WATER QUALITY OF MINED AND UNMINED WATERSHEDS IN EAST TENNESSEE

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ABSTRACT

In late 1980 and early 1981 monitoring stations were installed in three small watersheds in the Cumberland Mountains and three in the Cumberland Plateau of east Tennessee to evaluate the effects of surface mining on water quality. Each set 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 were also taken into account.

Analyses were made to determine seasonality of stream parameter concentrations, differences due to watershed conditions and changes in stream water quality over time. It was found that seasonal variations in water quality and flow rates are related. Significant differences in water quality were found between mined and unmined watersheds, with mined ones generally having higher levels of minerals and greater turbidity. The Cumberland Mountains unmined watershed had greater values than the old mined one for most of the parameters tested, apparently due to a road. Water quality of the newly mined plateau watershed improved with time, while that of the mountain decreased, apparently due either to poor reclamation practices or road use. Time elasped since mining was associated with water quality, with older areas having better water quality.

INTRODUCTION AND OBJECTIVES

Surface mining for coal has been practiced for over two hundred years in the United States. The first operations were very small and consisted of removing exposed or thinly covered coal deposits by manual labor. Later, draft animals were used to remove the overlying materials on deeper coal beds, with limited environmental impact.

With the technology of steam and internal combustion engines came the ability to produce machinery that could remove large volumes and great depths of soil. After World War Two, machines capable of removing entire mountaintops were developed and the environmental impact of mining became severe. Entire drainages were altered and reclaimed 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 have been affected in this manner in the Appalachian region (Seitz 1981).

The increasing visibility of watershed damage from surface mining prompted the establishment of monitoring stations by 1950, where water samples and flow rates were measured (Dyer 1982). Most of the early stations were on large watersheds with many land uses, making it very difficult to attribute water problems specifically to surface mining. In this study monitoring stations were established on small watersheds in an effort to overcome this problem.

The objectives of the work reported here were twofold. The first was to compare unmined, old mined and newly mined watersheds on each of six watersheds to determine the differences in their water quality. The second was to determine rate of recovery of water-quality parameters following mining.

The research reported here is based upon cooperative efforts of the Department of Forestry, Wildlife and Fisheries, The University of Tennessee and the U.S. Forest Service, U.S.D.A., Northeastern Forest Experiment Station, Research Work Unit FS-NE-1605.

METHODS AND MATERIALS

In late 1980 and early 1981, stream flow and precipitation monitoring equipment was installed at the confluences of each of six watersheds in the coal region of eastern Tennessee. Each site selected represented either an "old mined", a "newly mined" or an unmined condition. All watersheds selected were between 88 and 253 acres in size and contained a perennial, first-order stream.

Unmined watersheds were not to have roads or cuts that exposed bare ground and were not to have been farmed, disturbed or developed. Old vegetated logging roads and skid trails were allowed. However, some water sheds with a mixture of grassland or pasture were used when necessary.

Old mined watersheds should have had 10 to 100 percent of their area disturbed by surface mining before January 1972, with no surface mining or reclamation after that date. Whenever possible, watersheds were selected in which only one coal seam had been mined.

Newly mined watersheds were to have been mined since January 1972. From 10 to 100 percent of the area was disturbed by surface mining and active mines were permitted. Areas with old mines that were worked before 1972 were permitted, provided that areas previously mined were reworked after January 1972. Watersheds with only one coal seam or those that had only one seam mined were selected, when possible.

The average yearly temperature is around 14 degrees Celsius with winter temperatures averaging four degrees C. and summer temperatures average 25 degrees C. Precipitation averages 50 to 55 inches annually and is distributed fairly evenly throughout the year. Thunderstorms and showers sometimes produce high rates of precipitation during midsummer. Winds average five to seven miles per hour (Gale Res. Co., 1978).

The rocks of Tennessee's coal region are largely Pennsylvanian, composed of layers of sandstone, shale, coal and very thin limestones. Two major stratigraphic sequences are recognized (Luther 1959). The lower has three groups which are thick sandstone and conglomerate separated by approximately equal amounts of shale. The upper part has six groups with larger more prominent shale layers found only in the Cumberland Mountains. Soils overlying these materials are acidic with pH ranging from below four to 5.5 and are low in natural fertility and organic matter (Springer and Elder 1980; Elder et al 1958).

A rainfall and stream flow monitoring station was installed at each watershed. Precipitation was monitored with P501-I Remote Recording Rain Gauges by Weather Measure Corporation, which continuously measured one-hundredth inch increments using a tilting bucket. A battery powered Model 101 Datapod by Omnidata accumulated the data. The instruments were located in an open area where no objects could hinder precipitation freefall.

A trapezoidal venturi flume stream flow gauge was constructed

at the mouth of each watershed, where possible, on bedrock. Depth of flow in the flume was used to calculate stream flow in cubic feet per second (CFS). A stilling well with a float was used to measure water levels. Data were collected with a battery powered Model 7000 Series Stevens Digital Recorder at five minute intervals on punched paper strip charts.

Water samples were collected every four weeks at each site if water was flowing through the flume. Water samples, charts, data storage modules (DSMs) and data sheets were sent to the Northeastern Forest Experiment Station in Berea, Kentucky, for processing. Water samples were analyzed for 33 elements and properties according to Dyer (1982).

Proc X11, from the Econometrics and Time Series (SAS 1984) program package, was used to test for seasonal significance of fluctuations in stream water quality indicators.

The General Linear Model (Proc GLM in SAS 1985) was used to test water parameters for correlations with stream flow, date, watershed and water quality. Based on past experiences, data were converted to logarithmic values to adjust for increases in variability of water quality data over time.

The "Estimate" option in the Proc GLM program (SAS 1985) was used to compare differences in water quality between watersheds. "Newly mined" and "old mined" conditions were compared with the unmined watersheds.

Final analyses were made to test for significant differences in water quality over time and for these, Proc GLM "Estimate" statements (SAS 1985) were used.

Table 1. Seasonal Fluctuations in Water Quality.

Watershed	SO_4^-	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

Standards for water quality were those established by the Environmental Protection Agency (EPA 1976A, 1976B; EPA 1980) and the Department of Health, Education and Welfare 1962 (HEW 1962).

RESULTS AND DISCUSSION

Of the 33 different water quality parameters recorded: sulfate, iron, total dissolved solids (TDS), pH, lead, turbidity, zinc, manganese, magnesium, sodium, nickel and calcium were anlayzed in this study.

Tests were made first to determine whether concentration fluctuations for the parameters tested were random or seasonal. SO_4, Fe, TDS, Ca and CFS were selected initially and their values averaged quarterly from 1981 through 1984. Since this program does not allow missing values, two watersheds with intermittent streams were excluded. These streams were assumed to have seasonal fluctuations since they flow during the winter and are dry each summer. Seasonal variations in the other watersheds were significant (Table 1).

With the exception of "Date" a signficiant relationship was found between most water quality parameters and their various independent factors (Table 2). The large number of correlations with "CFS" and "Watershed" indicate that concentration levels are related to flow rates and that each watershed has a different seasonal concentration regimen, an assumption further strenthened by the interaction of flow and watershed (CFS*Watershed) as an independent factor.

The greatest differences in water quality were between the newly mined and unmined watersheds of the Cumberland Mountains group (Table 3). The newly mined site had the largest area disturbed and there was a stream flowing through the mined area, which probably accounted for the large differences ($p = .01$) in values. Differences between newly mined and unmined, and the old mined and unmined watersheds on the Plateau were smaller, but still highly significant in most cases.

Differences between old mined and ummined mountain watersheds were small, indicating that the old mined watershed was more nearly recovered than the others. In fact, the unmined area has significantly greater concentrations of many elements, perhaps due to drainage from a road discharging into the stream.

Both "newly" mined watersheds had significant changes in most water quality indicators over time (Table 4). One increased in concentrations and values (Cumberland Mountains) while the other decreased (Cumberland Plateau). The other watersheds changed, but most of the analyses showed no significant differences.

Table 2. Relationship of Flow, Date and Watershed to Water Quality.

Element[1]	CFS	Date	Watershed	CFS*Watershed	Date*Watershed
SO_4	***	***	***	***	***
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 percent level
** significant at the 95 percent level
* significant at the 90 percent level
NS not significant

Table 3. Concentration Differences Between Watersheds for 1981 and 1984 (milligrams per liter).

Water Property	unmined -vs- "newly" mined (-) (+) 1981 ave.	1984 ave.	unmined -vs- old mined (-) (+) 1981 ave.	1984 ave.
		Cumberland Plateau		
SO_4	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**
pHa	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	0.03b	0.02b	0.01b	0.01b
Ca	24.12*	15.33*	2.64**	1.04**
		Cumberland Mountains		
SO_4	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**
pHa	-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
a units are in log(1/(H+))
b values were zero for unmined, could not compute significance

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		
SO_4	-***	-***	-*
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	+***

[1] as logarithm of concentration
+ increased over time
- decreased over time
*** significant at the 99 percent level

Water Property[1]	"Newly" Mined	Old Mined	Unmined
	Cumberland Mountains		
SO_4	+**	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

** significant at the 95 percent level
* significant at the 90 percent level
NS not significant
ID insufficient data.op

Sulfate (Figure 1) is a problem in only one of the study areas, Davis Creek, a "new" mine. Concentrations averaged over four times the recommended limit for potable water of 250 mg/liter and increased throughout the study period (Figure 1A). Seasonal variations are apparent. Sulfate and iron are associated with pyrite weathering. The two newly mined watersheds both had amounts well in excess of standards which existed in 1981. Davis Creek concentrations increased and Denny Cove decreased during the study. By 1984, Denny Cove had iron levels comparable to the unmined watersheds. Davis Creek levels increased to approximately 70 times accepted standards of 0.3 mg/L during the study.

With the exception of Davis Creek, TDS levels did not pose major problems (Figure 2). Davis Creek averaged over three times the suggested standard (of 500m/L) and was still increasing when the study was terminated.

Water acidity is of concern only in Davis Creek, where values dropped from pH 5.5 to about pH 4 by the end of 1984. Denny Cove also decreased significantly from 1981 to 1984.

Lead is a problem in only one watershed, Davis Creek. From the beginning of the study it exceeded the average concentration standard of 0.05 mg/L (on the average) and increased throughout the study.

All six watersheds exceeded the turbidity standard of 5 Jackson Turbidity Units. Suzanne Creek, unmined, had the lowest levels with an average of approximately seven turbidity units. Turbidity at newly mined Denny Cove decreased (P =≤ .01) over the study period and was comparable to the old mined watersheds levels by the end of the period. Davis Creek had the highest levels. Lake City water had high turbidity, probably due to sediment from a road through the watershed.

SULFATE

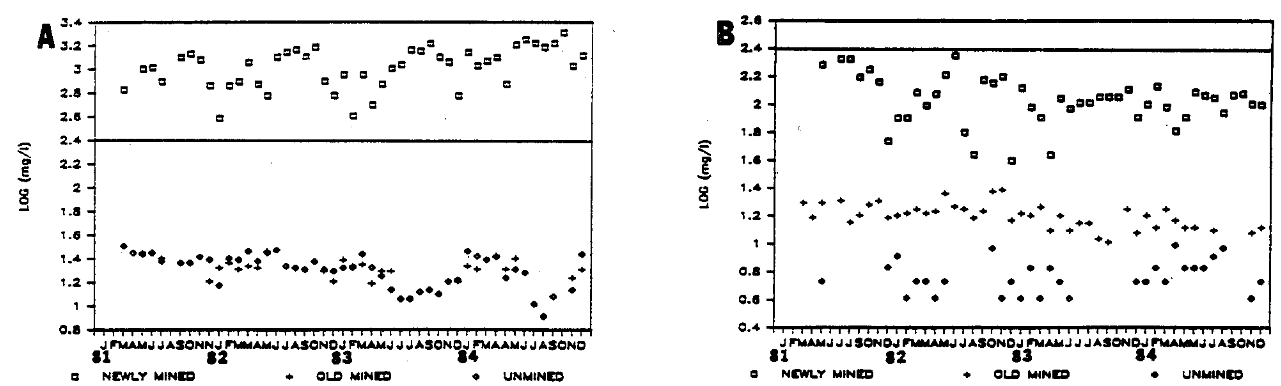

FIGURE 1. *Periodic sulfate levels from 1981 through 1984. A. Cumberland Mountains streams: newly mined (Davis Creek), old mined (Crooked Fork) and unmined (Lake City). B. Cumberland Plateau streams: newly mined (Denny Cove, old mined (Corn Branch) and unmined (Suzanne Creek). Solid line (________) indicates EPA's acceptable level.*

TOTAL DISSOLVED SOLIDS

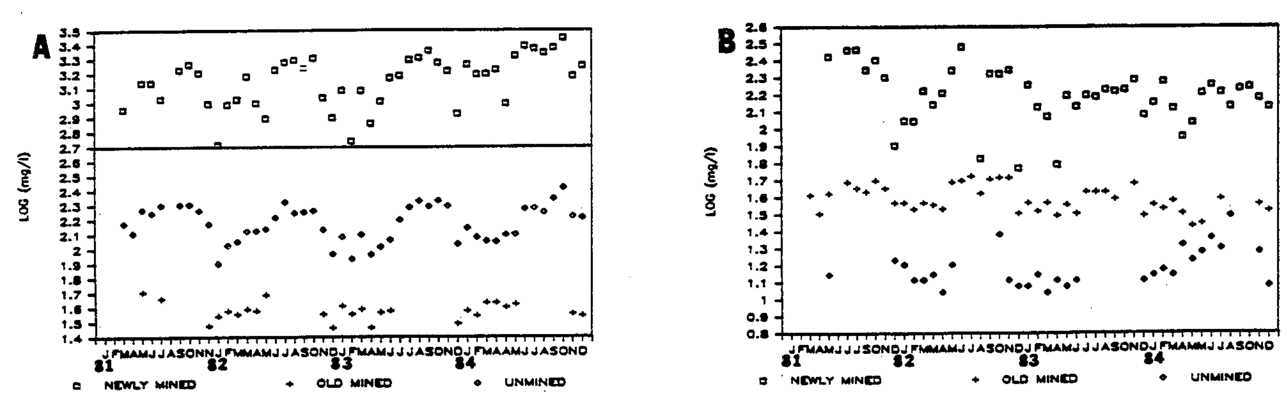

FIGURE 2. *Periodic total dissolved solid (TDS) from 1981 through 1984. A. Cumberland Mountains streams: newly mined (Davis Creek), old mined (Crooked Fork) and unmined (Lake City). B. Cumberland Plateau streams: newly mined (Denny Cove, old mined (Corn Branch) and unmined (Suzanne Creek). Solid line (________) indicates EPA's acceptable level.*

Zinc concentrations for the six study areas were all below the acceptable drinking water standard of 5 mg/L; however, values for Davis Creek exceed standards for fresh water aquatic life.

Davis Creek (newly mined) had concentrations of manganese greater than 100 times the permissible standard of 0.05 mg/L, with less in Denny Cove (newly mined) (approximately 100 times greater) and Corn Branch (old mined) (Figure 3).

Although water quality standards are not available, magnesium concentrations showed large variations between study areas and during the study (Figure 4). Davis Creek had the highest values and highly significant increase during the study period.

Concentrations of sodium in Davis Creek were three to four times greater than the standard of 20 mg/L and there was a highly significant increase in levels during the study period (Figure 5). High levels of sodium in the unmined Lake City watershed are unexplained, unless due to roads or homesites (Figure 5).

Water quality standards for nickel approached the analytical limits of our equipment. The two newly mined watersheds were well above the potable water standard of 13.4 mg/L and Davis Creek exceeds the more liberal edible aquatic organism standard by three to four times.

MANGANESE

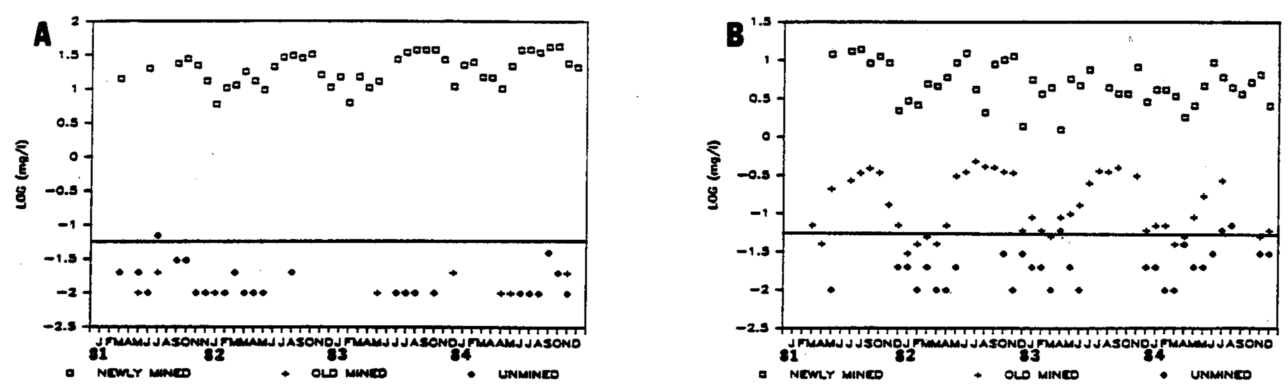

FIGURE 3. *Periodic manganese levels from 1981 through 1984. A. Cumberland Mountains streams: newly mined (Davis Creek), old mined (Crooked Fork) and unmined (Lake City). B. Cumberland Plateau streams: newly mined (Denny Cove, old mined (Corn Branch) and unmined (Suzanne Creek). Solid line (________) indicates EPA's acceptable level.*

MAGNESIUM

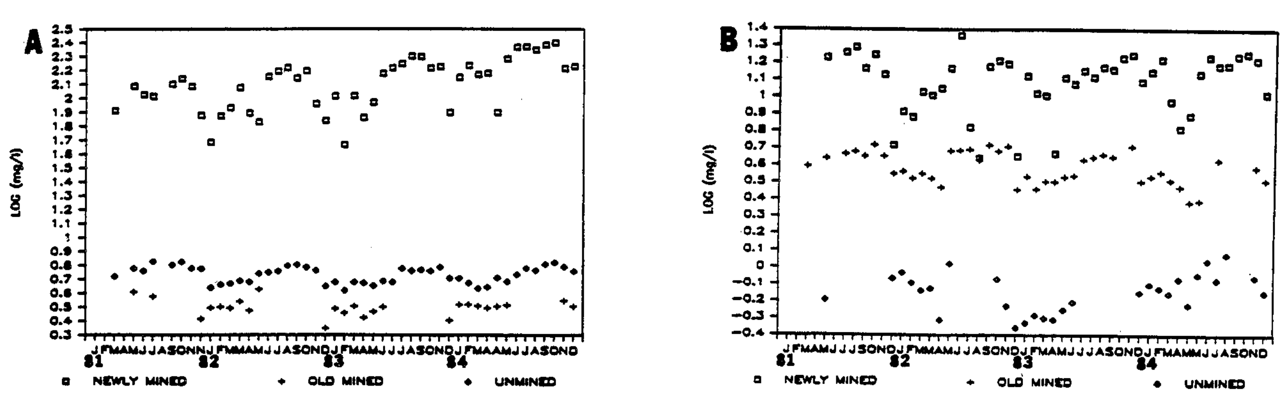

FIGURE 4. *Periodic magnesium levels from 1981 through 1984. A. Cumberland Mountains streams: newly mined (Davis Creek), old mined (Crooked Fork) and unmined (Lake City). B. Cumberland Plateau streams: newly mined (Denny Cove, old mined (Corn Branch) and unmined (Suzanne Creek).*

Although quality standards for calcium have not been set, calcium concentrations varied greatly between the study areas and over time (Figure 6). Davis Creek had the highest concentrations and showed a highly significant increase during the study period. Denny Cove was next highest in 1981, but by 1984 was comparable to Lake City.

Research presented here indicates that the recovery of old mines, even without reclamation efforts, is well advanced over 15-20 years. This does not preclude the desirability of an even faster recovery through proper reclamation. The research also reveals that haul roads which remain open to the public for indiscriminate use, as well as those in place prior to mining, can exacerbate any problem of water quality from mined watersheds.

The number of different factors influencing the watersheds, such as size of mined area, geology, soils, roads, mine operators and other watershed uses made it difficult to evaluate the effects of mining. Three 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, starting before mining is initiated. The third would be to select watersheds that have perennial streams and have monitoring stations both above and below mine sites.

SODIUM

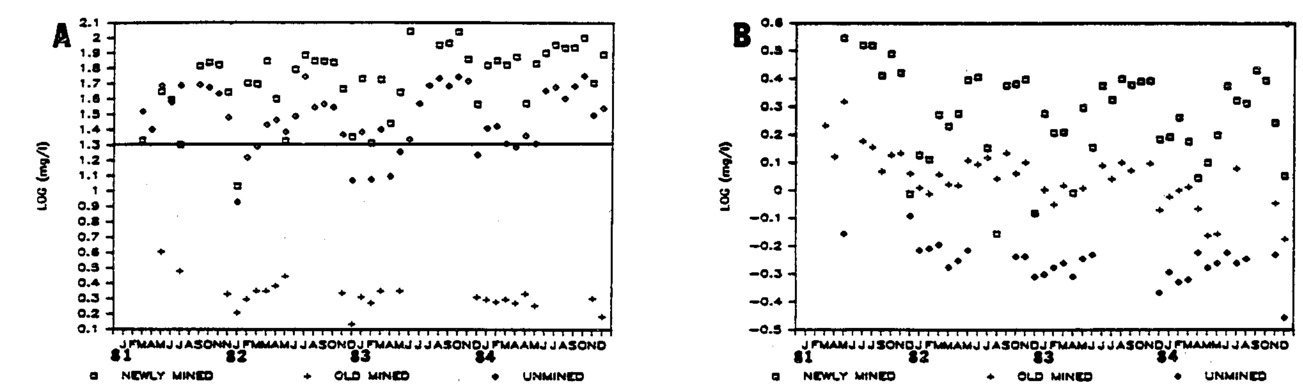

FIGURE 5. *Periodic sodium levels from 1981 through 1984. A. Cumberland Mountains streams: newly mined (Davis Creek), old mined (Crooked Fork) and unmined (Lake City). B. Cumberland Plateau streams: newly mined (Denny Cove, old mined (Corn Branch) and unmined (Suzanne Creek). Solid line (________) indicates EPA's acceptable level.*

CALCIUM

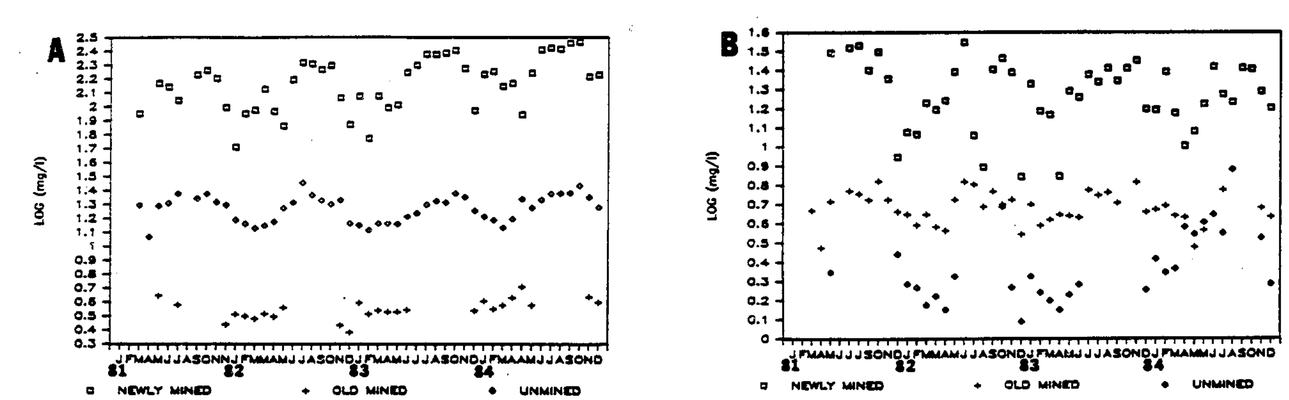

FIGURE 6. *Periodic calcium levels from 1981 through 1984. A. Cumberland Mountains streams: newly mined (Davis Creek), old mined (Crooked Fork) and unmined (Lake City). B. Cumberland Plateau streams: newly mined (Denny Cove, old mined (Corn Branch) and unmined (Suzanne Creek).*