thin shale that usually contains the Petros or Black Wax coal seam. The stratum is commonly 40 to 60 feet thick, but it may be locally absent.

Third Shale Interval: Between 40 and 190 feet thick, with the Coal Creek coal seam found near the base. This coal has a pH between 2.8 and 6.1 (Buckner et al), and has been mined in parts of the study areas.

Stephens Sandstone: A thin-bedded, fine-grained sandstone that ranges from zero to 40 feet thick.

Lowest Shale Interval: From 30 to 240 feet thick, it averages about 175. Its base rests on the Poplar Creek coal seam. It also contains a thin, discontinuous sandstone.

APPENDIX B

SOIL DESCRIPTIONS

Cumberland Plateau

All soils of the plateau watersheds were formed from weathered products of nearly hortizontal sandstone, with the result that there are few differences in the various soil series. All but one are very permeable to roots and water and are highly susceptible to erosion if cultivated or disturbed (Elder et al. 1958). The soil series are as follows:

Muskinghum stony-fine sandy loam, rolling phase (5-12% slope): An excessively drained, shallow upland soil with a pH between 5.1 and 5.5 and sandstone fragments on the surface and throughout the profile. Some white quartz pebbles are also scattered throughout the soil. Bedrock is usually one to two feet deep, but outcrops of bedrock are common. Internal drainage is rapid and water supplying capacity is low (Elder et al. 1958).

Muskinghum stony-fine sandy loam, hilly phase (12-25% slope): Differs from the rolling phase by occurring on steeper slopes and being slightly shallower and stonier. Some areas have lost much of their surface layer (Elder et al. 1958).

Hartsells fine sandy loam, rolling phase (5-12% slope): Subject to erosion. It averages between two and five feet deep, with shallow areas and bedrock occasionally exposed. Internal drainage and water supplying capacity are all medium. In areas used for pasture and crops, an eroded rolling phase may be present. Here, erosion has removed 25 to 75 percent of the original surface layer (Elder et al. 1958).

Linker loam, rolling phase (5-12% slope): A friable well-drained soil of the rolling uplands, it is formed from thick-bedded conglomerate or of almost level-bedded acid sandstone. This soil has less sand than Hartsells soils and has few stones. The pH of this soil is between 5.1 and 5.5. and internal drainage is medium to high. In areas used for crops or pastures, an eroded rolling phase may exist, where 25 to 75 percent of the original surface layer has been lost (Elder et al. 1958).
Cotaco and Atkins silt loams (0-3% slope): These are imperfectly drained soils formed from alluvial-colluvial deposits, with patterns so intricate it is not feasible to separate them. They are formed from materials washed or rolled mainly from the Hartsells and Muskinghum soils. The pH is between 4.5 and 5.0. and areas in saucerlike depressions around heads of drains have no surface drainage, causing ponding of water in the winter and other wet periods. Internal drainage is slow (Elder et al 1958).

Cumberland Mountains

These soils are much more variable in composition and characteristics than the plateau soils. The parent material for some is a mixture of shale, siltstone and sandstone. A description of each follows:
Muskinghum silt loam (20-60% slope): A moderately deep, well-drained soil on steep mountain slopes and on long, linear, steep ridges in the valley. It is formed from weathered shale, siltstone and sandstone. Coarse fragments of shale, siltstone and sandstone are found throughout the subsoil. Permeability is moderate and available water capacity is low (Moneymaker 1981).

Gilpin silt loam (5-20% slope): A moderately deep, well-drained soil formed in residuum of shale and siltstone. It has a range in pH from 3.6 to 5.5. Permeability is moderate and available water capacity is medium. Erosion hazard is slight under forested conditions (Moneymaker 1981).

Jefferson fine sandy loam (12-25% slope): A deep, well-drained soil formed from shale and sandstone colluvium; it contains five to ten percent pebbles and has a pH between 4.5 and 5.5. Soil depth is approximately 66 inches. Permeability is moderately rapid and available water capacity is high (Moneymaker 1981).

Jefferson soils (20-50% slope): These are moderately steep to steep loamy soils with a wide range of stone content. A typical area is about 50 percent Jefferson cobbly loam, 25 percent Jefferson gravelly loam, 15 percent Jefferson loam and 10 percent Grimsley soils. The Grimsley soils are mainly found near drains. Soil depth is approximately 66 inches and pH is between 4.5 and 5.5. The cobbly loams have a medium water holding capacity and a moderate erosion hazard. Jefferson soils differ only in the amount of coarse material they contain (Moneymaker 1981).

Grimsley stony loam (15-50% slope): A well-drained soil of coves and lower mountainsides formed from sandstone and shale colluvium. Soil depth is about 58 inches and the pH is between 4.5 and 5.5. Available water capacity is low and permeability is moderately rapid. This soil contains many cobbles and stones and has a moderate erosion hazard (Moneymaker 1981).

Ramsey-Rock outcrop complex (25-65% slope): Contains areas of steep Ramsey soils and Rock outcrops so intermingled that they could not be mapped separately. Ramsey sandy loam makes up 60 to 80 percent of each mapped unit, with sandstone bedrock about 14 inches deep. It is excessively drained and permeable. The pH is between 4.5 and 5.5, and sandstone outcrops protrude two to ten feet above the surface (Moneymaker 1981).

Barbourville stony fine sandy loam (2-7% slope): Formed from recent colluvium or alluvium of Muskinghum and Jefferson soils, it is fairly high in organic matter and moderately well supplied with nutrients. The pH range is from 5.1 to 6.0 and internal drainage is moderately rapid. Numerous stones, up to 12 inches across, are found throughout the soil (Elder et al. 1958).

Jefferson gravelly loam (5-15% slope): Deep and well-drained, this soil is formed from sediments moved downslope from soils underlain by sandstone and shale. Bedrock is found at a depth of around 66 inches. Pebbles usually make up 20 to 25 percent of the soil, but may be absent. The pH for this soil is between 4.5 and 5.5. Available water capacity is medium and permeability is moderately rapid (Moneymaker 1981).

Bethesda soils (0-70% slope): Deep, well-drained soils formed in a mixture of partially weathered fine earth and fragments of shale, sandstone, coal and siltstone which has been recently exposed by surface mining. Depth to bedrock is greater than five feet. This soil contains many coarse fragments, including boulders. Permeability is moderately slow and pH ranges from 3.6. to 6.0 (USDA SCS unpublished).

Jefferson-Grimsley complex (30-60% slope): These are small areas of

Jefferson gravelly and Grimsley stony loams so intermingled that they could not be mapped separately. Stones and cobbles make up one-third to one-half of the soils volume (Moneymaker 1981).

Muskinghum-Gilpin-Petros complex (15-60% slope): Small areas of Muskinghum, Gilpin, and Petros soils so intermingled that they could not be mapped separately. The Muskinghum silt loam, which comprises 40 to 60 percent of the area, and Gilpin silt loam, which comprises 25 to 45 percent, have already been discussed.

Petros shaly silt loam is an excessively drained soil formed in residuum from weathered products of shale and siltstone. It makes up 10 to 20 percent of the complex and has a pH between 4.5 and 5.5. Hard rippable bedrock occurs around 25 inches deep. Available water capacity is low and erosion hazard is moderate (Moneymaker 1981).

Muskinghum-Sequoia-Petros complex (30-60% slope): The three soil types are in such a mixture that they could not be mapped separately. Muskinghum silt loam, which makes up 40 to 60 percent, and Petros shaly silt loam, which makes up 10 to 20 percent of the unit, have already been described.

Sequoia silt loam makes up 25 to 45 percent of this complex. It is a well-drained, moderately permeable soil formed in residuum of acid shales and siltstones. Soft shale bedrock begins around 38 inches in depth, with hard shale below five feet. Available water capacity is medium and pH is between 4.5 and 5.5 (USDA SCS unpublished).

APPENDIX C

DESCRIPTION OF STUDY AREAS

Cumberland Plateau

Unmined, Suzanne Creek, Brayton Quad, Bledsoe County: This watershed was around 132 acres in size with an eastern aspect. The elevation from confluence to ridgetop was about 160 feet. Forest cover (Figure 14) was mainly mature hardwoods of white (*Quercus alba*), scarlet (*Q. coccinea*), chestnut (*Q. prinus*) and black oak (*Q. velutina*) and hickories (*Carya* spp.). Black gum (*Nyssa sylvatica*), and sourwood (*Oxydendrum arboreum*) were also found, with red maple (*Acer rubrum*) and yellow poplar (*Liriodendron tulipifera*) more promminent in the bottoms. The understory contained young of the overstory, dogwood (*Cornus* spp.), sassafras (*Sassafras albidum*), *Vaccinium* spp., *Gaylussacia* spp. and *Smilacina* spp., with various mosses, ferns, some yellow poplar and green brier (*Smilax* spp.) in the bottoms. Younger hardwood stands consisted of scarlet and chestnut oak, sourwood and sassafras, with hickories, black gum and oaks in the understory.

The cultivated fields contained mixtures of corn, soy beans and personal gardens during the study period. Fallow fields contained a large variety of vegetation including, red (*Trifolium pratense*), white (*Trifolium repens*), and yellow sweet clover (*Melilotus officinalis*), fescues (*Festuca* spp.), crown vetch (*Coronilla varia*) and brambles (*Rubus* spp.). The fields also had sassafras, hickories, grapevines (*Vitis* spp.), winged sumac (*Rhus copallina*), purslane (*Portulaca oleracea*) and black locust (*Robinia pseudoacacia*). Most trees and shrubs

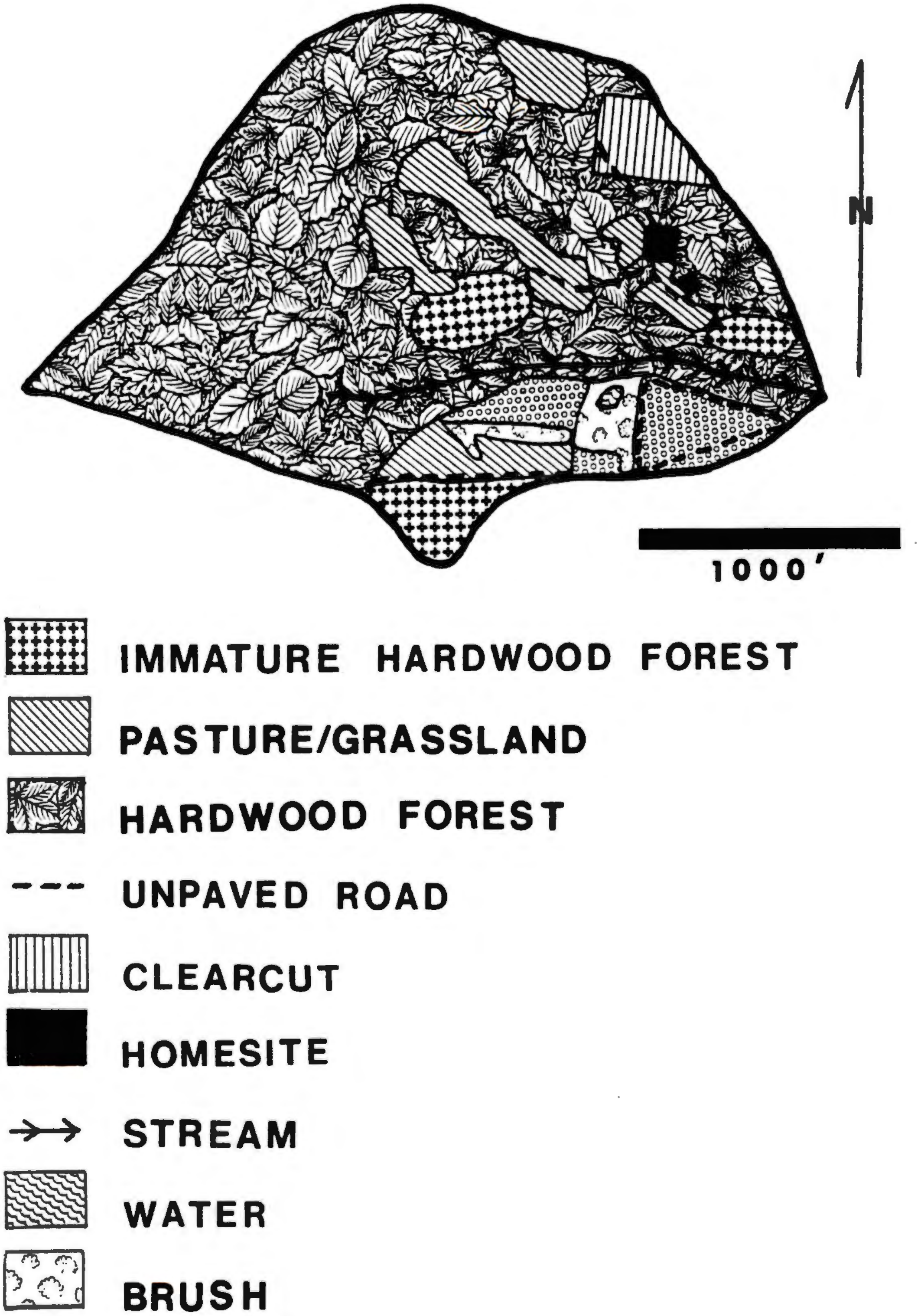


Figure 14. Suzanne Creek study area, land cover.

were between two and six feet tall and covered less than 10 percent of the area.

The surface geology of this watershed contained one stratigraphic unit, Newton Sandstone layer (Hershey 1979) and the only mapped soil type, according to (adjacent) soil maps, was Muskinghum stony fine sandy loam, rolling phase (Hubbard et al. 1938). However, this soil does not lend itself to agriculture due to its stoniness. Since this area had been farmed, the soils were more probably Hartsells fine sandy loam, rolling phase or Linker loam, rolling phase or a combination of the soil types mentioned.

There were houses on this watershed and during the summer the stream could be dry for two to three months.

<u>Newly Mined, Denny Cove, White City Quad, Marion County:</u> This watershed was about 88 acres in size and has a western aspect. Elevation from the confluence to ridgetop was 220 feet. Approximately 25 percent of the watershed was disturbed by surface mining activities between 1975 and 1979 (Dyer 1982) (Figure 15). Sewanee Coal was mined at an elevation of around 1850 feet (Hershey 1979). The coal had a pH around five and was often covered by a very acid black shale with a pH of 2.8 (Buckner et al. unpublished).

The mined area was almost completely revegetated with orchard grass <u>(Dactylis glomerata)</u>, clovers, and 10 to 15 foot black locust. Small gullies were present but they are now grassed and stable. The flume was located directly below a very shallow pond. The open area around the pond was vegetated with a variety of early successional species including cattails <u>(Typha spp.)</u>, grasses, brambles, sassafras, Virginia pine

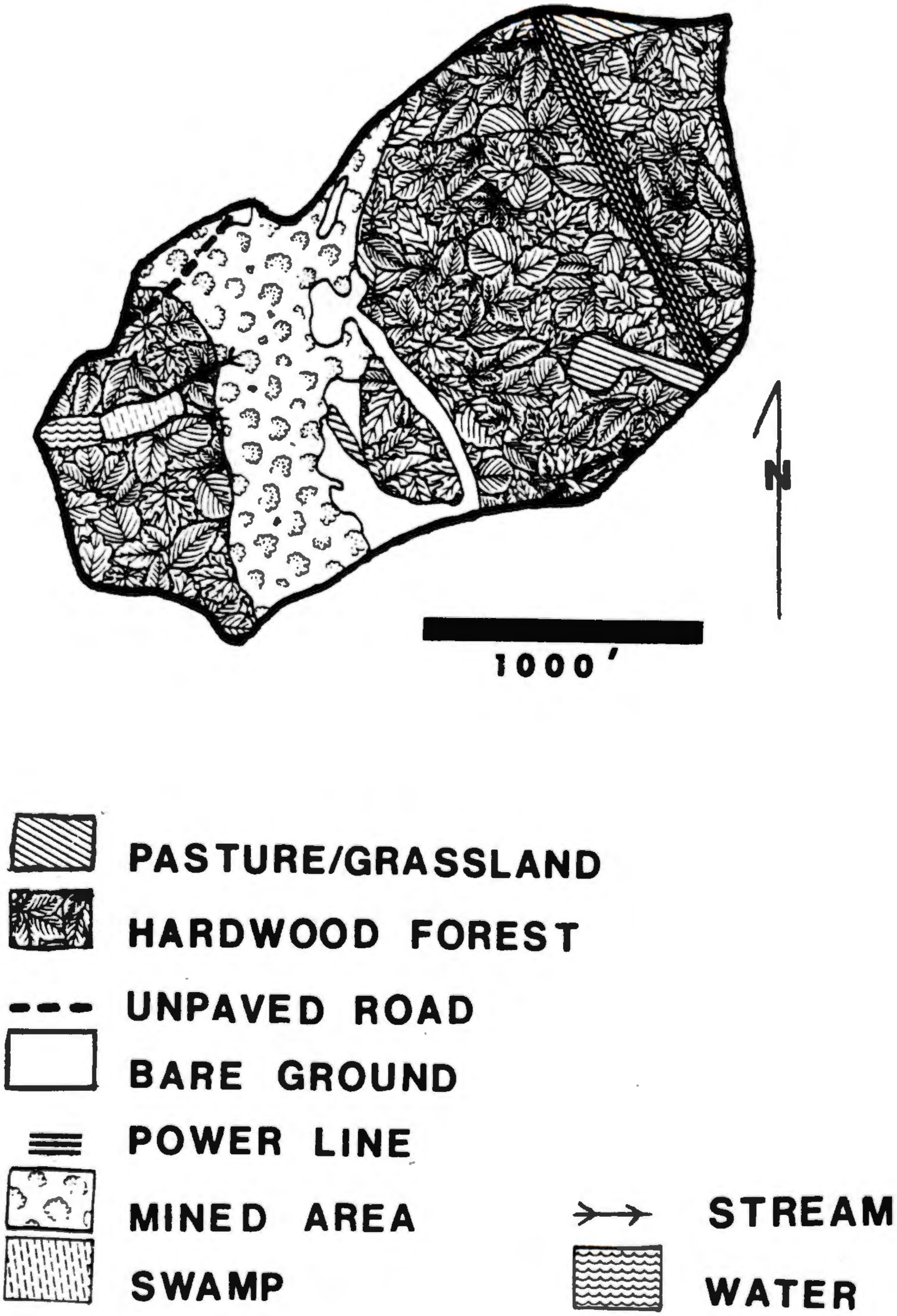


Figure 15. Denny Cove study area, land cover.

(Pinus virginiana), sourwood, black locust, sumacs (Rhus spp.), yellow poplar and red maple.

Above the pond was a swampy area with many dead trees, and some live red maple, sweet gum (Liquidambar styraciflua), black willow (Salix nigra), sedges (Cyperaceae), grasses and cattails. Above the swamp the stream bed was very orange where subsurface mine drainage surfaces.

Forest overstory was uniform and consists mainly of white, chestnut and scarlet oaks, hickories, scattered Virginia and shortleaf (Pinus echinata) pines and eastern red cedar (Juniperus virginiana), with some yellow poplar and red maple in the hollows. Large sweet gums and yellow poplars were found adjacent to the swamp. The understory consisted of a variety of oaks, hickories, dogwood, sourwood, black gum, green brier, grapevine, Vaccinium spp., Gaylussacia spp., sassafras and azaleas (Rhododendron spp.).

The surface geology of this watershed (Figure 16) included Newton sandstone from 1880 to 1980 feet, Whitwell shale from 1810 to 1880 feet and Sewanee conglomerate from 1760 to 1810 feet (Hershey 1979). Four different soil types were found within this area (Figure 17) (Elder et al. 1958).

Old Mined, Corn Branch, Tracy City Quad, Grundy County: This watershed was about 140 acres in size and had a southwestern aspect. Elevation from confluence to ridgetop was 120 feet. Approximately 30 percent of the area was disturbed by surface mining before 1972 (Dyer 1982). Sewanee coal, with a pH of five and usually covered by black acid shale, was mined at around 1900 feet (Hershey 1979). The rest of the watershed

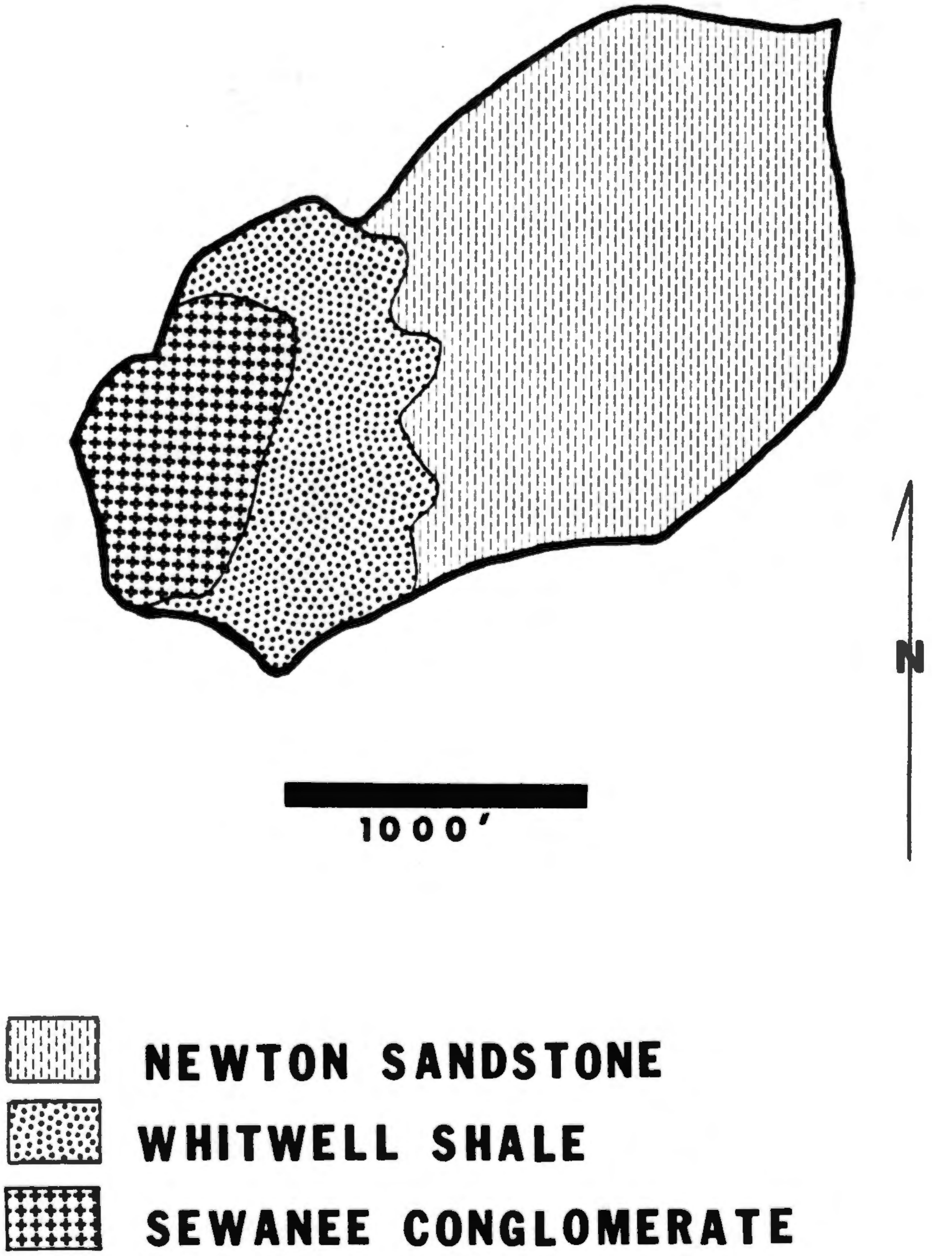


Figure 16. Denny Cove study area, surface geology.

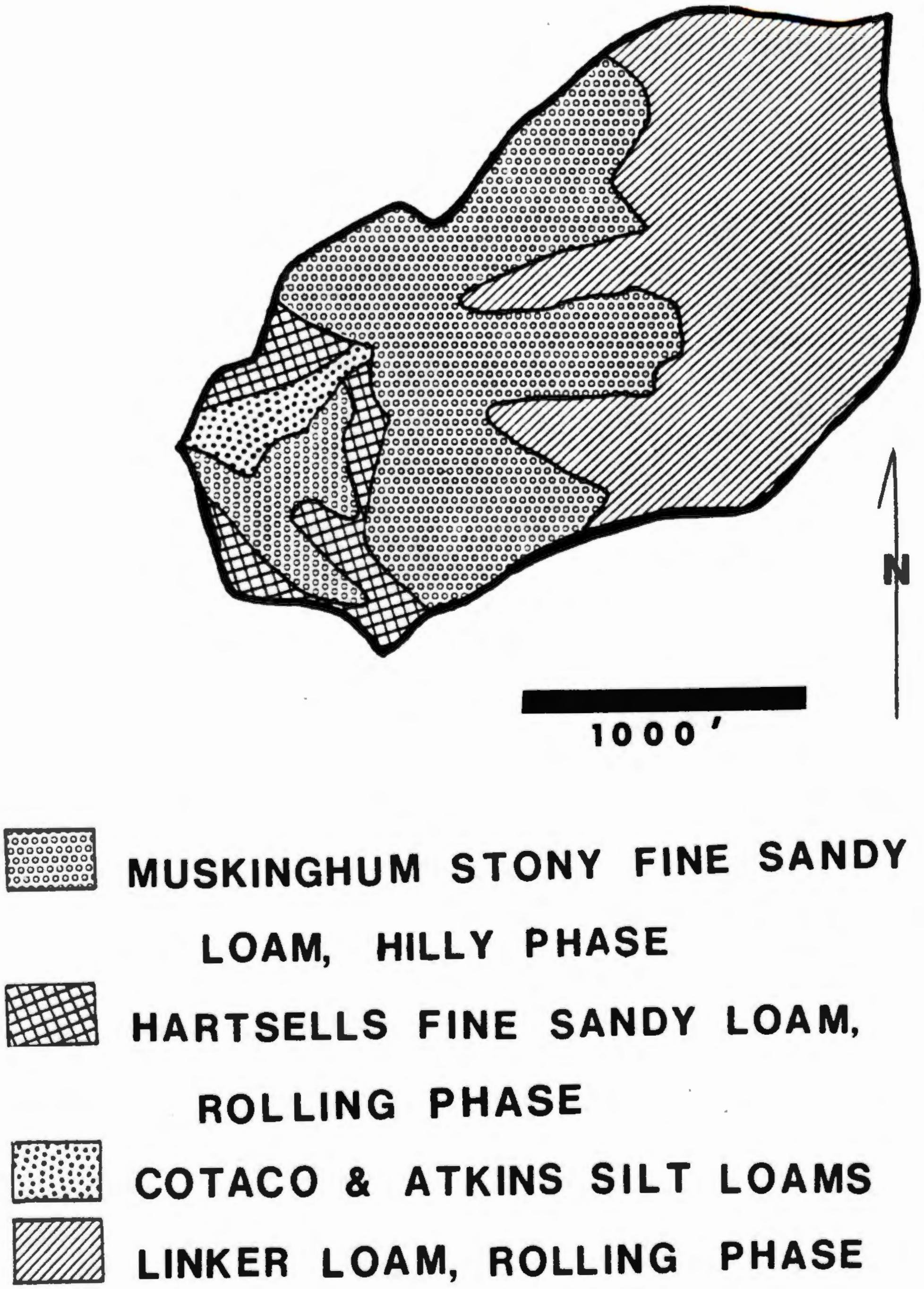


Figure 17. Denny Cove study area, soils.

was a mixture of forest, hayfields, grasslands, and homesites (Figure 18). The stream was intermittent in the summer.

Most bare areas in this watershed were on the edges of the disturbed areas and had compacted soils and large deep gullies. A number of ponds were found in the gullies. The spotty vegetation around barren areas consisted of Virginia pine, grasses and Vaccinium spp. on the east side, and loblolly pine (Pinus taeda), brambles and grasses on the west side. The central disturbed area had loblolly and Virginia pines, sassafras, sourwood, yellow poplar and black cherry (Prunus serotina). There were many early successional shrubs, brambles and grasses. This area had many ridges and furrows remaining from the mining operation. Most of the vegetation was between five and 15 feet tall, however on the western side there was a stand of loblolly pine with trees up to 12 inches in diameter.

A swampy area below the disturbed area contained mostly sweetgum and yellow poplar. On drier slopes and ridgetops there were white, scarlet, post (Quercus stellata), chestnut and black oak, sweet gum, hickories, sourwood, sassafras, black gum and red maple. The understory consisted of young of the overstory, especially hickory, along with dogwood, green briar, Vaccinium spp. and Gaylussasia spp.

The surface geology (Figure 19) consisted of Newton sandstone from 1940 to 2010 feet and Whitwell shale from 1890 to 1940 feet (Hershey 1979, 1982). Hartsells fine sandy loam, rolling phase, was found along the ridges and Muskinghum stony fine sandy loam, hilly phase, on the slopes (Figure 20) (Elder et al 1958).

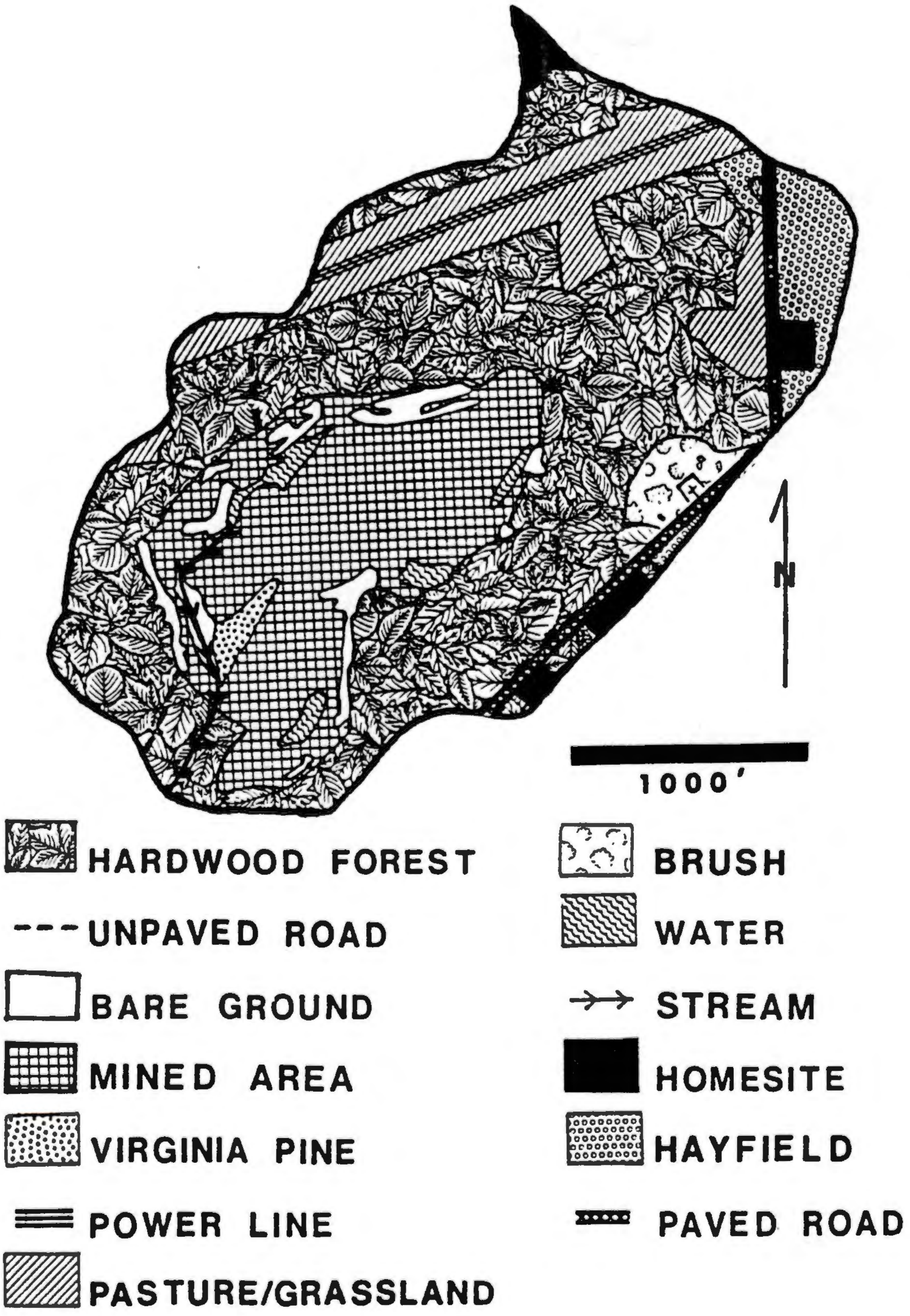


Figure 18. Corn Branch study area, land cover.

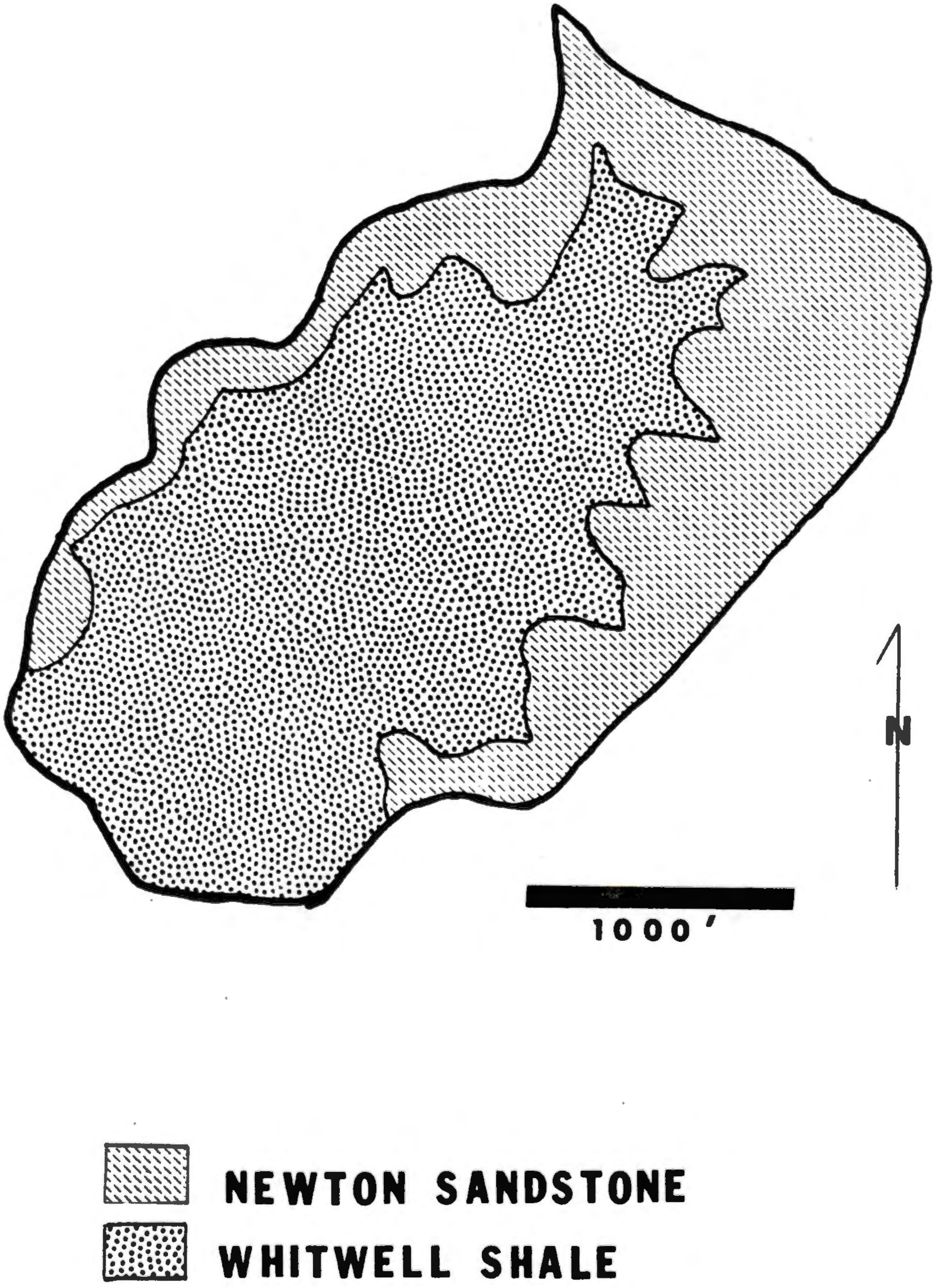


Figure 19. Corn Branch study area, surface geology.

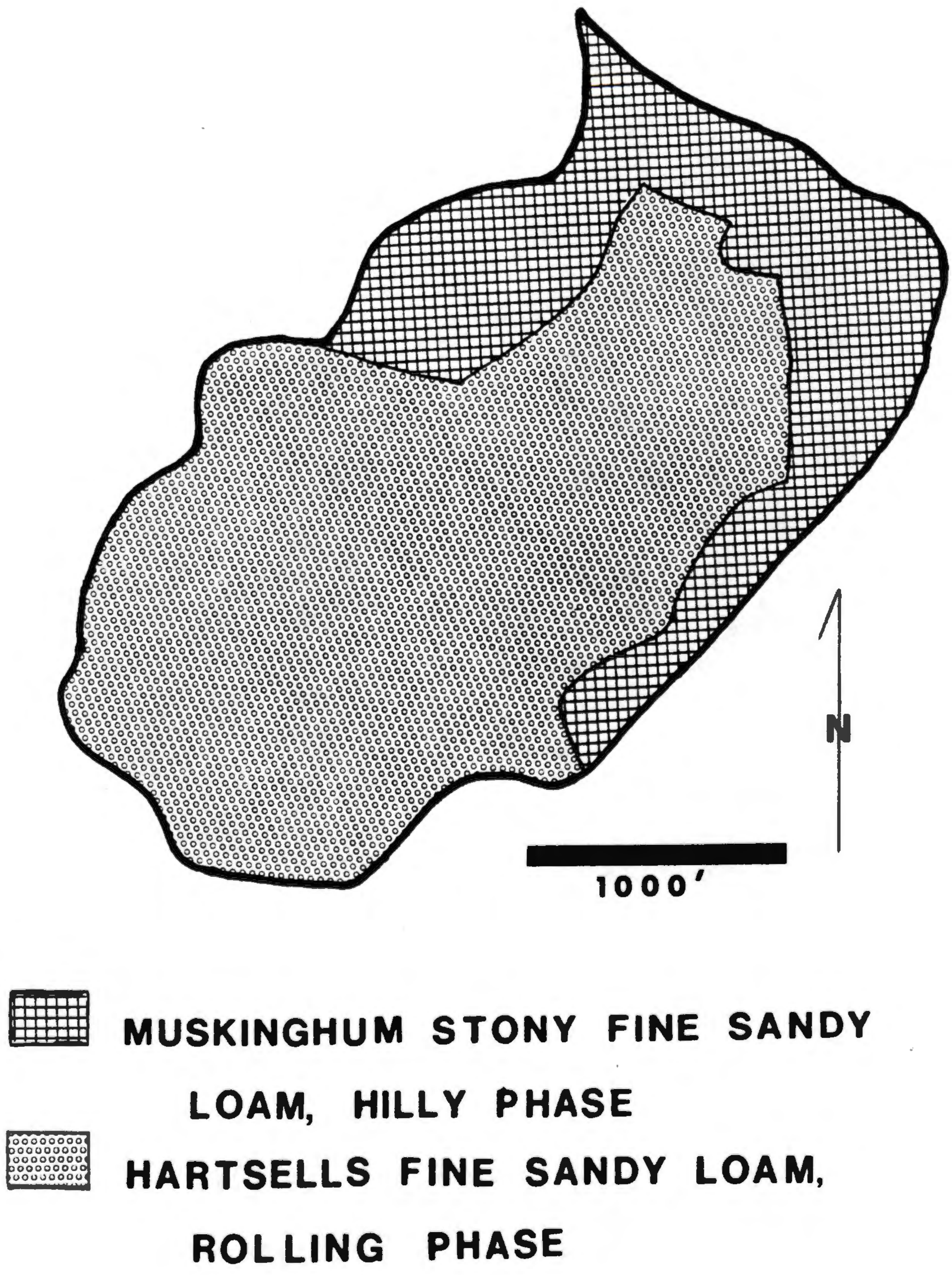


Figure 20. Corn Branch study area, soils.

Cumberland Mountains

Unmined, Lake City, Lake City Quad, Anderson County: This watershed was around 88 acre in size and had an eastern aspect. Elevation from the confluence to the ridgetop was about 1220 feet. It was almost completely forested except for a few houses (Figure 21). Materials from the road were washing into the stream and dumping from the road in at least one area had resulted in household trash of all types in and adjacent to the stream. In addition, the stream banks were sloughing off in some of the steeper areas. The drainage area was quite rocky and small rock outcrops were present. This stream flowed continuously and usually had algal growth in the flume.

The forest in the upper half of the watershed was open and had many ice damaged trees. Major species in the overstory were hickory, yellow poplar, red maple, black cherry (Prunus serotinus) and chestnut oak. Northern red oak (Quercus rubrum) and white oak were also found in hollows. Brush and brambles were found in the understory along with dogwood, black locust, green brier and young of overstory. Some Virginia pine and mountain laurel (Kalmia latifolia) were found on the ridges.

The lower half of the watershed had no ice damage and contained less brush and brambles in the understory. The overstory consisted of chestnut, white and northern red oak, sweetgum, red maple and basswood on the upper end, with sycamore (Platanus occidentalis), balck cherry, yellow poplar and American beech (Fagus grandifolia) near the mouth. The understory consisted mainly of trilliums (Trillium spp.), false nettle (Boehmeria cylindrica), jewel weed (Impatiens pallida) and yellow buckeye (Aesculus octandra) along the bottom and dogwood, sassafras,

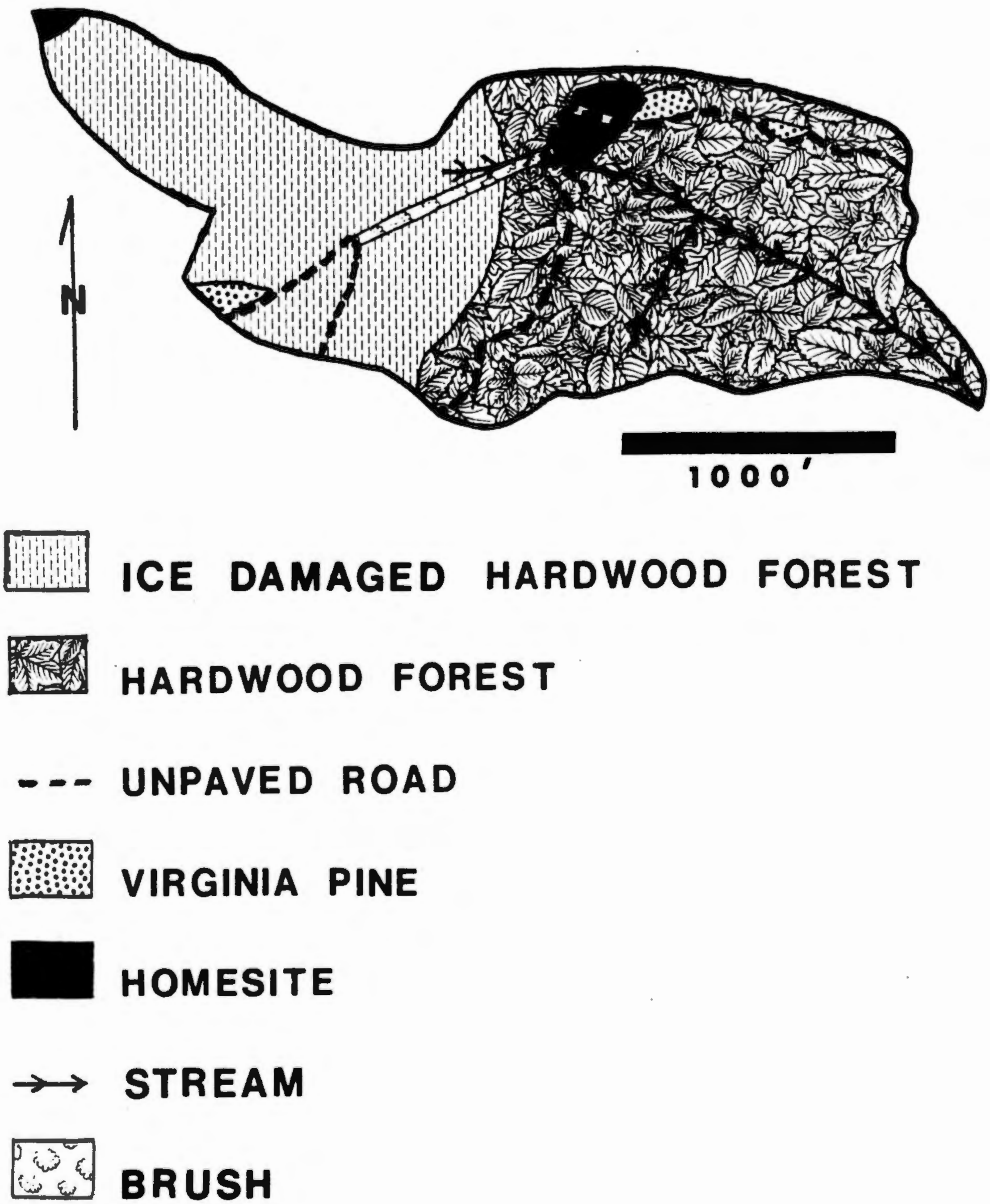


Figure 21. Lake City study area, land cover.

poison ivy (Rhus radicans), green brier, Virginia creeper (Parthenocissus quinquefolia), ferns, Vaccinium spp. and Gaylussacia spp. elsewhere.

Its surface geology included three stratigraphic groups (Figure 22): the Graves Gap group from 1900 to 2150 feet, the Indian Bluff group from 1420 to 1900 feet and the Slatestone group from 930 to 1420 feet (Swingle 1959). Five soil types had been mapped (Figure 23) (Moneymaker 1981).

Newly Mined, Davis Creek, La Follette Quad, Campbell County: This watershed was approximately 259 acres in size and had a western aspect. The elevation from the confluence to the ridgetop was about 610 feet. Approximately 35 percent of the area had been disturbed by surface mining since 1972, the most recent operation completed in late 1981. Three, possibly four different coal seams had been mined from this area: Jellico coal at around 1800 feet, Blue Gem coal (according to adjacent geologic maps) at 1650 feet, Petros or Black Wax coal (according to the Tennessee Department of Geology) at 1550 feet and Coal Creek coal was mined near the base. A very narrow buffer strip appeared to have been left along the stream.

With the exception of a few homes near the mouth of the watershed, the undisturbed area was hardwood forest (Figure 24). There were many new dirt roads through the forested section and some drill holes, probably from oil and gas exploration activities. Some of these roads, as well as a power line access road, drained directly into the stream. The forest overstory consisted of white, chestnut and scarlet oak, hickory, yellow poplar, red maple and black cherry, while bottoms and coves had more yellow poplar and beech with hemlock (Tsuga canadensis) and great

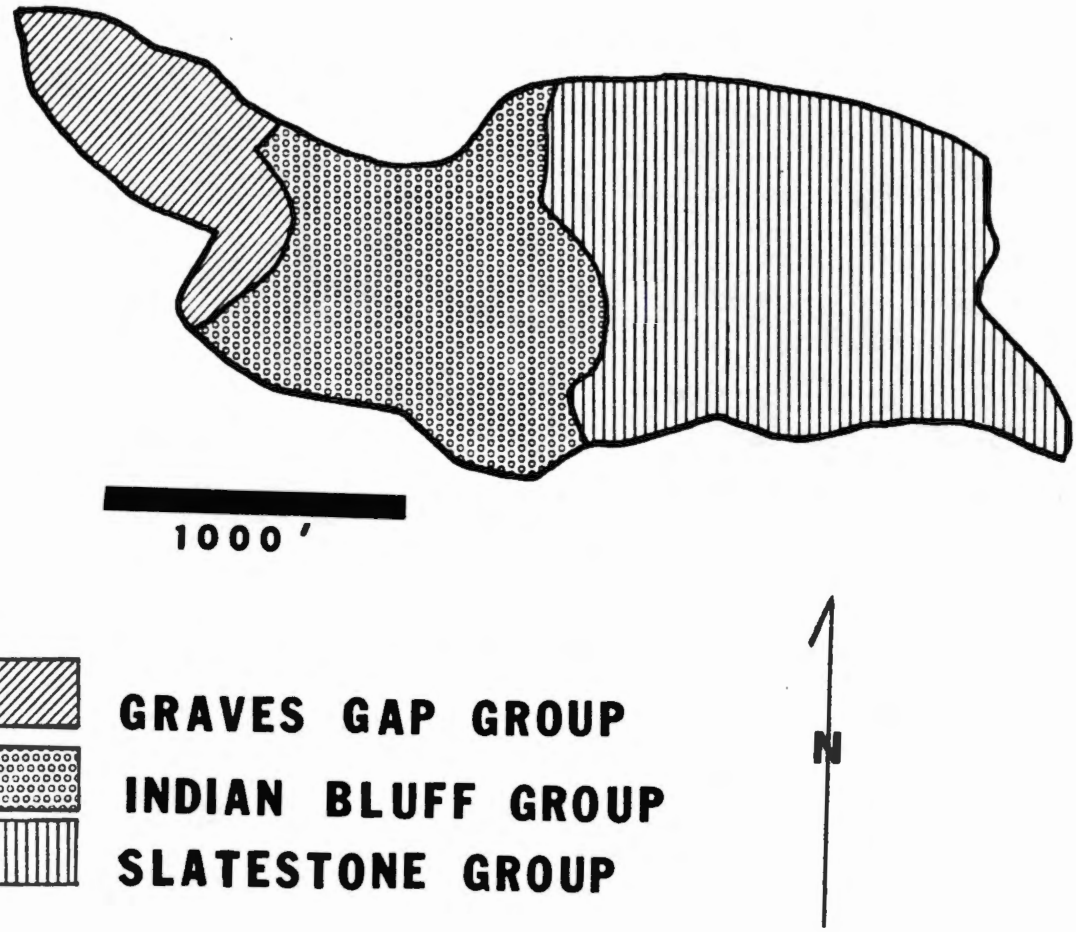


Figure 22. Lake City study area, surface geology.

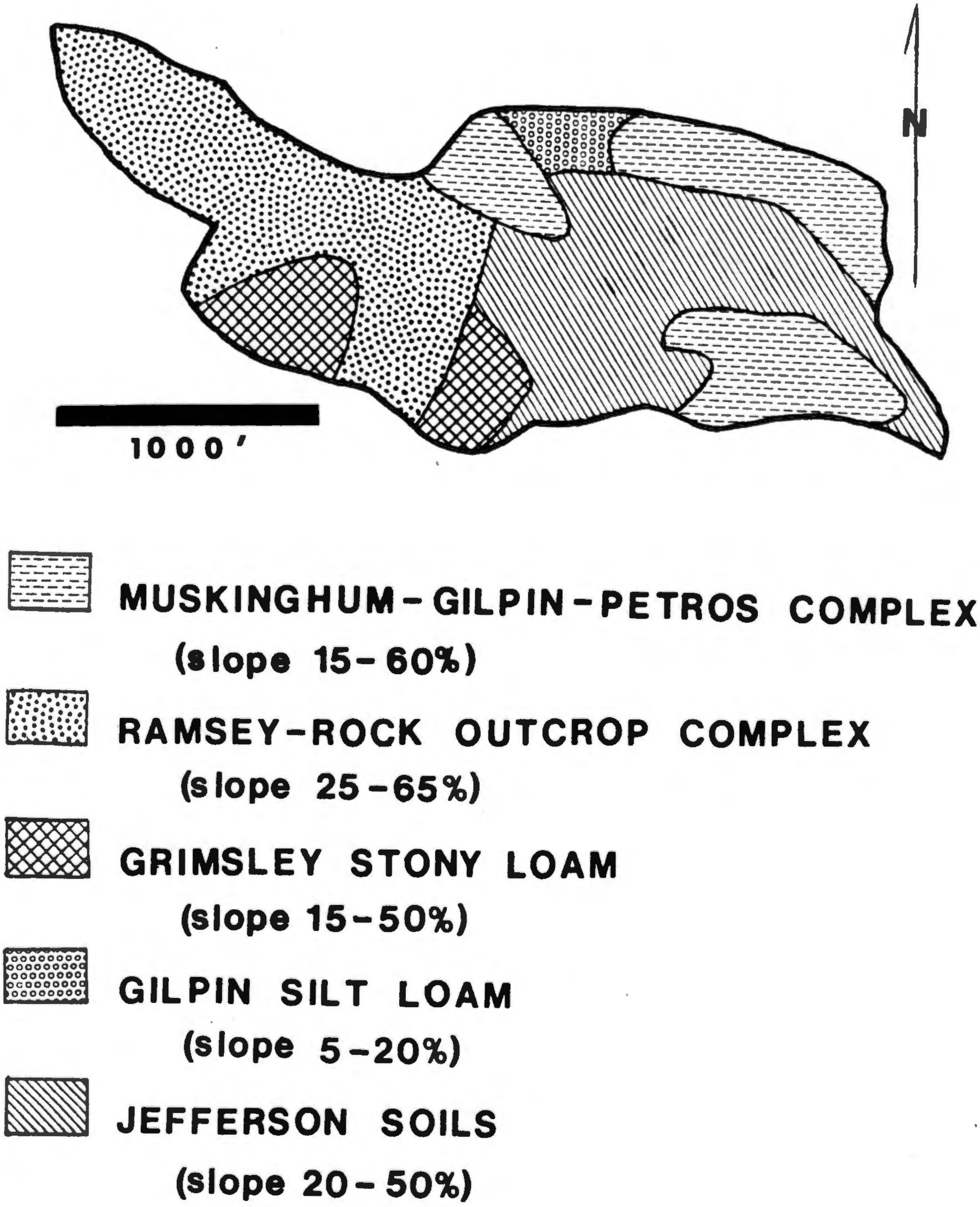


Figure 23. Lake City study area, soils.

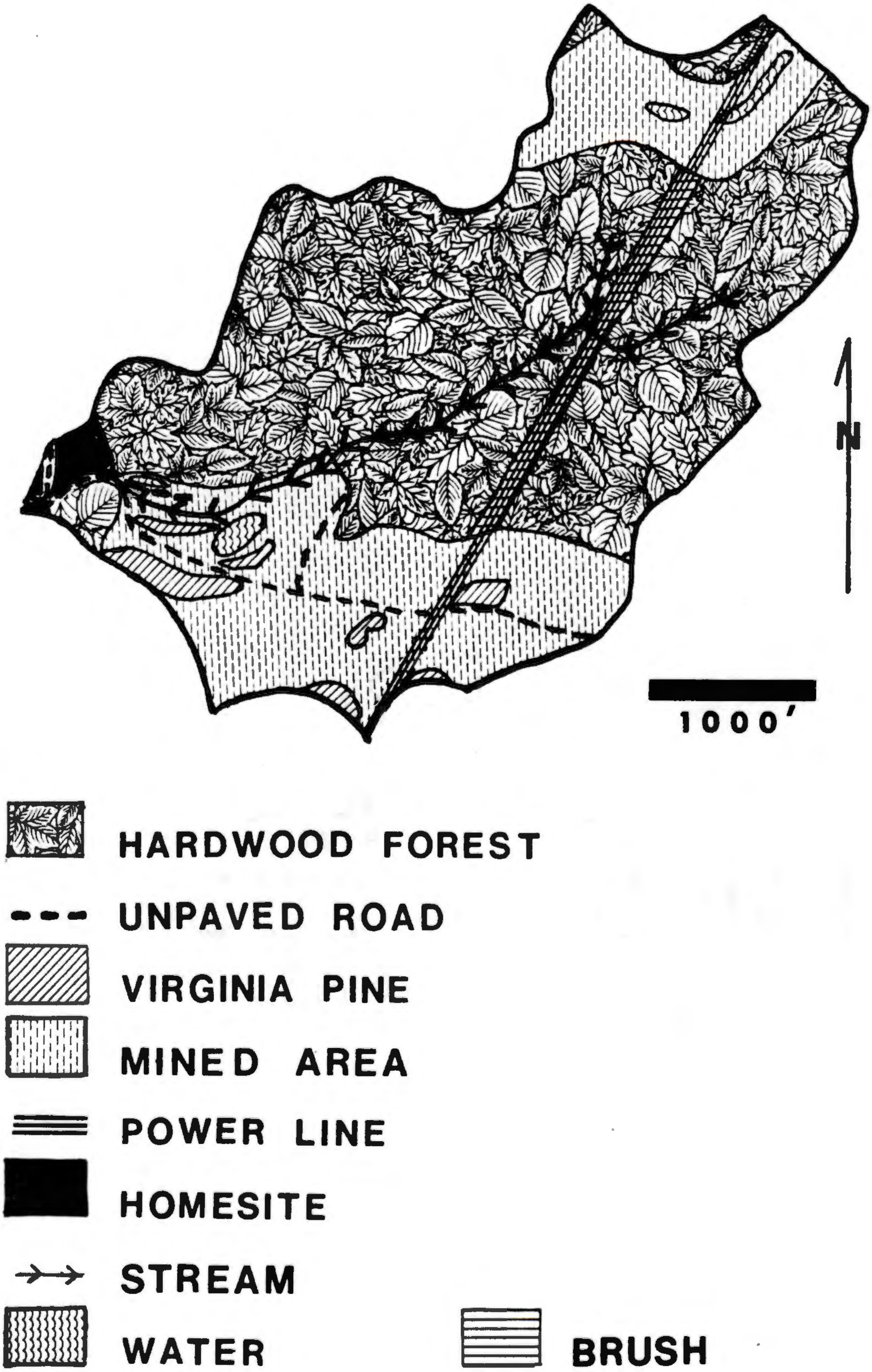


Figure 24. Davis Creek study area, land cover.

rhododendron (*Rhododendron maximum*) in the cooler areas. The understory contained red maple, dogwood, black gum, sassafras, greenbrier, sourwood, *Vaccinium spp.* and *Gaylussacia spp.* In a few areas the stands were younger with a few old dominants. Scattered pines and laurel thickets were also found on southern ridges. Much of the area was rocky, with thin soils and with large rock outcrops.

The upper surface mined area was covered with various grasses, sericia lespedesa and pine and small black locust thickets. There were exposed highwalls and two small ponds that had almost disappeared. There were also a few bare spots.

The lower mined area was covered largely with grass, sericia lespedesa and yellow sweet clover. Pines had been planted over much of the area, but survival was poor. Bare spots and gullies were present and some of the drainages had rip rap along with settlement ponds to reduce erosion problems. Clumps of Virginia pine were scattered throughout the area. Vegetation along the stream through the striped area included small white oak, Virginia pine, sycamore, black willow (*Salix nigra*) and hazel alder (*Alnus serrulata*).

The stream in this watershed flowed continuously. The color of the water and streambed was reddish below the bottom stripmine, but relatively clear above it. Garbage and other trash could be seen near the mouth of the stream. The residuum of large mass movements of streambed materials had also been observed.

The surface geology included two stratigraphic groups (Figure 25), the Indian Bluff group from 1800 to 1920 feet and the Slatestone group from 1310 to 1800 feet (Englund 1968). Four soil types were also found

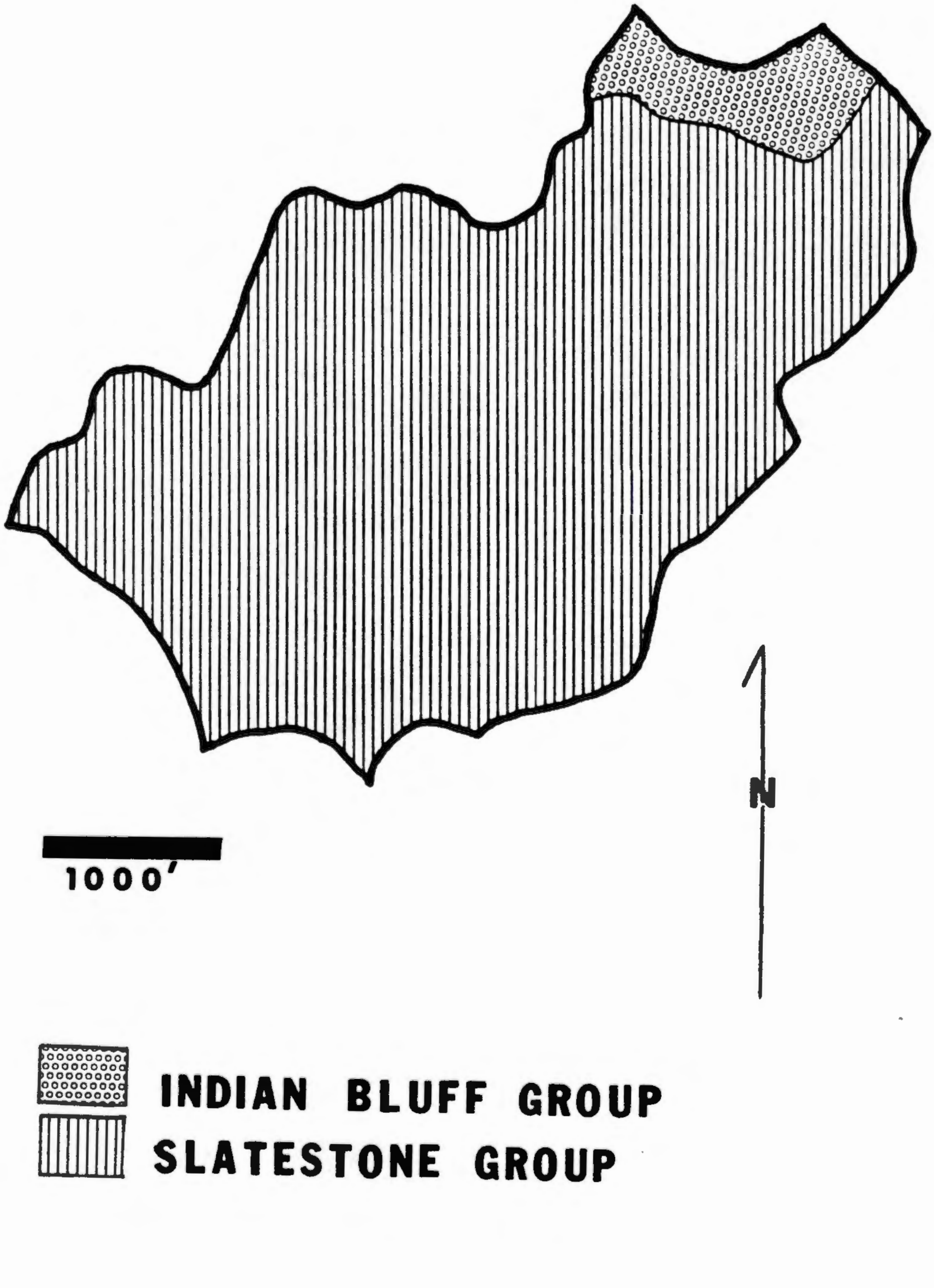


Figure 25. Davis Creek study area, surface geology.

within this area (Figure 26). The Bethesda soils type had formed as a direct results of mining activities (USDA SCS unpublished).

Old Mined, Crooked Fork, Petros Quad, Morgan County: This watershed was about 121 acres in size and had a western aspect. Elevation from the confluence to the ridgetop was about 1120 feet. It was almost completly covered with hardwood forest (Figure 27) and less than 10 percent had been disturbed by surface mining (Dyer 1982). Three seams of coal supposedly were mined in this area: Windrock coal near the top at around 2360, Joyner coal at around 1700 feet and Jellico coal at around 1670 feet. However, there was only one strip cut where the Jellico and Joyner coals were and the high walls left are only 15 to 20 feet high, indicating that only one of the coal seams were mined.

The highest disturbed area appeared to have been mined after 1972 and was largely vegetated with grasses, sericia lespedesa and scattered small locusts and pines. The slope between the pond and road had two plantings, one of European black alder (*Alnus glutinosa*) and one of sawtooth oak (*Quercus acutissima*). A ditch above the road collected most of the flow from the upper disturbed area and emptied it into the adjacent watershed.

The undisturbed areas had an open understory with yellow poplar, red maple, black cherry, chestnut and northern red oaks and sweetgum in the overstory. Scattered white (*Pinus strobus*) and Virginia pine and mountain laurel thickets were found on the ridges. The valley has many bolders, indicating mass movement. Near the confluence yellow poplar, beech, sycamore and white oak predominated. In most areas the under-

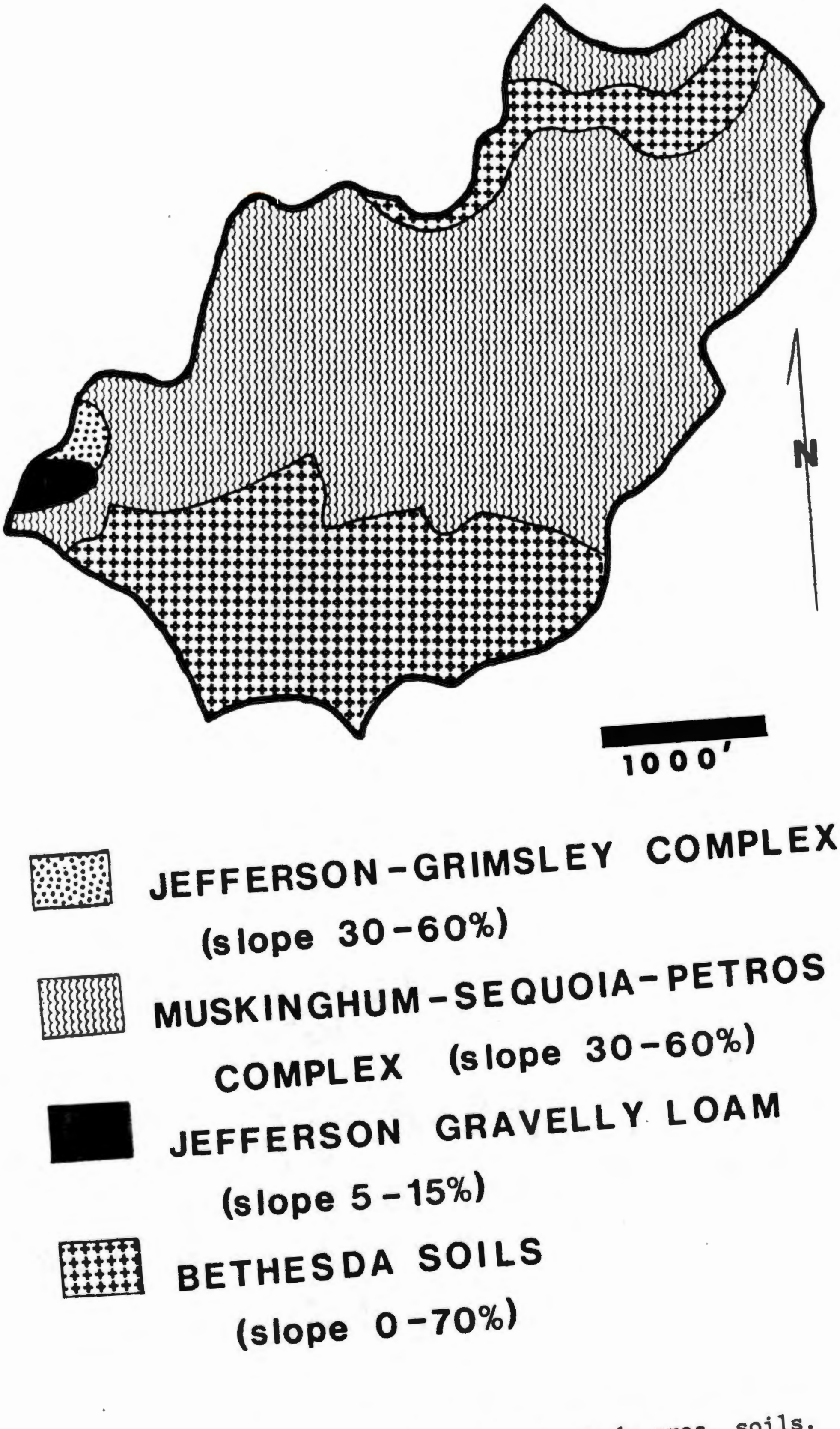


Figure 26. Davis Creek study area, soils.

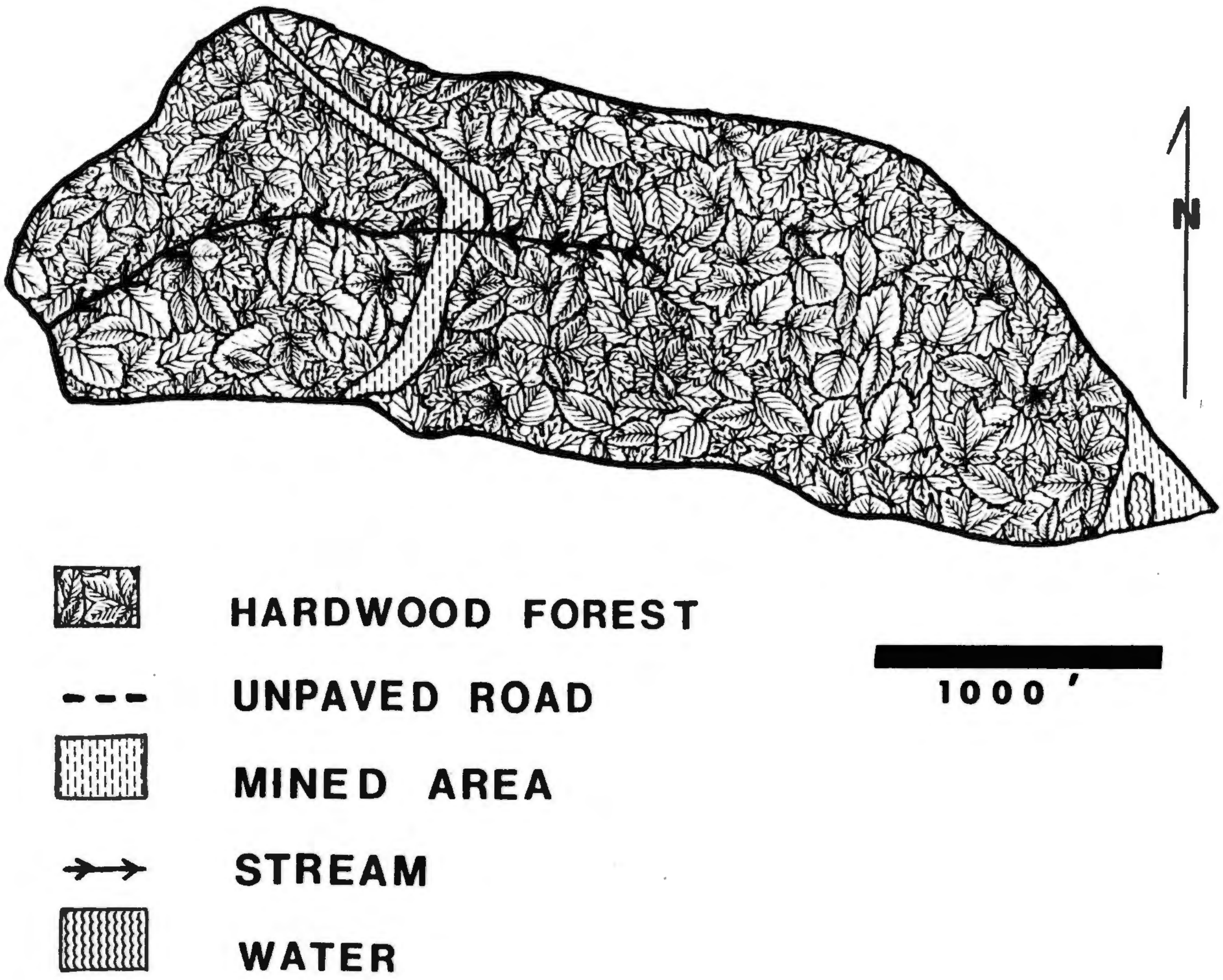


Figure 27. Crooked Fork study area, land cover.

story consisted of grape, dogwood, black gum and saplings of the over-story.

As mentioned earlier the lower mined area was small, about 15 to 20 feet wide. There were some small areas of standing water and exposed springs. The area was almost completely naturally revegetated. The stream was intermittent, flowing only during the winter and other wet periods.

The surface geology consisted of four stratigraphic groups (Hershey 1975): The Redoak Mountain group from 2360 to 2450 feet, the Graves Gap group from 1930 to 2360 feet, the Indian Bluff group from 1680 to 1930 feet and the Slatestone group from 1330 to 1680 feet (Figure 28) (Hershey 1975). Three main soil types were also located on this water-shed (Figure 29) (Morgan County SCS unpublished).

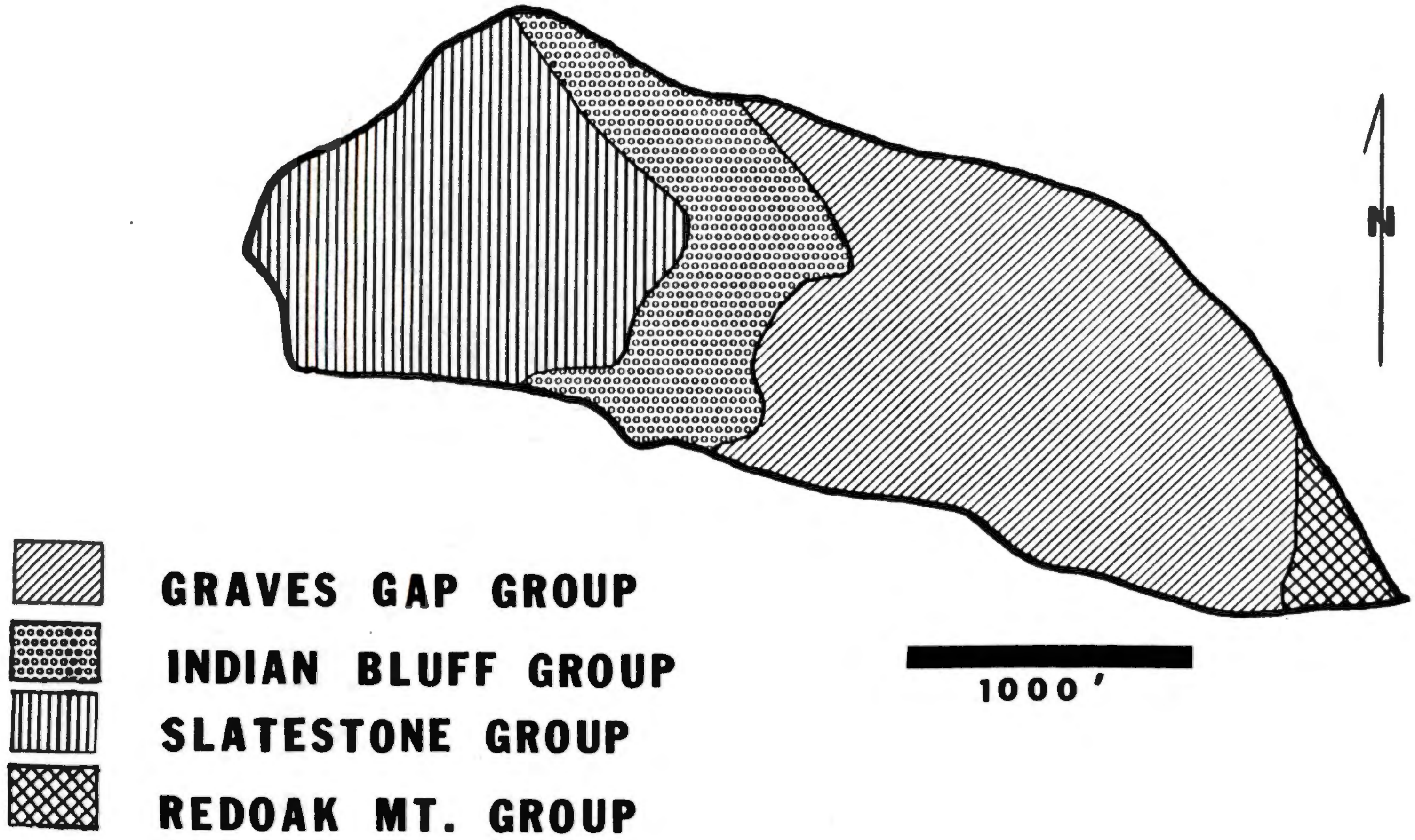


Figure 28. Crooked Fork study area, surface geology.

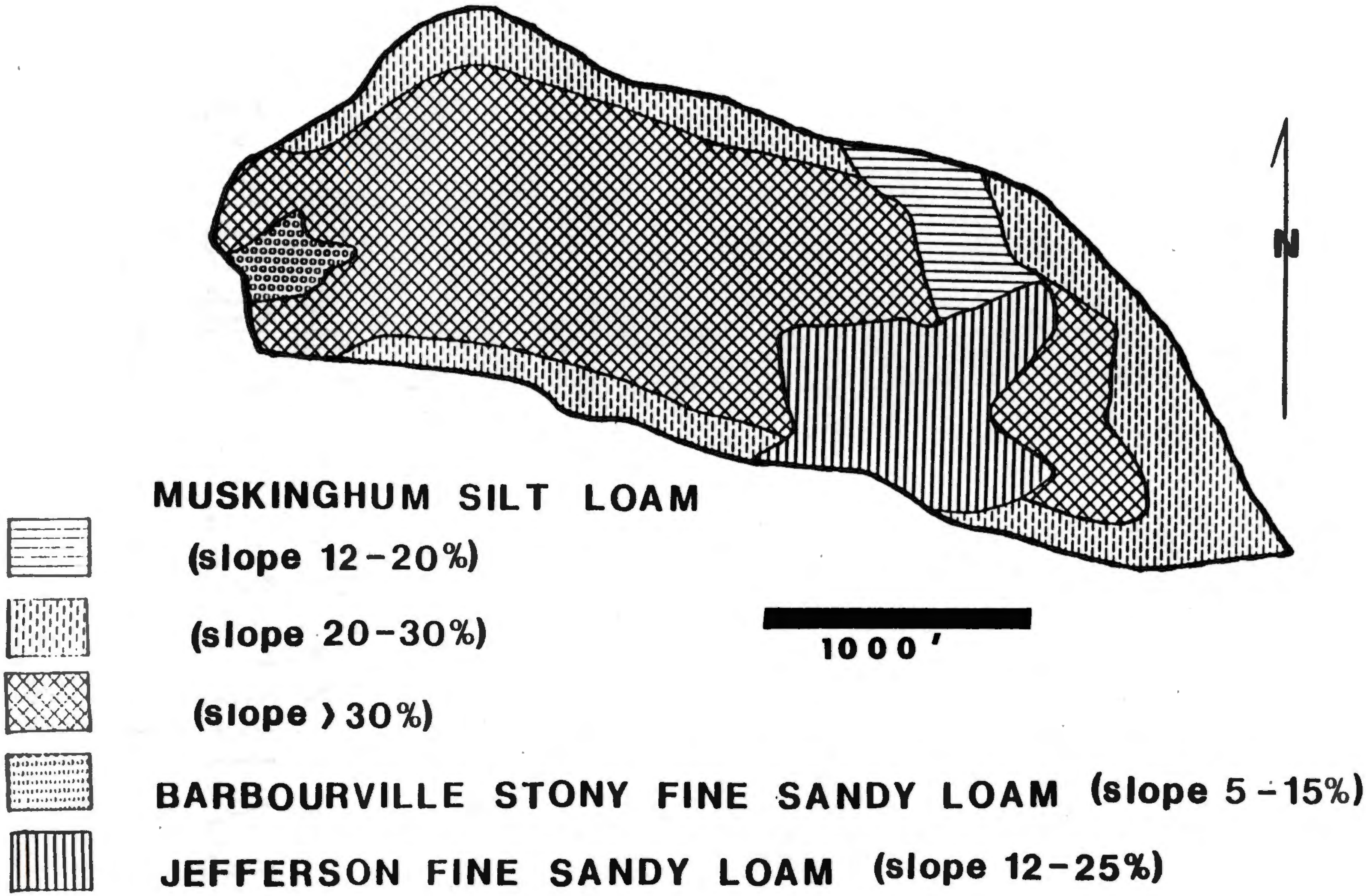


Figure 29. Crooked Fork study area, soils.

VITA

Charles William Becker III was born in Washington, D. C. on May 1, 1957. He spent most of his youth in northern Virginia where he graduated from Brentsville District High School in 1975. He worked in a steel fabrication plant in Gainesville, Virginia as a steelworker and maintenanceman until attending Virginia Polytechnical Institute and State University. As a student, he was very active in forestry and wildlife organizations but also worked to support himself. After graduating with a BS in Forestry and Wildlife, with a minor in biology, in March of 1981, he worked on the Jefferson National Forest in Virginia. In March of 1983 he accepted a position with a landscaping and tree care company in Aldie, Virginia where he was in charge of their spraying program. In January 1984 he began work towards a M.S. degree at the University of Tennessee where he was active in the school organizations and was elected an officer to two of them. He received his Master of Science in forestry in 1986.

Charlie is single and enjoys most outdoor activities and sports. He is a member of the Society of American Foresters and the American Forestry Association.