To the Graduate Council:

I am submitting herewith a thesis written by Louise Eva Gorenflo entitled "A Survey of Surface Mining in Grundy County, Tennessee as It Affects Water Quality." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Ecology.

Roger A. Minear, Major Professor

We have read this thesis
and recommend its acceptance:

Accepted for the Council:

Vice Chancellor
Graduate Studies and Research

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A SURVEY OF SURFACE MINING IN GRUNDY COUNTY, TENNESSEE AS IT AFFECTS WATER QUALITY

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Louise Eva Gorenflo

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ABSTRACT

This survey investigated the effects of surface mining upon surface water quality in the southern coal fields of Grundy County, Tennessee. Streams from mined watersheds were compared with unmined watershed streams.

Samples were collected biweekly from August 1977 to January 1978 for chemical analysis of metals, pH, alkalinity and sulfates. Significant differences were found among streams and sampling dates. Streams severely affected by surface mining had both low pH and high metal concentrations.

Benthic samples of aquatic insects were collected from February to April, 1978. Diversity indices were determined from eight Surber samples using the Shannon-Weaver diversity index. Significant differences were found between the community structure of streams in watersheds disturbed by surface mining and baseline streams. Streams affected by surface mining has an improverished community structure. Much of this degradation can be accounted for by sedimentation.

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CHAPTER I

INTRODUCTION

Coal remains the United State's largest non-renewable energy reserve. Eastern bituminous and anthracite coal deposits of the Appalachians account for 55% of the nation's total researves based on caloric value (McCormick, 1975). The Appalachian region contains a linear belt of coal bearing strata at and beneath the surface running through the region in a northeast to southwest direction (Appalachian Regional Commission, 1969).

Tennessee lies in the Southern end of these coal deposits. In 1976 Tennessee mined 8.6 million tons of bituminous coal, 1.3% of the nation's total production; however, the state during that same period was a net energy consumer as it burned 3.1 times as much coal as it mined (Chandler, 1978).

Area mining is the technique used in Grundy County, Tennessee, the study area. The surface area mining process disrupts watershed topography (Herricks, et al., 1974; Breidenback, 1975; Plass, 1975). During mining the rock strata above the coal seam is shattered, the overburden removed and cast to the side of the excavation or cut, and the coal is then removed and the spoil pushed back into the cut. The fracturing of the overburden expands the total volume of the material, producing mounds of spoil.

Area mining disturbs a much larger percentage of a watershed than does contour mining (Herricks, et al., 1974). During the mining process the heterogeneous mass of shattered rock strata is exposed to weather-

ing which releases chemical constituents into surface and subsurface flow (Plass, 1975). Mining changes the permeability and retention capacity of the soil. The removal of vegetative cover increases erosion which produces high suspended solids in streams (Herricks, et al., 1974).

The purpose of this study was to measure chemical parameters and aquatic insect community structure to determine the impacts of area surface mining upon surface streams in Grundy County, Tennessee. Studies of this nature have been conducted often elsewhere (Patrick, 1974; Minear and Tshantz, 1977); however, little research of this scope has been conducted in this section of the Southern Cumberlands. This study surveys the water quality of streams draining the orphan and active mines around the community of Coalmont, the most intensively disturbed area by hectares in Grundy County. Reference stations were used to contrast watersheds disturbed by surface mining with those that were undisturbed. Biweekly samples from these watershed streams were taken from eleven stations and analyzed for metals, pH, alkalinity and sulfate. Aquatic insect communities were sampled and analyzed for species diversity and abundance. These measures were used to determine differences among streams.

CHAPTER II

LITERATURE REVIEW

A. Acid Mine Drainage

Occurrence

Two types of untreated wastewater from mines occur: alkaline and acid (ferruginous) (Breidenbach, 1975). Alkaline drainage generally has a pH greater than 7 and less than 10 mg of Fe/1: it is associated with areas with large amounts of calcareous materials in the overburden. Acid drainage generally has a pH less than 6 and contains concentrations greater than 10 mg of Fe/1. Occurrence of either is determined by regional and local geographic conditions. Table I depicts the range of values used to determine mine drainage classes for parameters measured in this study. In this study, mean pH values are determined as follows:

$$- \log \left(\frac{\sum n \text{ - antilog pH}}{n} \right)$$

Pyritic Oxidation: formation

The process of acid mine drainage formation is well known (Parsons, 1957; Striffler, 1973, Williams, 1975). Freshly exposed geologic material containing iron sulfides or other sulfur bearing compounds undergo rapid weathering to release sulfuric acid and quantities of other elements. Iron sulfides are the source of acid producing material (Parsons, 1957; Caruccio, 1973; Gang and Langmuir, 1974). This material occurs in different crystalline forms (yellow pyrites,

TABLE I

CRITERIA FOR DETERMINING DRAINAGE CLASSES

	Criteria A[1]				Criteria B[2]					
					Acid			Alkaline		
	CLASS 1 Acid Discharge	CLASS 2 Partially Oxidized	CLASS 3 Neutralized to Alkaline	CLASS 4 Neutralized Not Oxidized	Min.	Max.	Mean	Min.	Max.	Mean
pH	2-4.5	3.5-6.6	6.5-8.5	6.5-8.5	2.6	7.7	3.6	6.2	8.2	7.7
Alkalinity					0	184	5	30	860	313
Fe(II)	500-10,000	0-500	0	50-1,000						
Fe(III)	0	0-1,000	0	0						
Fe (total)					.08	440	52.01	.02	6.70	.78
Fe (dissolved)					.01	440	50.1	.01	2.7	.15
Mn					.29	127	45.11	.01	6.8	.61
Al	0-2,000	0-20	0	0	.1	271	71.2	.1	.85	.2
Zn					.06	7.7	1.71	.01	.59	.14
Sulfate	1,000-2,000	500-1,000	500-10,000	500-10,000	22	3860	1842	42	3700	1297

NOTE: All values in ppm except for pH.

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

Breidenbach, A.W. Development document for interim final effluent limitations guidelines and new source performance standards for the coal mining point source category. E.P.A.

marcasites, black amorphous pyrite) which have different rates of reactions and vary in the resultant pH and amount of sulfate produced: marcasite is the least stable polymorph (Riley, 1960). Grains of iron sulfide may occur in inch thick layers in a coal seam or as crystals distributed throughout the overburden (ibid.).

Chemistry of Formation

According to Barnes and Romberger (1968) and Stumm and Morgan (1970), the chemical reactions of iron sulfide oxidation and production of acid in the presence of air and water are presented as follows:

$$FeS_2 + \frac{7}{2}O_2 + H_2O = Fe^{2+} + 2SO_4^{2-} + 2H^+ \quad (1)$$

$$Fe^{2+} + \frac{1}{4}O_2 + H^+ = Fe^{3+} + \frac{1}{2}H_2O \quad (2)$$

$$Fe^{3+} + 3H_2O = Fe(OH)_3(s) + 3H^+ \quad (3)$$

$$FeS_2 + 14Fe^{3+} + 8H_2O = 15Fe^{2+} + 2SO_4^{2-} + 16H^+ \quad (4)$$

Acid is produced by three pathways: iron sulfide is oxidized in a moist environment to form ferrous iron and sulfuric acid (1), ferric iron is rapidly reduced by iron sulfide, releasing additional acidity and new ferrous iron (4), or ferric hydroxide is formed with additional acidity in areas of a stream with sufficient alkalinity to buffer the acid mine drainage (3) (Stumm and Morgan, 1970). $Fe(OH)_3$ rapidly precipitates from solution with low resultant concentrations of Fe (Barnes and Romberger, 1968). Ferrous iron oxidizes very slowly to produce ferric iron (1000 day half time at pH 3) and thus can be considered a rate determining step (3) (Stumm and Morgan, 1970). The overall reaction can be described by the following equation (Barnes and Romberger, 1968):

$$4FeS_2 + 15O_2 + 14H_2O = 4Fe(OH)_3 + 16H^+ + 8SO_4^{2-} \quad (5)$$

As can be seen from equation 5, the dissolution of 1 mole of pyrite releases 4 equivalents of acidity.

Pyritic oxidation can occur within two feet of the surface, and the products are then subsequently flushed out. Von Demfange and Warner (1975) observed that over a period of eight to sixteen years greater than 90% of the pyrites in the top two feet of spoil had been oxidized.

Factors Affecting Degree of Acidity

The rate of acid generation increases where marcasite, the more reactive iron sulfide polymorph, is present (Parsons, 1957; Barnes and Romberger, 1968; Gang and Langmuir, 1974). The more iron sulfide present, the greater the concentration of sulfate and amount of acidity produced (Stumm and Morgan, 1970). Smaller sulfide grain size, increased rock porosity, and higher oxygen content are other conditions causing increased acid production (Barnes and Romberger, 1968; Gang and Langmuir, 1974). Moisture is essential for the process to occur.

Catalytic bacterial action occurs in both the oxidation of sulfur and Fe(II) under low pH conditions. Some bacteria (Thiobacillus ferroxidans, T. thiooxidans, Ferrobacillus ferroxidans) mediate the oxidation of ferrous iron, the rate determining step (Mellon Inst., 1970, Stumm and Morgan, 1970; Williams, 1975).

The degree of acidity is modified by the water's alkalinity, a function of the amount of calcareous material present in the substratum (Breidenbach, 1975, Plass, 1975). Alkalinity of a water is its quantitative capacity to be neutralized by a strong acid to a designated pH (Standard Methods, 1975). It results from the action of dissolved CO_2 (H_2CO_3) upon basic materials in the strata, primarily $CaCO_3$. Premining

alkalinity levels are caused by surface geology, soils and vegetation residues (Plass, 1975). Plass (ibid.) found that alkalinity is consistently higher during growing seasons. Generally, it is believed that moderate increases in alkalinity levels favor increased aquatic biologic activity (Hynes, 1970a). A high buffered water is able to resist potential pH changes due to the influx of acid effluents (Stumm and Morgan, 1970).

pH - Indicator of Disturbance

Water quality is widely evaluated through pH determinations, a measure of the concentration of hydrogen ions in a solution at the instant of measurement (Caruccio, 1973). By itself, pH is not an adequate indicator of mine drainage pollution although it can indicate when pollution levels become severe enough to damage stream ecosystems (Striffler, 1973). Plass (1975) emphasized that each watershed has unique characteristics which together with flow determine pH.

Impacts of Acid Mine Drainage (AMD)

The impacts of AMD are well documented. Damage generally increases with increases in coal production and with lower concentrations of bicarbonate in the receiving streams (Barnes and Romberger, 1968). In poorly buffered waters solutions of a very small amount of ferrous sulfate are sufficient to produce a marked reduction in pH (Collier, et al., 1964).

The New River Basin Study measures the impact of alkaline mine drainage upon the receiving streams (Minear and Tschantz, 1976). The undisturbed basin waters acquire little mineral content as rain waters flow through surface and subsurface pathways to the watershed mouth,

causing low and uniform alkalinity of pH primarily controlled by dissolved CO_2 from the atmosphere and from decomposing vegetation. Much less similarity exists among disturbed streams, according to the degree and type of disturbance and time since disturbance. In streams with low alkalinity, pH oscillations have been found to be more dramatic.

Some trends of pH variations have been found. The lowest pH occurs during low water discharge because the constituents causing low pH have a higher concentration at these times (Collier, et al., 1964). Seasonal trends have been established: lowest pH values occur in summer due to an increase in chemical and bacterial oxidation rates because of warmer temperature, and decreased precipitation permits concentration of AMD (Dills and Rogers, 1974). Porous spoil banks containing pyritic materials may contribute to the base flow of acidic streams by serving as ground water reservoirs during drier months (ibid.) Increased precipitation can cause a dilution effect by increased surface drainage into streams (Collier, et al., 1964).

AMD also affects the stream's biota. Fauna experience decreased numbers and diversity due to decreased pH and ferric hydroxide precipitate despite availability of niche space (Patrick, 1974). Most inland waters containing good fish faunas range from pH 6.7 to 8.6: only 5% of waters with fish are less than pH 6.7 (Battelle Corp., 1971). Low pH causes death or inhibits the growth of bacteria and other aquatic organisms which contribute to stream purification (Koryak, 1972).

Ferric hydroxide and dissolved Fe also affect water quality (Carrucio, 1973). Only 5% of fish supportable waters have concentrations of Fe (total) greater than .7 mg/1 (Mathews, 1976). $Fe(OH)_3$, or "yellow boy," is deposited on fish gills and is believed to smother

fish eggs (Warner, 1973). It, too, is responsible for a lowered species diversity and biomass (Koryak, et al., 1972).

B. Presence and Toxicity of Metals and Sulfate

Introduction

The study of relationships between geology and the dissolved minerals in the water provides an understanding of changes in chemical quality of the water which occur during and after stripmining (Curtis, et al., 1964). Ionic species in solution may be more influential in determining biotic effects than AMD (Dills and Rogers, 1974). Significant quantities of Al, Co, Ni, Mn, and Pb are present with all iron sulfides (Gang and Langmuir, 1974). Maximum amounts of metals in water are limited by rates of release from the rock, reactions involving oxidation and reductions, adsorption and desorption, complexation, and solution or precipitation (ibid.). Geochemical variations between growing and dormant seasons have been observed in premining streams except for the parameters sulfate and Mn: Al and Zn are significantly higher during the growing season (Plass, 1975).

Toxic and other effects of metals have been studied (A.D. Little, 1971; Breidenbach, 1975; Hood and Horton, 1976; Burrows, 1977). A number of factors affect chemical toxicity in water: temperature, pH, dissolved oxygen, suspended solids and turbidity, water hardness and CO_2 concentrations (Battelle Corp., 1971). Table II outlines toxic and other effects of metals and sulfate upon biota.

Much work has been focused on the sources and aquatic chemistry of aluminum, the most prevalent constituent of the earth's crust (Whetstone and Musser, 1962). The form and concentration of Al in

TABLE II

TOXICITY AND OTHER EFFECTS OF METALS AND SULFATE[1]

Species	Organism	Dose	Effect
Aluminum	Mammals	>1,400 ppm	Lowered level of inorganic P in bones.
	Humans	--	Large amounts change route of elimination of inorganic P.
	Higher Plants		Affects uptake and transport of P and Ca - more toxic in acid spoils.
Cadmium	Humans		Hemoglobin content decreased in blood. Hypertension linked to retention of Cd in kidneys. Disorder of renal functions. Decreased level of inorganic P. Sizeable loss of minerals from bones. Possible mutagen.
	Fish	5-10 ppb	Toxic level.
Calcium	Humans	--	Associated with lower death rates from coronary diseases. Excessive concentrations - predisposition to formation of concretions in body leading to kidney and bladder stones.
		100-150 mg/l	Elevated occurrence of urinary disease, arthritis and poly-arthritis.. May cause heavy encrustation in piping.
Magnesium	Humans	>1,000-2,000 mg/l	Associated with lower death rates from coronary heart diseases. Purgative effect. May cause heavy encrustation in piping.
Cobalt	Humans		Affects hemoglobin content of blood.
Iron	Benthos and Fish		Deposition of ferric hydroxide on benthos, gills of fish.
	Humans	.1 mg/l	Taste threshold ($FeSO_4$).
Lead	Humans		Change in blood enzymes, decreases longevity. Possible mutagen.
Manganese	Rabbit	500-600 mg/kg/day	Stunts growth, interferes with bone development.

TABLE II

(Continued)

Species	Organism	Dose	Effect
	Rat	5 mg/kg/day	Decreases serum glucose. Kidney damage and inhibition of thyroid function.
		.2-.3 mg/1	Stains materials, especially when pH raised (laundry, etc.) May cause heavy encrustation in piping.
Zinc	Humans	"high"	Disorder of renal functions. Decrease of phosphate levels in blood serum. Sizeable loss of minerals from bones, especially Ca. Possible carcinogen.
	Fish	.1-1.0mg/1	$ZnSO_4$ lethal.
	Mammals	750 mg/kg	Reported acute minimum lethal oral dose.
		5 mg/1	Taste threshold which persists through conventional treatment.
Sulfate	Cattle	>2,220 mg/1	(In water). Become rundown, ragged.
	Dog	>2,500 mg/1	Diarrhea.
	Humans	600-1,000 mg/1	Diarrhea in infants. Affects palatability when excessively high.

SOURCES: Berg, W.A. and Vogel, W.G. 1968. Manganese toxicity of legumes seeded in Kentucky stripmine spoils. U.S. Forest Service Research Paper NE-119.

A.D. Little, Inc. 1971. Water Quality Criteria Data Book, Vol. 2. Inorganic pollutants of freshwater. Water Pollution Control Research Series: 18010 DPV 07/71.

Breidenbach, A.W. 1975. Development document for interim final effluent limitations guidelines and new source performance standards for the coal mining point source category. E.P.A.

Hood, W.E. and Horton, F.E. 1976. Geochemistry of Cadmium as related to coal stripmining. Research proposal submitted to E.R.D.A.

Burrows, W.D. 1977. Aquatic aluminum: Chemistry, toxicology and environmental problems. CRC Critical Reviews in Environmental Control.

water, generally considered highly resistant to dissolution, depends on the pH and nature of substances dissolved in receiving water and to a lesser extent on the temperature and duration of exposure to water (Corbett and Growitz, 1976; Burrows, 1977). Dissolved aluminum is derived from the action of acid water on surface and near surface alumino-silicate minerals: clays and feldspars (Gang and Langmuir, 1974).

Acid waters contain more soluble Al than do neutral or alkaline waters. Aluminum hydroxide ($Al(OH)_3$) is nearly insoluble between pH 5.5 to 8 (Whetstone and Musser, 1962). In natural waters concentrations of less than 1 to 2 parts per million (ppm) are found and much of this is colloidal and disassociated: significant concentrations of Al are only found in waters less than pH 5 (Collier, et al., 1964).

Hood and Horton (1976) have studied the aquatic chemistry of cadmium, long recognized as a toxic element. Cd has a strong tendency to be adsorbed on particulate matter in streams with little of the metal dissolved in the water itself. Its solubility increases with decreasing pH. When Cd is released into a watercourse, it is distributed between the aqueous phase and the stream sediment in cation exchange reactions with clay minerals. Cd ions are strongly bound to hydrous oxides and manganese oxides. Its formation of organic complexes increases with increasing pH.

Calcium and magnesium, present in limestone, sandstones and clay minerals, are brought into solution upon exposure of unweathered calcium and magnesium and pyritic materials (Collier, et al., 1964; Plass, 1975). If carbonate sources are responsible for Ca and Mg, elevated concentrations of Ca and Mg with the onset of mining can

be advantageous as increased amounts of carbonate species in solution raise the pH, improving biotic conditions and reducing concentrations of some metallic ions (Plass, 1975; Minear and Tschantz, 1976).

Iron, total and dissolved, is one of the major pollutants of coal mine drainage, concentrations of which are largely controlled by pH (Breidenbach, 1975). Ferric hydroxide, a red precipitate, is soluble when the pH is less than 3 (Collier, et al., 1964; Connell, et al., 1975). At pH greater than 6 the amount of ferric hydroxide is solution is below detection limits of most methods because of its limited solubility in that pH range (Collier, et al., 1964).

Dissolved manganese, a sensitive indicator of mine drainage, is derived from manganese dioxide minerals weathered from sandstones (Collier, et al., 1964; Striffler, 1973). The aquatic chemistry of the manganous form is closely associated with ferrous iron (Collier, et al., 1964).

Zinc is present in significant quantities in spoil materials. Some evidence suggests that zinc ions are adsorbed strongly and permanently on silt, inactivating the metal (Gang and Langmuir, 1974; Breidenbach, 1975).

When baseline concentrations of sulfate are known, sulfate can be a sensitive indicator of mine drainage. It occurs in sandstones and shales overlying coal beds (Striffler, 1973; Plass, 1975; Caruccio, 1973). In the upper oxidized layers of soil and rock and undisturbed areas, metallic sulfides have been largely converted to sulfates and leached away; thus, spoil banks are the principle sulfate source (Collier, et al., 1964). The concentration of the sulfate anion reflects the extent of and passage of time since the mining disturb-

ance. The New River Basin study has found a lag in sulfate generation after the initiation of mining and long term production of sulfate from disturbed watersheds (Minear and Tschantz, 1976).

C. Sedimentation

Sources

Sediment is widely regarded as the major source of water pollution in the United States (Mills and Clar, 1976). Any land disturbing activity creates the potential for sediment pollution. Agriculture accounts for 50% of sedimentation; however, active surface mining and construction operations have the highest rates of erosion (ibid.). A number of pathways of sediment from surface mining exist: areas being cleared, grubbed, and scalped, haul roads, unreclaimed spoil piles and areas of active mining, slides, reclamation, and streams undergoing erosion (Curtis, 1973; Mills and Clar, 1976). A disproportionate amount of siltation occurs in the early mining phase; further, siltation appears to be seasonal due to the greater rainfall of March and April (Tschantz, 1976). The degree of erosion depends upon soil types, degree of slope, amount of rainfall, climate and the extent of disturbance in the watershed (Greene, 1975; Talak, 1977).

The New River Basin study has determined that the undisturbed streams remain below 25 mg/1 suspended solids and 50 mg/1 total solids without major fluctuations, proving to be relatively independent of climatological variations (Tschantz, 1976). Disturbed watershed streams frequently exceed the mining permit limitation of 100 mg/1 (ibid.). Branson and Batch (1972) observed that siltation was increased fifteen to thirty times that present in undisturbed streams in east-central Kentucky.

Effects

Sedimentation effects upon the stream channel include a decrease in light penetration and a blanketing of the benthos. Light penetration greatly influences productivity. Virtually no light is transmitted beyond 3 inches when solids reach 150 ppm (Battelle Corp., 1971). Ellis (1936) found that waters carrying large loads of erosion silt transmitted in general more red light, the shorter wavelengths being filtered out. Predaceous fish which feed by sight are at a disadvantage in turbid water while bottom feeding fish such as catfish or carp are known to increase in turbid waters (Battelle Corp., 1971).

Blanketing of the benthos with silt has dramatically adverse affects upon the biota. Deposited silt smothers algal growth and kills rooted plants (Hynes, 1970a). Soft shifting sand and light silt are particularly difficult substrata for benthic organisms although certain organisms have adapted to silted habitats with such modifications as extreme hairiness, flattening or operculate gills (Hynes, 1970a). Secondary productivity is known to decrease from course to fine substrate (Kimble and Wesche, 1975).

Sedimentation can eradicate fish spawning sites and the entire benthos through altering the nature of the substrate. Only small amounts of sand and silt shifting in the around gravel eliminates much of the benthic habitat (Battelle Corp., 1971). Bjorn (1974) discovered that insect densities are smaller in riffles with large amounts of sediment. Gammon (1970) noted that the average density of macroinvertebrates declined noticeably during periods of heavy sediment input. Branson and Batch (1972) noted that siltation may decrease the number of benthic organisms by 90% in one year.

D. Watershed Characteristics

Terrestial Conditions

Running water systems must be evaluated within overall watershed influences. The primary aquatic interface with the terrestial environment occurs in small watersheds and valley streams. Terrestial events largely determine what materials streams receive. Surface mining disturbances influence water quality due to a number of watershed factors: chemical oxidation products of geologic material, spoil properties which determine internal drainage, degree of drainage control on the surface, and the extent of natural or planted vegetation (Striffler, 1973).

Climate

Water resources of a watershed are controlled by rainfall and topography (Gerking, 1963; Curtis, 1973). Generally, rainfall is concentrated in the cool months of the year creating seasonal fluctuations of drought and flood (Gerking, 1963). Curtis (1973) observes that natural variations caused by climatic variability profoundly influence other perturbations within the watershed to such an extent that to report more than general trends with only one or two years of data is presumptuous.

E. Stream Characteristics

Stream Ordering System

The stream ordering system, as developed by Horton (1945), permits comparison of unlike drainage systems (Harrel and Dorris, 1968; Viessman, et al., 1972). Generally, physiochemical fluctuations decrease

as stream order increases. Cummins (1975) describes stream orders one to three as small headwater springs and streams dominated by terrestial settings which comprise 85% of all stream miles. Geologically, they are the youngest portions of a river system and are typified as being light and nutrient limited and dominated by coarse sediments. Headwaters have the most primitive insects derived from terrestial origins. Stream widths for orders one to three are .5m, 1 to 2m, and 4 to 6m respectively (ibid.).

Erosion-Deposition Concept

The erosion-deposition concept is another method of stream classification (Cummins, 1964). This model relates stream gradient to substrate (bottom-type). All the coarse particles are swept from areas of steep gradient and deposited in regions of low gradient (Hynes, 1970a). Cummins (1974) found an exponential decrease in median sediment particle diameter with distance downstream from the headwaters. Particular assemblages of biota are assocated with each area.

Energetics

Low order streams are largely considered allochthonous, dependent for a majority of the energy supply on the import of organic matter from the terrestial systems through which they flow. Cummins (1974) found that less than one percent of the total energy supply is fixed in the stream, allocthonous materials providing the bulk of reduced carbon. Nutrients are continually entering from upstream via ground or surface flow resulting in a continual renewal rather than recycling (Patrick, 1969). In small turbulent streams oxygen is normally near or above saturation, although a seasonal variation may be observed due

to decomposition of leaves or photosynthesis (Hynes, 1970a). Also, in the low order streams turbulent mixing ensures uniform distribution of dissolved substances.

Discharge

A primary physical parameter of streams is streamflow or discharge. Discharge reflects the hydrologic response of the stream to changes occuring throughout the watershed. Viessman, et al. (1972) observed that the nature of land forms and their disturbances, seasonal fluctuation of vegetative coverage or devegetation, and climatic variation influence streamflow.

Research has uncovered some of the dynamics occurring in mined watersheds. Such watersheds are generally more variable than control basins and tend towards higher storm flows and lower base flows (Curtis, 1973). Peak flow appears to be a function of magnitude or type of storm, time of year, and degree of surface mining (ibid.). Bohm, et al. (1974) found that during dry periods substantial surface runoff is intercepted as storage by the spoil banks and is gradually released to the stream as subsurface seepage; thus, during dry weather flow is uniformily increased by orders of magnitude. Initial mining causes higher downstream peak flows causing higher flood stages (ibid.).

Chemical water quality is also related to stream discharge. Salts move from spoil banks to streams by surface or groundwater flow. Soluble salts are concentrated at the spoil surface through evaporation and subsequently put into solution and transported by overland flow to a stream during storms (Curtis, 1973). Alternatively, Curtis, et al. (1966) noted that the salts are dissolved in the ground-

water as it percolates through the spoil and seeps into a stream. An apparent lag has been observed by Curtis (1973) between storm events and the occurrence of various chemical species in a stream due to the variation in time for chemical weathering of elements and different solubility rates, but also to the time necessary for elements in solution to migrate to stream channels.

Oscillations in water quality have been observed in mined watersheds. During storm events in undisturbed stream basins the absolute magnitude of variation in water quality parameters is quite small: variation in such watersheds has been found by Minear and Tschantz (1976) to be independent of stream flow and climatological conditions. However, storm events in disturbed watersheds trigger great fluctuations in the concentration of individual constituents from sample to sample, thus indicating a close relationship between daily rainfall data and concentration of constituents although a simple association pattern is not evident (ibid.). During periods of minimal precipitation, sulfuritic salts and acidity which accumulate in the mines are then flushed out by major storm events, creating a slug of mine drainage products (ARC, 1969). Herricks and Cairns (1974) report that during low flow conditions water quality deteriorates as the water becomes more acid with higher concentrations of metals and sulfates.

F. Aquatic Insects as Biological Indicators

Introduction

The major taxa of invertebrate groups in freshwater are Insecta, Mollusca, Oligochaeta, Crustacea (Amphipoda, Isopoda, Decapoda), and in some studies, Nematoda (Cummins, 1974). Aquatic insects are the

biotic focus in this study, the major orders being Trichoptera, Ephemeroptera, Plecoptera, Diptera, Coleoptera, Megaloptera, Odonata and Hemiptera.

The functional role of macroinvertebrates in flowing water ecosytems is to convert into tissue and carbon dioxide reduced carbon compounds from primarily allochthonous materials (Cummins, 1974). Nutritional requirements of aquatic insects are the intake of adequate calories to meet energy costs and storage and sufficient protein to sustain adequate growth.

Aquatic insects have a number of survival strategies which account for their persistence through adverse conditions (Hynes, 1970a). Patrick (1969) found that short generation time and high reproductive rates provide a stable population base. Patrick (1970) observed that production of eggs which are able to overwinter and resist dessication allows species to persist through cold, drought and other environmental stresses.

Life histories are generally univoltine with some multivoltine cycles occuring in running water habitats: many Ephemeroptera, Plecoptera, Trichoptera and some Simuliidae experience univoltine life cycles; some Ephemeroptera and Simuliidae experience multivoltine life cycles (Hynes, 1970a). Single generation species are only found as nymphs during certain limited seasons. Seasonal variation in species compostion in a stream must be considered in the study design.

Aquatic insect ecology is still largely exploratory and descriptive. An inablity to identify many immature insects persists. For many of our North American species life cycles are unknown, immature stages undescribed and the total span of emergence periods is unrecorded

(Gaufin, 1973). Further, sampling methods remain inadequate, especially in view of the depths many insects penetrate (Hynes, 1970a).

Two main approaches to the study of aquatic insects have emerged. K. W. Cummins has led the way in the study of the energetics of stream biota through the measure of biomass and production. The other approach, the one taken in this study, is to analyze community structure and to describe the community in terms of species frequency and the numerical abundance of the species (Hairston, 1959, Wilhm and Dorris, 1966).

Community Structure

An ecosystem is a natural unit composed of abiotic and biotic elements interacting to produce an exchange of materials. This interaction results in a characteristic assemblage of organisms. Community structure is the complex of individuals belonging to different species in the ecosystem. Structures change in response to fluctuations in the components of the system: food source, substrate, climate and pollution are among these factors.

Different stream types have characteristic types of community structure, such as montane or lowland, erosional or depositional. Stream size also influences species composition, larger streams having generally more species (Minshall, 1969). The more alike two streams are in size, type and local climate, the more similar community structure will be (ibid.). The lotic habitat is rigorous, and unpredictable events can drastically affect populations. Patrick (1969) typified benthic community as young and immature because of widely fluctuating populations, high metabolic rates, short life cycles and high reproductive rates.

Community organization results from the outcome of interspecific competition for the available resources, and is biotically expressed in relative abundance, trophic relations and spatial distribution of the constituent species (Hairston, 1959). Cummins (1974) found significant differences in these ecological parameters among growth phases of a given species. The general pattern of trophic organization is based on feeding mechanisms, with food texture and particle size relative to the size of the food gathering device of primary importance (Cummins, 1973). Different species in the same functional group are by definition very similar; however, many taxa bracket more than one trophic level if the opportunity arises. Wilhm and Dorris (1968) generalize that natural undisturbed systems are typified by the presence of a few species with a few individuals each, the various functional groups all represented.

Aquatic insect populations are normally considered to be dispersed according to a contagious or negative binomial distribution (Southwood, 1968, Elliot, 1971). Populations tend to be clumped in space due to the uneven distribution of environmental factors. This property affects the sampling program and methods of analysis.

Factors Controlling Distribution of Aquatic Insects

Natural variations and human perturbations affect community structure. In the New River Basin study (Vaughan, 1977) factors related to oxygen content, water micro-velocity, turbidity and litter accounted on a monthly basis for 60 to 90% of the observed variation in insect populations. The complex interaction of variables must be evaluated prior to estimating the effect of a particular stress. A

number of factors are recognized as the primary determinant of micro-distribution.

1. Substrate. The influence of the substrate is considered by many to be of primary importance in controlling presence and distribution of fauna and food materials (Hunt, 1930, Cummins, 1962). Kimble and Wesche (1975) reported that the larger the substrate particle and more complex the substratum, the more diverse the invertebrate fauna, concluding that stony reaches of streams are richer in terms of species number and total biomass than are gravel, muck or sand substrate types. Rubble or rocky substrates have a richer community structure because more space is available for colonization than on silt or gravel, it is more stable and less likely to wash out, and a greater probability exists that organic matter will lodge among stones and provide food for the benthos (Hynes, 1970a). Certain species seem to select habitats on the basis of bottom types as reported in the studies by Linduska (1942) on mayfly species and by Pennak and van Gerpen (1947) on species of various orders. Substrate degradation, such as gross siltation, can change community structure drastically (Weber, 1973, Talak, 1978). Researchers (Cummin, 1962, Hynes, 1970a; Weber, 1973) conclude that only fauna from sites with similar substrates will provide valid data for comparison.

2. Current Velocity. The other factor which researchers consider of great importance in determining diversity and biomass is current velocity. Velocity, inherently more ephemeral than substrate, sets limits on the range of substrate particle size (Weber,

1973). Cummins (1974) investigated the growth of vascular hydrophytes and accumulation of particulate detritus in various velocity regimes. Aquatic insects rely upon current speed for feeding purposes and respiratory requirements. Linduska (1942) found that even though most species are capable of inhabiting situations under a wide range of surface velocities wherever suitable bottom types are present, the position of many species in a given site was apparently determined by stream velocity.

3. Center-edge Effect. Hynes (1970b) found that as species pass through various life stages, they tend to concentrate towards the center of the stream. In smaller streams (less than 10 m wide) the center is more densely populated than the sides (Hynes, 1970a).

4. Riffle Habitat. Riffles and pools are the two basic stream types generally controlled by substrate and current velocity (Cummins, 1964). In rapidly flowing water, characterizing erosional habitats or riffles, finer sediments are removed. Characteristic benthic assemblages typify such habitats which are adapted for clinging on rocks or avoiding current by suckers, hooks, cases, dorsalventral flattening or living in leaf packs (Cummins, 1975). Gerking (1963) enumerated characteristics which distinguish differences among riffles: variation in amount of surface of rubble exposed per unit volume of water, shade, substrate and chemical conditions prevailing in the pool above.

5. Riparian Vegetation. Woodall and Wallace (1972) suggested that riparian vegetation may greatly influence a stream's community structure. Organic inputs to forested streams occur from direct

litterfall, lateral movement down stream banks, and blowdown of trees, treetops and branches. Sedell (1973) found that the leaves of different tree species were processed at different rates dependent on the insects' leaf type preference. Cummins, et al., (1973) discovered that aquatic insect shredders attack leaves previously colonized by microbial flora.

6. Alkalinity. Some work has been done on the effect of alkalinity on benthos. Armitage (1958) found that the population size of aquatic insects increases with increased alkalinity. Hynes (1970a) concluded, however, that it is perhaps not possible to isolate alkalinity from the other variables to account for population differences.

7. Liability to Spates and Droughts. Gaufin (1962) found that univoltine species occur in eastern intermittent streams in which eggs survive the drought. Late emerging insects are the most severely affected by drought as most dry periods occur during the summer. Species able to burrow into subsurface flow are especially adapted for drought liable streams. Periods of high water reduce invertebrate faunas in streams. Hynes (1970a) generalized that streams more liable to spates have less abundant and diverse fauna than others.

8. Temperature: Seasonal Variation. Cummins (1974) termed stream insect communities as temperature compensated, i.e., communities have organisms capable of processing organic matter at reasonable rates below normal optimal temperatures, unparalleled in temperate terrestial systems. A general tendency toward cold stenothermy exists among many stream insects (Hynes, 1970b).

Emergence is also influenced by temperature (Hynes, 1970a). Seasonal variation in abundance and distribution patterns are significant. Major inputs of particulate organic matter occur in the fall, initiating the dominant period of processing which continues through early spring. Tebo and Hassler (1961) reported that Trichoptera, Coleoptera and Diptera are in peak abundance during autumn.

In winter the standing crop of the benthos is highest in streams (Mackenthun, 1973). Hynes (1970a) generalized that during winter biomass may increase despite the decline of recruitment from newly hatched eggs, especially if mayflies and stoneflies are present. Tebo and Hassler (1961) discovered minimum abundance in all orders during December and January; however, plecopterans and dipterans experience peaks in species composition during November to December and January to February, respectively

During spring streams experience a loss of both biomass and numbers because of emergence, but a resurgence of growth also occurs (Hynes, 1970a). March to May is the period when mayflies are in their peak abundance (Tebo and Hassler, 1961).

During summer stream flows are at their minimum. Trichopterans peak from June to October (ibid.). Usually a steep decline in biomass occurs during the summer season (Hynes, 1970a).

9. Drift Organisms. Researchers have concluded that organisms are set into drift due to density dependent mechanisms, although catastrophic events are also responsible for dislodging insects from their footholds (Minshall and Winger, 1968). Waters (1966) found that the greatest drift rates occur during hours of darkness. Drift organisms become significant in pollutional studies when they are taken in a sample and mistakenly considered members of that community (Gaufin, 1958).

10. Human Perturbation. As Cummins (1973) wrote, "One of the most ubiquitous features of freshwater habitats is their present rate of change in response to man-engendered perturbations." Perturbations cause changes in the species present and in the size of populations.

The modes of human engendered stress on aquatic ecosystems are legion. This study focuses on the effects of surface mining. Yet it should at this point be obvious that the interaction of biotic and abiotic variables which determine community structure are most complex. It becomes the task of the field ecologist to locate similar sampling stations to make meaningful comparisons. Even then, results must be qualified to admit that variations could be due to some other parameter than the one being studied.

The Use of Aquatic Insects as Indicators of Stress

Because researchers have observed that abundance and diversity of microinvertebrates are affected both by natural environmental factors

and anthropogenic water quality changes, benthic organisms have been used as indicators of water quality. The assumption underlying the use of biotic indicators is that the qualitative and quantitative composition of an aquatic population is determined by both short and long term recurring critical conditions (Gaufin and Tarzwell, 1952). Aquatic insects are especially useful as indicators because of the length of their life cycles, the central position they hold in the food chain, and their lack of mobility in comparison with fish (Mackenthun, 1966; Gaufin, 1973; Dills and Rogers, 1974). The distinct advantage of the indicator organism analysis over chemical analysis lies in the problem of sampling. Chemical substances affect water and act in a wide range of concentrations, and vary continuously and erratically in concentrations; moreover, chemical surveys indicate conditions only at the instant of sampling (Gaufin and Tarzwell, 1952; Wilhm and Dorris, 1968). Aquatic insect communities, however, represent a complex of organisms which have adapted over a period of time to specific environmental conditions; thus, community structure is useful to indicate past as well as present benthic water quality at fixed points (Gaufin and Tarzwell, 1952; Mackenthun, 1966).

Recovery of a stream occurs as a function of time or distance from the stress. Recovery over distance is usually applicable when the stress is not completely eliminated under conditions when the gradient is well defined, the stress is controlled by such watershed characteristics as tributary location and discharge, and viable recolonization centers if present (Herricks and Cairns, 1973). Recolonization occurs through drift, upstream flight of ovipositing adult females, and upstream movement of larval organisms (Hynes, 1970a).

A community under environmental stress is known to have a specific response. Herricks and Cairns (1973) found that when tolerance limits are exceeded, large numbers of species are eliminated from the community, the community's functional ability (trophic organization) is impaired or destroyed, and that through a decrease in diversity, redundancy may be eliminated leaving functional niches vacated.

Herricks and Jensen (1974) typified the effects of acid mine drainage as a high intensity stress of long duration. The residual toxicity of some materials may make sections of the receiving streams unsuitable for recolonization for long periods of time.

The indicator organism scheme is the classification of taxa according to their presence or absence, tolerance or intolerance to environmental conditions. Tolerant species, normally a moderate constituent of every diverse stream community, increase in population enormously when conditions are such that less tolerant species are incapable of survival (Weber, 1973). Wurtz (1955) found that absence of intolerant species was more significant than the presence of tolerant species in describing community structure.

The possibility always exists that presence or absence of species may be due to other environmental conditions than the one being studied. Evidence which correlates biotic distribution to a physico-chemical parameter is generally weak because that distribution could be controlled by some other parameter (Cummins, 1974). The problems of drift organisms further complicates evaluation of community structure. Dambach (1967) underlined the difficulties in using the indicator organism scheme in the evaluation of acid mine drainage: regional differences in species and environmental conditions, variability in the types of pollution, and non-uniformity in the mechanisms of evaluation.

G. Impact of Mining on Aquatic Inspects

Impact on Community Structure

Generally, acid mine drainage greatly reduces the numbers of species present, the few species remaining often having fairly large populations due to the absence of predators and competitors (Lackey, 1938; Patrick, 1974). Tomkiewicz and Dunson (1977) found that insect communities of reasonable diversity and biomass persisted at pH 4.8 to 5. Biotic investigation in the New River Basin (Vaughan, 1977) also found that existing contour mining practices affect population size, species richness and species equitability of the organisms studied relative to the amount of disturbance: in each case the control stream diversity was significantly greater than for the disturbed streams.

Tolerance to Acid Pollution and Metals

Much qualitative work has been done on the effects of pH on aquatic insects. Warner (1973) found that an abrupt diversity decrease occurs between pH 4.0 and 4.4. At pH less than 4.0, Oliff (1963) uncovered virtually no fauna at all in a stream blanketed with ferric hydroxide. Emergence of aquatic insects, a critical life cycle stage, was studied over a range of pH values by Bell (1971, 1977). He discovered that for certain species the pH must be greater than 5.5 to permit 50% successful emergence, the pH range required for emergence varying from family to family.

Limited laboratory study on pH tolerance has been reported. The work by Bell and Nebeker (1969) concentrated on short-term conditions. Gaufin (1973) supported their conclusions that species can live for

short periods of time at pH values below those normally found in the field. Future work needs to be done on long term effects of low pH on growth, emergence and reproduction.

Limited evidence suggests that the greatest impact of low pH on aquatic insects is the creation of conditions that puts high concentrations of metals into solution. Warnick and Bell (1969) found that heavy metals were the most important parameters influencing mortality of different species. Generally, insects are more tolerant to both low pH and metals than are many fish (ibid.). Sykora, (1972) found that prolonged exposure of young Cheumatopsyche larvae to high concentrations (20 mg/1) of ferric hydroxide prevented successful emergence. Too little work has been done on the toxicity of metals to aquatic insects.

Sedimentation Effects

Sedimentation is perhaps the most important effect on the biota (Sykora, 1972). Available habitats are severely reduced due to the blanketing action of fine silt deposits over the benthos. The newly deposited silt over the pre-existing substrate has a low stability as it is subject to disturbance by the next high waters (Tebo, 1955). Faunal improverishment of highly silted areas occurs through the increase of drift organisms as the concentration of suspended solids in water increases (Gammon, 1970, Brusven, 1974). Just as sediments are know to cover fish eggs, it can be assumed that the same fate is experienced by insect eggs (Stroud, 1967; Hynes, 1970a; Talak, 1977). An indication of the susceptibility of aquatic insects to sediment is that in surface mined streams, bottom feeding fish are the first to disappear (Branson and Batch, 1971).

Recovery of Streams

Biologic recovery and restoration of damaged streams is based on the type, intensity and duration of the stress. Residual toxicity and sedimentation may make sections of receiving streams unsuitable for recolonization for many years (Talak, 1977). Work in the New River Basin (Vaughan, 1978) indicated that the population crashed within three years of the onset of mining and then slowly returned to the original size over a period of twenty years. Although species richness and equitability eventually recovered in the New River Basin, species composition has been altered, with those species least tolerant of siltation most susceptible to attrition.

Sensitivity of Order

1. Ephemeroptera. This order, found in maximum numbers in course gravel and rubble or mud suitable for burrowing forms, survives in a wide range of current speed and exposure (Pennak and Van Gerpen, 1947; Leonard, 1965). Mayflies have been found to be the most sensitive order to the effects of surface mining and are rarely found in streams receiving acid mine water and sediment (Collier, et al., 1964; Bell, 1971; Patrick, 1974). Certain species of Baetis, Callibaetis, Paraleptophlebia and Stenonema are more resistant and have been found in water with pH as low as 4 (Bick, et al., 1953; Roback and Richardson, 1969; Bell and Nebeker, 1969). Warnick and Bell (1969) found Ephemerella the most sensitive genus to metals, while Bell and Nebeker (1969) reported that this genus was eliminated in waters near pH 4.5.

2. Plecoptera. Stoneflies are moderately tolerant to AMD and sedimentation (Bell, 1971; Green and Morgan, 1974; Patrick, 1974). Gaufin (1973) found that long term exposure to pH less than 4.5 completely eliminated individuals of the species studied. Warner (1968) collected stoneflies exposed to a short-term pH value of 3.1. Bell and Nebeker (1960) reported that long-term exposure at pH values of 3.5 completely eliminated plecopterans.
3. Odonata. Dragonflies and damselflies are also moderately tolerant to AMD and sedimentation (Roback and Richardson, 1969; Bell, 1971; Patrick, 1974). Certain species, however, are highly tolerant. Stickney (1922) collected Libellula pulchella at a low pH. Bell and Nebeker (1969) found Boyeria vinosa at pH 4. Bick, et al. (1953) reported that dragonflies were some of the most numerous forms in their acid stream investigation.
4. Trichoptera. Caddisflies are considered fairly tolerant as a group (Roback, 1965; Bell and Nebeker, 1969; Gaufin, 1973; Patrick, 1974). Cheumatopsyche and Hydropsyche are reported tolerant of wide ranges of chemical conditions (Roback, 1965). Hydropsyche betteni survived at pH 4 (Bell and Nebeker, 1969) with a 50% successful emergence rate at pH 4.7 (Bell, 1971). Ptilostomis has also been collected at stressed sites (Roback and Richardson, 1969). Concentration of iron was not found to be a factor in the distribution of caddisflies (Roback, 1965).
5. Diptera. This order has a very large ecological niche and is often used for biotic evaluation of water quality. The order is generally considered to be tolerant (Green and Morgan, 1974).

The Chironomidae appear to be the most tolerant family as it is generally diverse and well established in most sites (Roback and Richardson, 1969; Nichols and Bulow, 1973; Patrick, 1974). Larvae of Simuliidae, the black flies, are confined to riffle areas. They develop large populations in streams when carnivorous insects such as the mayflies and stoneflies are absent (Patrick, 1970). Antocha of the Tipulidae has been reported tolerant of AMD (Nichols and Bulow, 1973).

6. Megaloptera. Sialis appears tolerant to AMD (Roback and Richardson 1969). Patrick (1974) reported that this genus was the only active predator when AMD was the greatest.
7. Coleoptera. Aquatic beetles, especially Dytiscidae, are commonly found in sites stressed by AMD (Roback and Richardson, 1969; Warner, 1973; Patrick, 1974). Hyrophilids have also been collected under adverse AMD conditions (Patrick, 1974).
8. Hemiptera. At sites of extreme AMD conditions, this order often has the largest population although only a few species may be present; Corrixidae, Gerridae and Veliidae are the families most often collected (Roback and Richardson, 1969; Patrick, 1974).

H. Regulations

Abatement and Management Techniques

The primary abatement and management responsibility for existing mines is charged to the private mine operator who by state and federal legislation must comply with certain prescribed mining practices. Environmental costs are lower at the time of mining if the miner integrates reclamation and pollution control into the mining process than they become later as a public responsibility (ARC, 1969).

Abandoned mines have become the responsibility of public agencies. Management and abatement techniques have been developed to remedy intolerable situations. The techniques range from source control and treatment of polluted waters to pollution dilution and permanent containment of affected waters (ibid.).

State Regulations Affecting Water Quality

The state of Tennessee first passed legislation regulating surface mining in 1967. A historical outline of Tennessee Stripmine Law and Regulation appears in Table III. Primary and secondary drinking water quality standards promulgated by the state for parameters measured in this study are presented in Table IV. Effluent parameters for surface mine discharges which are measured by the state are the same as those measured by National Pollutant Discharge Elimination System (NPDES) and Office of Surface Mining Permits (Table V.)

Federal Regulations Affecting Water Quality

In 1972 the Federal Water Pollution Control Act (FWPCA) was passed by Congress, requiring swimmable fishable waters by 1983 and zero pollution by 1985. The FWPCA established the National Pollutant Discharge Elimination System (NPDES) which is administered by the Environmental Protection Agency. NPDES requires point source dischargers to obtain a permit. Receipt of the permit imposes on the discharger requirements to attain FWPCA goals. The permitting authority receives data on dischargers based on monitoring results collected and analyzed by the discharger (Schaffer, 1975). July 1, 1977 was the deadline to reach effluent limitations which represent application of the "Best Practicable Control Technology."

TABLE III

HISTORICAL OUTLINE OF TENNESSEE
STRIP MINE LAWS AND REGULATIONS

Law	Regulation Impacts
No law prior to 9/67	No state strip mine control.
9/67 - Tennessee Strip Mine Law of 1967	First state provision for strip mine regulation and control, permits, reclamation and enforcement. $400/acre bond.
3/71 - Tennessee Strip Quality Control Act	Established Division of Water Quality under the Department of Public Health. Water Quality discharge permit application required prior to mining.
3/72 - The Tennessee Surface Mining Law, Amendments of 1967 Law.	3/73 - Regulations Pertaining to Surface Mining. More specific regulation criteria: toxic materials segregation, grasses and trees revegetation required; $600/acre bond requirement.
3/74 - The Tennessee Surface Mining Law, Amendments to provide for more specific regulation and control to minimize environmental degradation.	6/74 - Regulations Pertaining to Surface Mining. More specific regulation criteria: prospecting permit required, specific rules on access roads, no highwall after 7/75, landslide prevention rules, no mining within 100 feet of flowing stream centerline, $1,000/acre bond. 12/75 - Addendum to Regulations Pertaining to Surface Mining. Adoption of drainage control handbook; major revegetation changes. 7/76 - Addendum to Regulations Pertaining to Surface Mining. More specific regulations relating to contour mining. 8/77 - Addendum to Regulations Pertaining to Surface Mining. Adoption of provisions to bring state law into compliance with Federal Surface Mining Control and Reclamation Act of 1977 to enable state to enforce interim standards.

SOURCE: Minear, R.A. and Tschantz, B.A. 1976. The effect of coal surface mining in the water quality of mountain drainage basin streams. Journal of the Water Pollution Control Federation, 48 (111).

TABLE IV

DRINKING WATER QUALITY STANDARDS, DIVISION OF WATER QUALITY
TENNESSEE DEPARTMENT OF PUBLIC HEALTH
(for Substances Measured in this Study)

Substance	Total Concentration mg/l
Fe	.3
Mn	.05
SO_4	250.0
Zn	5.0
Cd	.01
Pb	.05

TABLE V

EFFLUENT LIMITATIONS IN MILLIGRAMS PER LITER (EXCEPT pH)
FOR NPDES PERMITS ISSUED TO SURFACE MINING OPERATIONS

Parameter	Daily Maximum Allowable	Average of Daily Values for 30 Consecutive Days
Iron, total	7.0	3.5
Manganese, total	4.0	2.0
Total, suspended solids	70.0	35.0
pH	----------within range---------- 6 to 9	

Effluent limitations monitored in NPDES permits are the same as established by the Federal Surface Mining Control and Reclamation Act of 1977 (Table V), except for the additional standards of settleable solids which is set at 1 ml/l daily maximum which the state requested also be set as a standard.

The Federal Surface Mining Legislation of 1977 (P.L. 95-87), administered by the Office of Surface Mining within the Department of the Interior, is the first attempt of the federal government to comprehensively regulate the mining and reclamation process. All new mines and existing mines producing more than 100,000 tons of coal annually are now regulated by this new law. Small operators producing less than 100,000 tons of coal annually are regulated beginning January 1, 1979, a provision which affects nearly all of the miners of Grundy County.

Criticism of Effluent Limitation Standards

A criticism of existing effluent limitations is that the effects of mining variations cannot be judged because premining values may exceed compliance standards (Plass, 1975). Further, regulated discharge limits rarely reflect changes in the potential for damage of waste discharge acting either alone under variable environmental conditions or in combination with several quite different waste discharges (Herricks, et al., 1974).

CHAPTER III

STUDY AREA

A. General

Grundy County is a sparsely populated rural county. In 1975 12,166 people lived in the 229,100 acre county (US Department of Commerce, 1977; Hedlund, A. and Earles, J. M., 1971). It is not well suited to agriculture. The economy of Grundy county is based on commercial broiler production, timber and coal. Large blocks of land are held by mining and timber companies. Little growth is projected through the year 2000 (TN Department of Public Health, 1976). Industries utilize water from public supply systems or wells rather than from surface waters (ibid.). All of the principle population centers are in need of wastewater collection and primary treatment. Figure 1 depicts the study area.

Savage Gulf Natural Area

Savage Gulf Natural Area includes over 8200 acres and there are plans to acquire more land. This area, containing the headwaters of the Collins River, partially drains surface waters affected by surface mining. The state divisions of surface mining and water quality are attempting to protect the area from further degradation by surface mining.

Previous Water Quality Surveys

Previous water quality surveys of the county are minimal. The



SCALE 1:250,000

Figure 1. Topographic Map of Grundy County, Tennessee.

only longterm water quality monitoring within the county is of the two public water supply systems. The only USGS or TVA monitoring station within the county is located at river mile 194.2 of the Elk River at the base of the Cumberland escarpment.

B. Geography

Geographic Location

Grundy County is near the center of the western edge of the Southern Cumberland Plateau, lying almost entirely within the boundaries of the coalfield. Rocks of Mississippian age are exposed on the western edge of the county where headwaters of the Elk and Collins rivers and Hickory Creek have cut back into the plateau and in a small area of the southern margin of the county where headwater tributaries of the Little Sequatchie River have cut into the hard resistant caprock. (Luther, 1959). The surface of the plateau lies at an elevation of 2000 feet and rises 20 feet to the mile from south to west. The plateau surface is level or gently rolling with ridges lying between different streams or on the Tennessee River Divide (Nelson, 1925). The plateau streams are small and shallow with low gradient until they reach the edge of the plateau where they fall rapidly to the valley floor (ibid.) The soils which stem from the Fort Payne formation are a cherty limestone (TVA, 1971). The Hartsell soils are relatively shallow, acid, and low in fertility (Byerly, 1978). Their preferred uses are pasture, hay, and forest (SCS and TVA, 1958).

The continental climate of the area provides widely fluctuating seasonal temperatures and rainfall (Gerking, 1963). Monthly mean temperature and precipitation in the area is shown in Table VI.

TABLE VI

MONTHLY MEAN TEMPERATURE AND PRECIPITATION IN AREA

Month	Precipitation (cm)	Temperature (C)
1	13.28	5.3
2	12.98	6.7
3	15.37	10.4
4	11.51	15.4
5	10.57	19.8
6	10.70	24.3
7	13.56	25.7
8	9.40	25.2
9	6.83	22.5
10	8.23	16.0
11	10.24	9.5
12	13.49	5.6

SOURCE: Tennessee Valley Authority, Division of Reservoir Properties. 1971. A recreation development plan for the South Cumberland area in Grundy, Franklin and Marion counties. Prepared for the Grundy County Conservation Board.

C. Stratigraphy

Pennsylvanian Rocks

The Pennsylvanian rocks of Grundy County all belong to the Gizzard and Crab Orchard Mountain groups. Figure 2 depicts the position of these groups in relation to the others found within the state.

Figure 3 represents a composite section of the coal measure in Grundy County (Hershey, et al., 1955). Beds belonging to the upper part of the Crab Orchard Mountain group are only preserved in the southeastern corner of the county (Luther, 1959). The lowest rocks exposed are of the Mississippian series of which the Bangor formation forms the bottoms of coves and lower sides of the mountain (Nelson, 1925).

The Gizzard group, varying in thickness, includes all the strata between the top of the Mississippian and base of the Sewanee conglomerate and includes the Racoon Mountain, Warren Point Sandstone and Signal Point Shale formation (Luther, 1959). The Racoon Mountain formation, an alteration of sandstone and shales, contains the Whiteoak and Bon Air coal seams, neither of commercial value (ibid.)

The Crab Orchard Mountain group, cropping out on the surface and around the plateau rim, includes the Sewanee conglomerate, Whitwell shale, Newton sandstone, Vandever formation and Rockwell conglomerate. The Whitwell shale, preserved only in the southeastern half of the county, contains the only known reserves of minable coal: the Sewanee seam (ibid.). The Newton sandstone is the only potential aquifer likely to be affected by surface mining (Byerly, 1978).

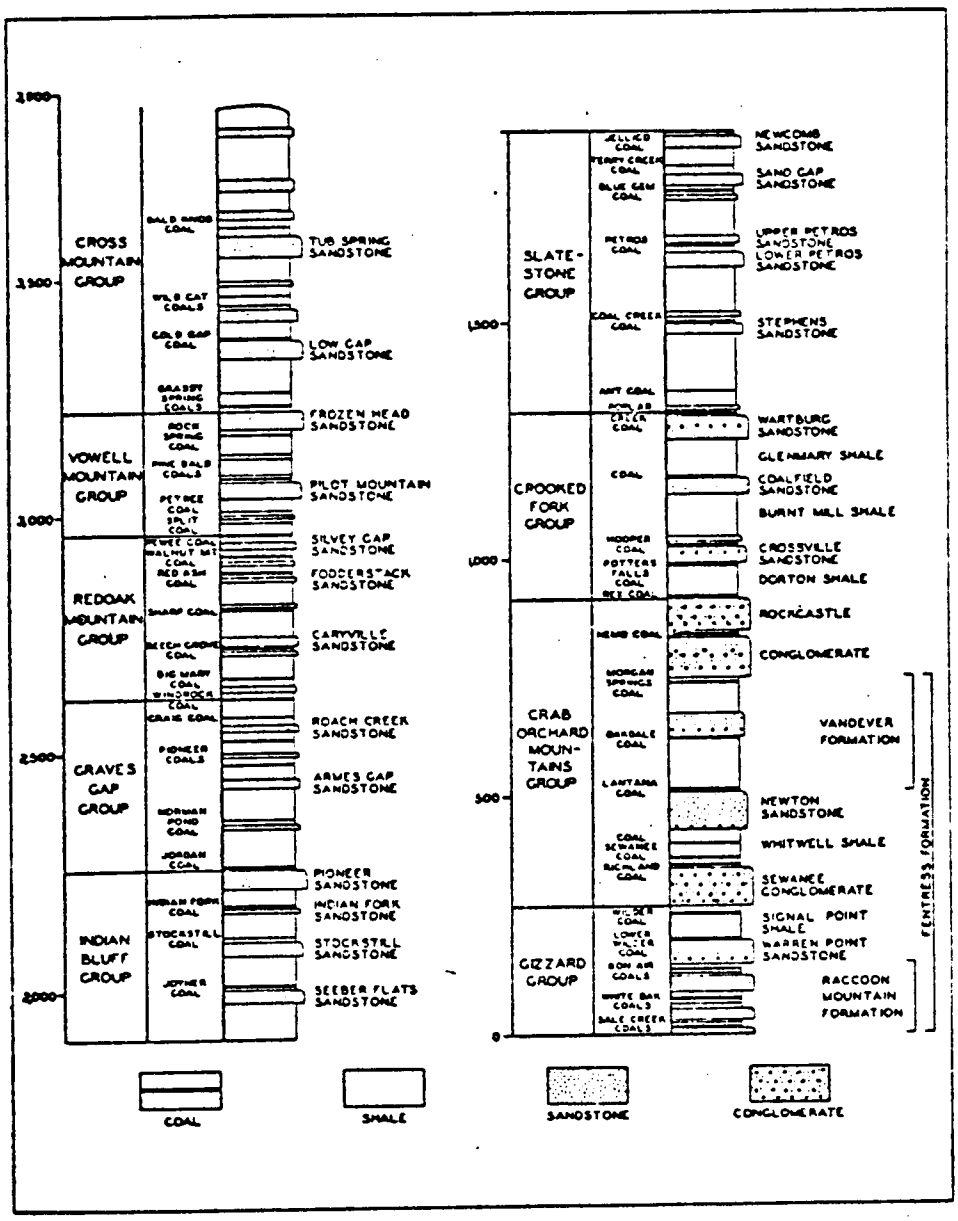


Figure 2. Generalized stratigraphic sequence of Pennsylvanian rocks in Tennessee

Source: Luther, E. T. 1959. The Coal Reserves of Tennessee. Tennessee Division of Geology, Bulletin 63, Nashville, Tennessee.

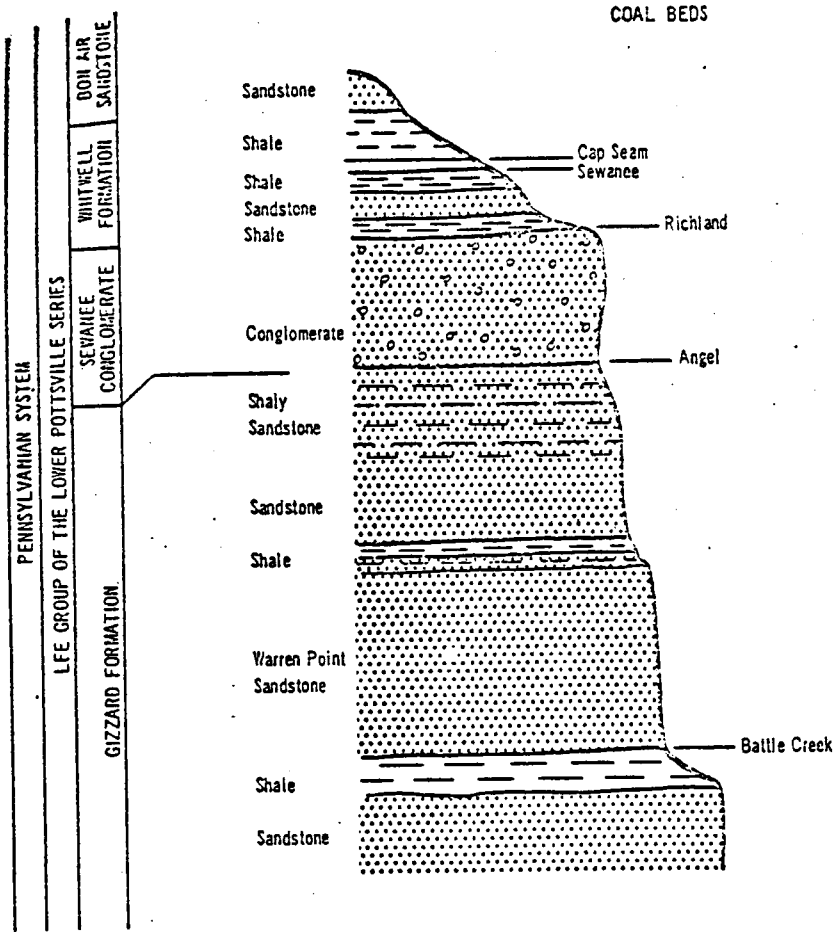


Figure 3. Composite section of coal measures in Grundy County, Tenn.

Source: Hershey, R., Williams, L. and Gandruid, B. W. Estimates of known recoverable reserves of cokery coal in Grundy County, Tennessee. U.S. Bureau of Mines: Reprint of Investigations 5148.

Coal Seams and Reserves

The Sewanee coal seam has been removed by erosion in the western and northwestern parts of the county: around Tracy City north to Coalmont it lies about 40 feet above stream level (Nelson, 1925). The only commercial seam in the county is not greater than 42 inches (Luther, 1959). The roof of the seam is a hard blue shale (Nelson, 1925). Sewanee coal is of metallurgical grade and is low in sulfur (Hershey, et al., 1955). No carbonate rock unit occurs in this portion of the stratigraphy; however, carbonaceous siderite nodules are scattered in some shaly units (Byerly, 1978).

Known recoverable reserves in the county are approximately 1.9 million tons (Gregg, 1978). This reserve estimate accounts for less than .7 percent of the estimated recoverable reserves of the state (Tn Energy Office, 1975). The seam has been mined extensively in the past which accounts for the low reserve estimate. Areas have already been mined out. The average overburden measures 25 meters. Grundy County mined .6 percent of the coal in Tennessee in FY 1975 (Tn Department of Labor, 1976).

Marine Origin of the Strata

The Gizzard formation was deposited on an old eroded land formation by an advancing sea (Nelson, 1925; Stutzer, 1940). The Whitwell shales, in which the Sewanee seam appears, is on the edge of a prograding delta (Byerly, 1978). The conglomeritic sandstones such as the Sewanee conglomerate subjacent to the Whitwell shales possibly represent barrier beaches while the coal bearing shales like the Whitwell represent barrier-back lagoon deposits (ibid.) The paleo-environment was transitional with a strong marine influence.

The basal portions of the Cumberland marine rocks were preserved under reducing conditions, forming and depositing iron disulfides (Williams, 1975). Caruccio (1973) has found that coals capped by marine roof rocks had a greater S content than the coals capped by continental roof rocks; thus, coal drainage from strata of marine paleoenvironments are more acidic than those associated with strata of non-marine paleoenvironments.

D. Mining History

Prior to the Surface Mining Legislation of 1967, 3707 acres has been disturbed, representing 86% of the present disturbance. Since then, approximately 700 acres have been disturbed (Leamon and Maher, 1974). The area around Tracy and Coalmont has been mined continuously since 1852 (Hershey, et al., 1955). During the late 1800's railroad lines were extended to Tracy City. By 1904, the line had been extended to Coalmont (Nelson, 1925.) Large mining operations such as that of the Tennessee Consolidated Coal Company exhausted much of the most easily retrievable and economic coal in the county prior to 1950 (Luther, 1959). Small surface mining operations continue, however, generally with inadequate reclamation. Big Creek Utility District, providing public water to over 4500 people and with 914 connections, has for its water source Ranger Creek (river km 11.5.) The system was completed and began operation in June 1964. In 1971 the Phipps Coal Company began stripping coal lands in the Ranger watershed. In the fall of 1971 the presence of Mn in the raw water began to increase and the pH decreased rapidly to the point that over 3000 fish died within a 45 hour period (Tn Department of Public Health, 1975). In August of 1977 the concentra-

tion of Mn in the raw water was 14.6 ppm with a pH of 2.4 compared to a premining concentration of 1.2 ppm with a pH of 6.1 (Bouldin, 1977). The increase of lime treatment makes it difficult to keep the hardness of the finished water within an acceptable range. Both the state and the Appalachian Regional Commission (ARC) have determined that the Ranger watershed of the Big Creek Utility District has priority in reclamation efforts.

The Tennessee Demonstration Project for Orphan Land Reclamation began September 1978 in Grundy County. This project, funded by the Federal Department of Conservation and managed by the SCS and TVA, demonstrates minimum treatment methods to correct problems of surface water flow, active erosion and acid mine site damage, and to enhance the aesthetic and recreational value of lands disturbed by surface mining and abandoned since 1967. This essentially make-work project limits expenditures to $80 per hectare and emphasizes hand labor. The Ranger watershed is the first area to be so treated in the county under this program.

E. Sampling Sites: Watershed and Stream Characteristics

Three water basins have headwaters arising in Grundy County: the Upper Cumberland basin, the Elk River basin and the Lower Tennessee River basin. Streams are controlled by rainfall as springs are scarce (Nelson, 1925), The disturbed streams were chosen on the basis of their similarity when possible, yet the overriding considerations were their proximity to abandoned mined lands about Coalmont, perennial flow, and access by vehicle. The undisturbed streams were chosen as close to the mining sites as possible. Prior water quality data is unavailable for

all streams except Ranger Creek at the site of the Big Creek Utility District treatment station. Figure 4 presents the sampling sites. Tables VII and VIII describe the watershed and stream characteristics at the sampling stations.

Upper Cumberland Basin

Coal mining causes the most extensive degradation of water quality within this basin: over 1200 stream miles are affected (Tn Department of Public Health, 1976). The Collins River which flows through the Savage Gulf Natural Area, arises in Grundy County. This stream has been included within the state's Scenic River Program as a Class II, pastoral river area. This program emphasizes preservation of natural water resources.

Within this basin are three of the five streams sampled to provide baseline data and two affected streams: Firescald, Piney, Armstrong, Big, and Ranger (I and II) creeks. Firescald and Piney creeks have been classed as rockbass streams by the state. Both streams where sampled are affected by minimal human population density.

Armstrong Creek has been clearcut since 1974. Clearcutting leads to a nutrient loss from the watershed and increases drainage 20 to 100 times for a period of one to three years (Sedell, 1973). Certain surface stream parameters are known to be affected: decrease in pH, sulfate decrease, increase in Ca, Mg, K, Na, Al, and nitrate (Likens, 1970). The stream was sampled to give some information on the effects of devegetation upon surface waters in the area separate from disturbance of the overburden.

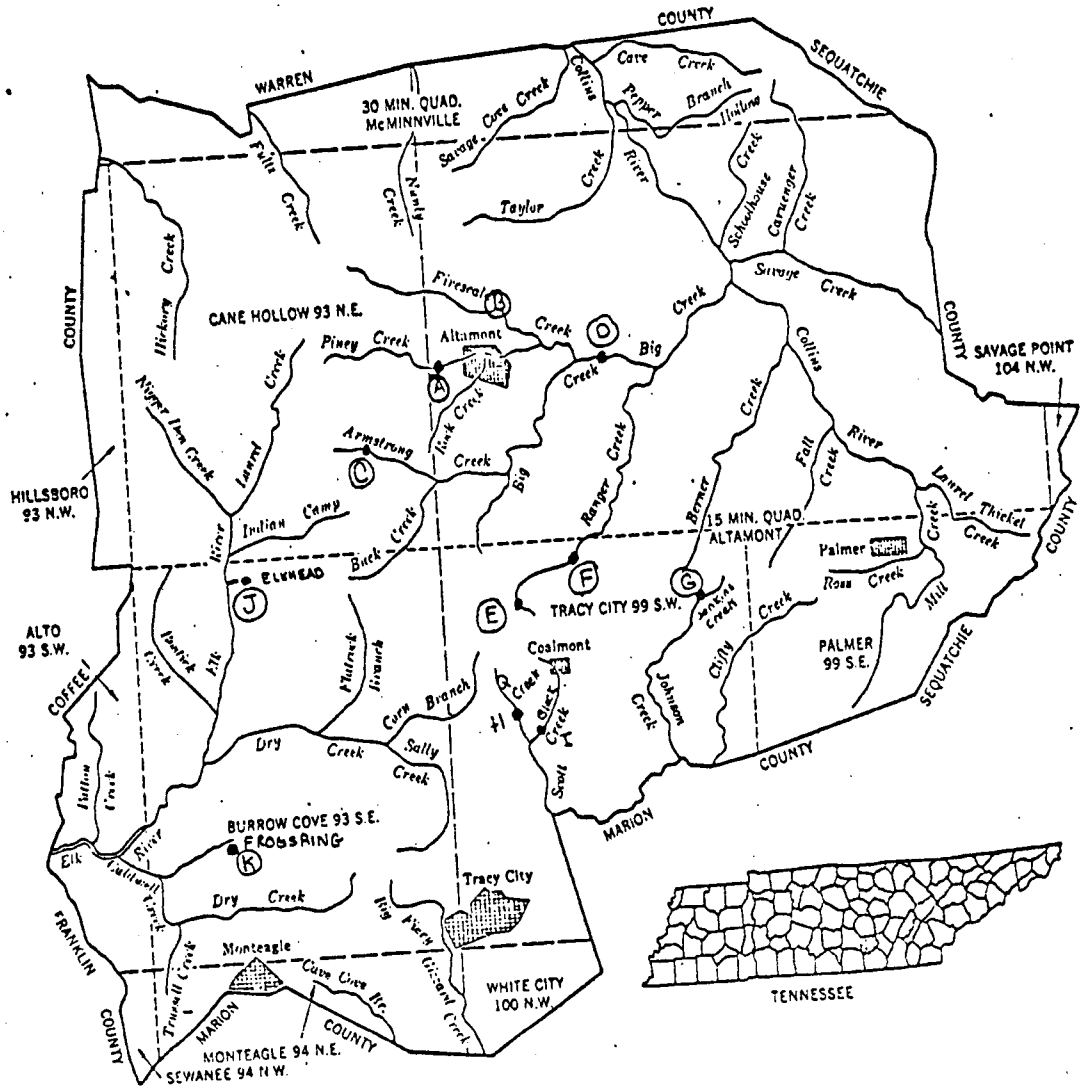


Figure 4. Sampling Stations in Grundy County, Tenn.

Source: Luther, E. T. 1959. The coal reserves of Tennessee. Tennessee Division of Geology, Bulletin 63, Nashville, Tennessee.

TABLE VII

WATERSHED CHARACTERISTICS

Map Code	Watershed	Basin	USGS/TVA Sheet	Hectares	Hectares a Disturbed	Percent Disturbed	Land Use Status
A	Piney	Upper Cumberland	Altamont	1,825.4	0	0	Second Growth Hardwood Low density population.
B	Firescald	Upper Cumberland	Altamont	1,189.4	0	0	Second growth hardwoods Low density population.
C	Armstrong	Upper Cumberland	Cane Hollow 93NE	411.1	0	0	Second growth hardwoods large portion clearcut.
D	Big	Upper Cumberland	Altamont	5,171.2	351.6	6.8	SW portion surface mined Remainder second growth.
E	Ranger I	Upper Cumberland	Tracy City 99SW	98.2	46.5	47.4	Mining activity ended in 1972.
F	Ranger II	Upper Cumberland	Tracy City 99SW	488.8	160.3	32.8	Mining activity ended in 1972.
G	Jenkins	Lower Tennessee	Tracy City 99SW	268.9	18.1	6.7	Virgin premining. Mining 5-10/77.
H	Q	Lower Tennessee	Tracy City 99SW	201.7	80.2	39.7	Mining began in 1961. New mining began 6/77.
I	Black	Lower Tennessee	Tracy City 99SW	739.5	103.4	14.0	Mining activity ended 1973. Coal tipple active.
J	Elkhead	Elk	Burrow Cove 93SE	b	0	0	Second growth hardwood.
K	Frogspring	Elk	Burrow Cove 93SE	b	0	0	Second growth hardwood. On escarpment in intermittent stream.

NOTE: a = Hectares disturbed by surface mining; b = Undetermined.

TABLE VIII

STREAM CHARACTERISTICS

Map Code	Stream	Stream Order	Riparian Vegetation	Substrate	Width (m.)
A	Piney	3	Hardwoods	Large and small boulders, bedrock, gravel.	4.4
B	Firescald	2	Hardwoods	Large and small boulders, bedrock and gravel.	4.1
C	Armstrong	2	Successional brush and pine	Bedrock, small riffle areas of rubble	3.7
D	Big	4	Hemlock, holly mixed with hardwoods	Bedrock, boulders and rubble	7.6
E	Ranger I	1	Cattails	Thick silt	.8
F	Ranger II	3	Hardwoods, cattails	Thick silt	2.1
G	Jenkins	2	Narrow hardwood belt	Deep silt sediment	1.6
H	Q	2	Narrow hardwood belt	Thick silt to clay	1.8
I	Black	2	Hardwoods	Thin layer of silt, rocks, gravel-coal mixture	3.7
J	Elkhead		Breakout	Boulders and gravel	3.0
K	Frogspring		Spring	Rock, boulders	.7

Tennessee Wildlife Resources Agency has classed Big Creek a potential rockbass and smallmouth bass stream except for its acid pollution (Tn Department of Public Health, 1976). This stream where sampled is of the 4th order in stream classification. The creek's southwestern headwaters arise in surface mined areas. Rusty Cup Creek, a tributary, drains a 9.7-hectare active mine. Drainage also occurs from orphaned mines abandoned since the early 1950's. Marginal attempts have been made to reclaim some areas. Natural revegetation has been severely limited because of the acid, shaly spoils. Water was sampled after waters from this mined area had been diluted by undisturbed drainage from other tributaries.

River km 12.7 to 15.9 of Ranger Creek are in violation of state water quality standards (ibid.). The uses impaired are public water supply, fish and aquatic life, and recreation. The parameters in violation are pH, solids, and toxic metals. Ranger Creek arises in the midst of the most intensively disturbed abandoned and active surface mined area in the county, with mines dating back to the 1920's. Ranger Creek was impounded in 1964 to form the Big Creek Utility District reservoir, the public water supply. Two stations were selected on Ranger Creek. The first site (Ranger I) was located above the reservoir within the orphan mined area. The second site was below the reservoir (Ranger II), well out of the disturbed area.

Elk River Basin

Grundy is the only county within the Elk River basin reporting significant coal mining operations (Tn Department of Public Health, 1974). The Elk River has primarily subsurface drainage on the plateau,

breaking out as the river in the southwestern corner of the county. The main branch of the Elk River arises at the base of the mountain 8 km west of Altamont and flows south through Burrow Cove (Nelson, 1925). Two sampling sites were chosen at the base of the escarpment to provide additional baseline data. Elkhead is the point at which the main flow of Elk River emerges from underneath the plateau. Frogspring is a typical spring of the area: subsurface flow rising to the surface then once again disappearing into the intermittent stream bed. The spring is on the researcher's property. The drainage area of neither Elkhead nor Frogspring could be determined because of their location on the escarpment and vagaries of subsurface flow under such conditions.

Lower Tennessee River Basin

Within the lower Tennessee River basin three disturbed watersheds were selected. The watershed of Jenkins Creek was first disturbed May, 1977. Active mining of a 20.2 hectare area ended midway during the sampling period, but no reclamation has yet occurred. Virgin premining conditions had existed. The sampling site and environs had been devegetated by the mining process, with only a narrow belt of hardwoods left paralleling the stream bed.

Mining operations began in the agricultural lands of the Q Creek watershed during 1962 with continuous mining to present. Current mining operations within the watershed began in June 1977. Riparian vegetation is limited upstream from the sample site as it had been cleared for pasture prior to mining.

Black Creek drains B Lake, a strip pit from mining activities of the 1920's. Scattered small mines occur throughout the watershed. At

least one mine is currently active. An active coal tipple also is located upstream from the sampling site. The low density community of Coalmont lies partially within this watershed. The substrate is composed of a thin layer of silt which covers scarce rocks and a gravely mixture dominated by coal particles.

Because of the large number of streams and various conditions of the watersheds, henceforth an identification code shall be used to aid the reader. Plateau baseline streams (Firescald and Piney creeks) shall be denoted as $Firescald_B$ and $Piney_B$. Escarpment baseline streams and Armstrong Creek are coded $Frogspring_b$, $Elkhead_b$, and $Armstrong_b$ Creek. Marginally affected stream are coded Big_m and $Black_m$ creeks. Severely disturbed streams are coded $Ranger_d$, $Jenkins_d$, and Q_d creeks.

CHAPTER IV

MATERIALS AND METHODS

A. Chemical Survey

Parameters Measured

The parameters measured, listed in Table IX, are criteria in state and federal water quality regulations and have been recognized as possible indicators of surface mining disturbance. This list represents only a portion of possible parameters measured in other similar studies. Ideal and actual detection limits have been indicated also in this table.

Method of Sampling

Collection of biweekly grab samples for water quality analysis began during August, 1977 and ended in January, 1978. The eleven stations were selected by September, and from then on all were sampled during each collection trip. Sampling was limited to weekends.

The field sampling procedure followed that of the long-term periodic sampling program of the New River basin study (Minear and Tschantz, 1978). Three 150 ml polyethylene sample bottles were filled at each stream. Samples were considered representative because the turbulent nature of small streams assures complete mixing (Hynes, 1970). Two 150 ml samples, one previously filtered through a 0.45 Millipore filter for the study of dissolved constituents, were acidified with 1/ml of ultrapure nitric acid each to hold metals in solution and avoid absorption to

TABLE IX

PARAMETERS MEASURED IN THIS SURVEY
AND METALS DETECTION LIMITS (ppm)

Parameter	Perkin Elmer Ideal Limites	Operating Detection Limits
pH	(100 FL)	25 (FL)
Temperature	--	--
Alkalinity	--	--
Sulfate	--	--
Total and dissolved Fe	0.01 (FL)	.1 (FL)
Total and dissolved Ca	0.001 (FL)	.1 (FL)
Total and dissolved Mg	0.0001 (FL)	.01 (FL)
Total and dissolved Mn	0.002 (FL)	.01 (FL)
Total and dissolved Zn	0.002 (FL)	.01 (FL)
Total and dissolved Pb	0.000005 (FU)	0.00003 (FU)
Total and dissolved Co	0.0004 (FU)	0.002 (FU)
Total and dissolved Cd	0.000003 (FU)	0.00003 (FU)
Total and dissolved Al	0.03 (FL)	1.0 (FL)

NOTE: FL = flame; FU = furnace.

walls of the sample bottles. The third untreated 150 ml sample was used to determine alkalinity and sulfate concentrations.

Analysis Techniques

Parameters measured in the field at each station were pH, air temperature and water temperature. The determination of pH was done potentiometrically with a portable pH meter which was standardized and temperature adjusted. Sulfate and alkalinity were determined as soon as possible after sampling. Unfiltered samples were used to measure alkalinity by potentiometric titration (Standard Methods 1976) in a field laboratory. Sulfate was determined from unfiltered samples turbidimetrically using a Hach Kit (1977). Total and dissolved concentrations of Fe, Ca, Mg, Mn,Zn and Al were determined on a Perkin Elmer Model 403A Atomic Absorption Spectrophotometer. Concentrations of total and dissolved Cd, Co, and Pb were obtained in replicate on a Perkin Elmer Model 403A Atomic Absorption Sprectrophotometer with an HGA graphite furnace.

Estimate of Sedimentation

The universal soil loss equation (Knox Co. SCS, 1973) was used to compute the expected metric tons of soil per hectare in order that a relative measure of bed load could be determined. The Universal Soil Loss equation is

$$A = RKLSCP$$

where A = annual loss per acre, R = rainfall, K = an erodibility value, LS = an adjustment factor for slope length and percent slope, and CP = a soil management factor. Short of gaging the streams, this method was

considered to be of the greatest value in determining relative sediment rates of the various watersheds studied. This approach has the serious limitation that it does not take into consideration how long land has been exposed to weathering which is an important factor in orphan mined lands. Nevertheless, in the absence of better data, this quantitative approach can give an indication of the possible amounts of soil removed annually from a watershed.

B. Quantitative Survey of Aquatic Insects

Reference station quantitative surveys compare disturbed sampling stations with undisturbed sampling stations. The requirements for a quantitative study are a sample unit area and sample design which permits statistical analysis, estimates of precision of results, and comparison with other investigators' data (Weber, 1973).

Stream Site Selection

Stream and watershed characteristics have already been discussed in terms of the actual sampling sites and in regard to how environmental variables influence the distribution of aquatic insects. Stratified random samples of riffle areas were taken to obtain an unbiased sampling data estimate of the population (Gaufin, et al., 1956; Cummins, 1962; Barber and Kevern, 1973). Selection of riffle segments was in recognition of the mosaic nature of habitats which can be utilized to facilitate planning of a sampling program.

In this study sites with similar substrate, current velocity and riparian vegetation were selected. Two baseline streams were compared

with Big Creek, the only disturbed stream with comparable substrate and riffle areas that was not choked with sediment. This particular analysis, then, was more of an exercise to study the techniques involved than an adequate quantitative survey of the benthos in the study area. Although these streams are not of the same order, the investigator considered them to be so similar with respect to the other variables that they were considered comparable.

Season of Sampling

Quantitative sampling of aquatic insects occurred in late winter and early spring of 1978. The effect of season on species compostion and population size has already been discussed. During this season of the year orders of the greatest predictable abundance are Plecoptera, Ephemeroptera and Diptera (Tebo and Hassler, 1961; Hynes, 1970a). During spring, streams experience a great loss of biomass and numbers because of emergence. Because sampling occurred over only one season, the communities present in the different streams could not be totally described. Nevertheless as all samples were taken within the same season, this investigator considers the results comparable and useful in evaluating the effects of surface-mining on aquatic insect communities studied.

Sample Size

As the number of samples increases, the number of uncollected species decreases (Southwood, 1968). The number of samples necessary to adequately describe the species present depends on the precision required, a function of the type of study. Gaufin, et al. (1956) report that 10 to 15% of species were not discovered on the average until at

least eight samples had been taken. In this study eight samples were randomly taken across a riffle area on each sampling date.

Sampling Device

The selection of the sampling device depends upon certain factors: the animals, nature of substrate, current, water depth and the object of the study (Southwood, 1968). Sampling bias is reduced to the expertise of the collector when a sampling device is used (Weber, 1973). A one foot square Surber sampler is often used to sample fast flowing shallow riffle areas and was so used in this study. The procedure for using a Surber sampler entails setting the sampler down into the stream without disturbing the substrate until the current fixes the net in position. Rocks are brushed off in front of the net and the remaining substrate stirred for a uniform period of time (Kimbel and Weshe, 1975; Surber, 1953; Kuehne, 1975). Organisms are then transferred to collection bottles by turning the net inside out. The Surber sampler used was modified to ensure that a good seal with the substrate was made to prevent loss of individuals.

Sources of error have been recognized in the use of the Surber sampler. Some stones lie partially within the sampling frame; rejection of these stones depends on personal judgement and this is highly variable (Southwood, 1965). Even within a riffle area a series of intergrading communities prevent true replication of samples taken (Armitage, 1958). Operator care and expertise also greatly influence the results. Overall, the coefficient of variation may be as high as 50% (Weber, 1973).

Measures of other Variables

Other parameters measured at the time of sampling included air and water temperature, velocity, substrate and depth. These measurements were taken to allow an evaluation of comparability among the streams sampled. A pigmy current meter was used to determine velocity across a riffle section at a standardized distance from the substrate. All the sampling sites were determined to be torrential using the scale developed by Hynes (1970a): the velocities were greater than 1.21 m/second. Substrates were compared using the method of Kimble and Wesche (1975): The mean size rock was determined by measuring the six largest rocks in the surber frame along their longest dimension. The largest rock is discarded and the remaining five are averaged. According to the classification of Hunt (1930), the three streams studied in this part of the survey had large rock bottom types, i.e., greater than 15 cm. Measurements for depth were taken at evenly spaced intervals across a riffle. Depth of water varied with flow but was comparable among the streams.

C. Qualitative Sampling Procedure

Advantages and Limitations

Qualitative surveys are attempts to collect all species present by an exhaustive sampling in all available habitat types. Comparisons are made among like habitats. The limitations on qualitative sampling include the subjectivity of techniques used and the inability to generate information on standing crop or productivity.

Techniques

The collection techniques used in this study were handpicking, kicking up substratum in front of a hand-held screen, and Surber sampling

for a period of 30 minutes at each site. Qualitative sampling occurred in all streams.

D. Preservation and Identification

Preservation

Samples were preserved in 50% isopropanol in the field. In the laboratory, samples were sorted to separate the aquatic insects from detritus and collected substrate. After identifying individuals within the sample, the samples were preserved with fresh 50% isopropanol.

Identification

The aquatic insects were identified using keys for Plecoptera (Usinger, 1956; Edmondson, 1959; Parrish, 1975; Wiggins, 1977), Ephemeroptera (Usinger, 1956; Edmondson, 1959; Lewis, 1974; Edmunds, 1976; Parrish, 1975), Coleoptera (Usinger, 1956; Edmundson, 1959; Brown, 1972; Parrish, 1975), Diptera (Usinger, 1956; Edmondson, 1959; Mason, 1973; Parrish, 1975), Hemiptera (Usinger, 1956), and Odonata (Needham and Westfall, 1955). Dr. David Etnier assisted with identification when necessary.

E. Analysis

Chemical Analysis

The results of the chemical analysis were presented graphically to determine the differences among streams and sampling dates. Disturbed and undistrubed streams were compared. The minimum, maximum, median and mean concentrations of the various parameters measured were determined. A two-way analysis of variance was conducted on the results of analysis

to determine significant differences among streams and sampling dates (Sokal and Rohlf, 1967). The Student-Newman-Keuls mean separations test (Sokal and Rohlf, 1967) was completed on the data to determine which streams were most similar to each other. The percentage of parameters not in compliance with current regulations was calculated by sampling date. Precipitation data summed over a week prior to the sampling date was graphically compared to analysis results. Precipitation data was collected at the Monteagle, Tennessee; weather station (NOAA, 1977-78).

Quantitative Biotic Analysis

In this phase of the study community structure wass analyzed and the community was described in terms of species frequency and numerical abundance. The species diversity index, a major tool used to analyze biotic communities, estimates richness of species and the distribution of individuals among species. Indices of diversity are derived from the information theory which postulates that information is measured as a function of the number of choices required to reduce a system to a given level of organization. The range of diversity indices in ecological literature is great (Dills and Rogers, 1959; Pielou, 1966; Wilhm and Dorris, 1968). Vaughan and his students (Tolbert, 1978; Vaughan, 1978) have used the Shannon Weaver index because it is most frequently used in the literature and confidence limits have been derived even though all of the collected individuals were not identified to species. At this level the index is a diversity index rather than a species diversity index. The Shannon Weaver diversity index is

$$H' = -P_i \text{Log} P_i$$

where P_i is the number of individuals of each taxon divided by the total number of all taxa (Poole, 1974).

Maximum values for diversity are achieved in a fixed population when each taxon has one individual and minimal values are achieved when all individuals belong to one taxon. High diversity values are associated with pristine streams and low values with stressed aquatic systems. Diversity indices were determined for each sampling date.

Diversity values in this study are based on eight .305m^2 samples/stream/sampling date. The values for the different taxa among the eight samples were pooled for a better measurement of diversity (Wihlm, 1967).

A one way analysis of variance was then performed to determine if a significant difference among the streams existed for diversity, number of individuals and number of taxa among the sampling dates (Sokal and Rohlf, 1969). A T-test was used to determine which streams were significantly different from each other on individual sampling dates (Hutcheson, 1978). Differences in percent composition by order were determined to further describe differences among the streams.

Qualitative Analysis

For each stream the community structure was described in terms of orders and functional groups present or absent. Comparisons among streams were then made. The taxa of individuals collected were enumerated to further demonstrate differences among streams.

The variety of techniques used was necessary to adequately describe a community's health without overemphasizing the presence or absence of intolerant species (Herricks and Cairns, 1973).

CHAPTER V

RESULTS AND DISCUSSION

Chemical Survey

The quantitative results of chemical analyses for the total concentrations for the various constituents measured from the disturbed and baseline streams are graphically depicted in Figures B-1 to B-17 which appear in Appendix B. Seen at the top of each graph is a representation of the total precipitation summed over the week prior to a sampling date. Also, where applicable, the State of Tennessee Department of Public Health Division of Water Quality standards for drinking water and NPDES standards for surface mine discharges (Table IV and V, page 37) are indicated. Significant differences were found among streams and, with the exception of alkalinity, Pb and Mn, among sampling dates for the parameters measured (Appendix C.)

Constituents

Alkalinity. The surface streams of the southern Cumberland Plateau have low alkalinities largely because of the minimal amounts of calcareous material present in the substratum (Byerly, 1978). Figure B-1 (Appendix B) represents the alkalinities found in the streams sampled. A significant difference was found among the streams for the amount of alkalinity measured; however, unlike most other parameters, no significant difference was detected among sampling dates, suggesting the stability of alkalinity across time (Appendix C.) Table X presents the characteristics of the behavior of the sampled streams.

TABLE X

CHARACTERISTIC STREAM BEHAVIOR
FOR ALKALINITY
(mg/l as $CaCO_3$)

	Minimum	Maximum	Median	Mean
$Armstrong_b$	2.09	106.60	5.59	16.77
Big_m	.86	9.08	3.54	4.26
$Black_m$	8.13	27.49	14.19	17.06
$Elkhead_b$	21.07	86.52	50.12	53.51
$Firescald_B$	2.87	56.30	6.27	12.87
$Frogspring_b$	211.56	491.15	253.40	310.21
$Jenkins_d$	0	6.70	.85	1.94
$Piney_B$	5.02	29.26	10.28	13.08
Q_d	0	64.80	13.33	18.59
$Ranger_d$ 1	0	0	0	0
$Ranger_d$ 2	0	2.10	0	.19

The two baseline stream on the Plateau, $Piney_B$ and $Firescald_B$ creeks, have low alkalinities. The two stations within the Mississippian aged Bangor limestone formation ($Frogspring_b$ and $Elkhead_b$ have greater alkalinities. $Armstrong's_b$ watershed had been clearcut in 1976, and its elevated alkalinity detected early in the sampling period paralleled a similar pulse of calcium and magnesium, among other metals. Both Q_d and $Black_m$ creeks are within the Lower Tennessee River basin. The subbasin in which they flow may have a higher level of calcareous material in the substratum as suggested by early sampling dates in other streams in the same basin. Because of the lack of a soils map for Grundy county, this possibility cannot readily be confirmed. The remaining streams disturbed by surface mining - Big_m, $Jenkins_d$, $Ranger_d$ 1 and 2 creeks - had low or zero alkalinity. The buffering capacity of these streams have been exceeded by acid generation.

pH. Because of the low alkalinity in baseline streams, the pH was controlled by dissolved CO_2 from the atmosphere and from decaying vegetation. Figure B-2 (Appendix B) depicts the results of analysis of pH for the streams surveyed. Table XI presents the characteristics of the streams' behavior. Both $Piney_B$ and $Firescald_B$ creeks were detected to have exceeded both state and federal pH standards (Table IV and V, page 37) on a number of sampling dates. $Armstrong_b$ Creek, within a clearcut watershed, had a lower pH than other baseline streams. $Black_m$ Creek's pH was more similar to the baseline streams than to other disturbed streams ($Ranger_d$ 1 and 2, $Jenkins_d$, and Q_d) which showed consistently lower pH values. The naturally low alkalinity of the plateau streams limited the buffering capacity within the streams and could contribute to the wide oscillation of pH found in the waters studied (Minear and Tschantz, 1976.)

TABLE XI

CHARACTERISTIC STREAM BEHAVIOR FOR pH

	Minimum	Maximum	Median	Mean
$Armstrong_b$	5.1	6.8	5.5	5.9
Big_m	4.6	5.7	5.3	5.3
$Black_m$	5.8	6.9	6.4	6.4
$Elkhead_b$	5.9	7.5	6.6	6.8
$Firescald_B$	5.5	7.2	6.2	6.4
$Frogspring_b$	7.6	7.9	7.8	7.8
$Jenkins_d$	3.7	5.4	4.6	4.9
$Piney_B$	5.8	6.8	6.5	6.4
Q_d	4.5	6.8	6.2	6.3
$Ranger_d$ 1	2.6	3.8	3.5	3.5
$Ranger_d$ 2	3.4	5.5	4.2	4.7

Iron. Table XII depicts the characteristics of the streams' behavior in relationship to iron concentration. Figure B-3 (Appendix B) represents the results of analyses for the streams surveyed. Total and dissolved iron concentrations are largely determined by pH (Breidenbach, 1975.) The streams with the lowest pH showed the highest concentrations of total iron: $Ranger_d$ 1 and 2, $Jenkins_d$ and Q_d creeks. Big_m Creek had low levels of total iron although ferric hydroxide had stained the substrate the characteristic orange-red. $Armstrong_b$ Creek in a clearcut watershed showed higher levels of iron than other baseline streams.

Manganese. Table XII presents the characteristics of the streams' behavior. Mn, a sensitive indicator of acid mine drainage, appeared in high concentrations in all streams affected by surface mining: $Ranger_d$ 1 and 2, $Jenkins_d$ and Q_d creeks and at lower concentrations in Big_m and $Black_m$ creeks. $Elkhead_b$, $Piney_B$ Creek, and $Frogspring_b$ showed only trace amounts of the metal. $Firescald_B$ and $Armstrong_b$ creeks had occassional slightly elevated concentrations. Figure B-4 (Appendix B) presents the results of analyses.

Calcium and Magnesium. In systems with an intact buffering system, concentrations of Ca and Mg parallel alkalinity levels closely (Wetzel, 1976.) Table XIII summarizes the behavior characteristics of the streams. Concentrations of both Mg and Ca were low in the poorly buffered baseline streams of $Piney_B$ and $Firescald_B$ creeks and higher in the better buffered systems of $Frogspring_b$, $Elkhead_b$, and $Black_m$ Creek. Big_m Creek with low alkalinity, also had low concentrations of Ca and Mg. $Ranger_d$ 1 and 2 and $Jenkins_d$ creeks with little or no alkalinity had higher concentrations of Ca and Mg. Q_d Creek with

TABLE XII

CHARACTERISITC STREAM BEHAVIOR
FOR TOTAL Fe AND Mn (ppm)

		Minimum	Maximum	Median	Mean
$Armstrong_b$	Fe	nd	3.4	nd	.4
	Mn	nd	.41	nd	.07
Big_m	Fe	.2	.35	.2	.2
	Mn	.54	.90	.71	.72
$Black_m$	Fe	.2	.6	.3	.3
	Mn	.10	.34	.14	.17
$Elkhead_b$	Fe	nd	.6	nd	.2
	Mn	nd	nd	nd	nd
$Firescald_B$	Fe	nd	.6	nd	.2
	Mn	nd	.1	nd	nd
$Frogspring_b$	Fe	nd	.1	nd	nd
	Mn	nd	.10	nd	nd
$Jenkins_d$	Fe	.3	10.0	.7	1.7
	Mn	.1	11.0	.3	1.90
$Piney_B$	Fe	nd	.2	nd	nd
	Mn	nd	.1	nd	nd
Q_d	Fe	.4	2.5	.8	1.0
	Mn	.10	46.0	4.00	10.70
$Ranger_d$ 1	Fe	2.4	10.8	4.3	5.4
	Mn	9.5	27.0	14.5	17.5
$Ranger_d$ 2	Fe	.4	1.8	.4	.6
	Mn	4.4	10.5	7.5	7.7

NOTE: nd = no detection.

TABLE XIII

CHARACTERISTIC STREAM BEHAVIOR
FOR TOTAL Ca AND Mg (ppm)

		Minimum	Maximum	Median	Mean
Armstrong$_b$	Ca	.3	36.5	.5	4.5
	Mg	.20	1.35	.25	.37
Big$_m$	Ca	2.2	3.5	3.0	2.9
	Mg	3.05	4.70	4.02	3.90
Black$_m$	Ca	4.6	10.5	7.6	7.5
	Mg	2.90	3.80	3.40	3.30
Elkhead$_b$	Ca	10.5	21.5	12.7	13.3
	Mg	1.50	3.25	2.00	2.10
Firescald	Ca	.4	16.5	.6	2.6
	Mg	.30	1.10	.35	.50
Frogspring$_b$	Ca	52.0	63.0	58.0	57.0
	Mg	14.0	17.5	15.2	15.5
Jenkins$_d$	Ca	.9	24.0	1.5	4.0
	Mg	.60	1.20	0.20	.40
Piney$_B$	Ca	.9	8.5	1.5	2.7
	Mg	.30	.80	.35	.44
Q$_d$	Ca	10.1	121.0	12.5	27.5
	Mg	9.00	95.00	11.10	10.70
Ranger$_d$ 1	Ca	16.0	49.0	24.5	29.3
	Mg	24.0	68.0	38.8	45.2
Ranger$_d$ 2	Ca	7.2	26.0	17.0	16.0
	Mg	11.5	23.0	19.0	18.8

alkalinity comparable to baseline streams exhibited the greatest concentration range of the two metals. Results of Ca and Mg are presented in Figures B-5 and B-6 (Appendix B) respectively.

Cobalt, Cadmium, Zinc, Aluminum, and Lead. Only streams affected by surface mining showed detectable amounts of cobalt (Table XIV) or cadmium (Table XIV). Co and Cd results of analyses are presented in Figures B-7 and B-8 respectively (Appendix B).

Zinc (Table XV) did not appear in detectable amounts in $Piney_B$ Creek, $Frogspring_b$, $Elkhead_b$ nor $Black_m$ Creek. The highest concentrations were found in the streams of watershed most severely affected by surface mining activities. Figure B-9 (Appendix B) presents the results of analyses.

Aluminum (Table XV) only appeared in detectable amounts in the most severely affected streams: $Jenkins_d$, $Ranger_d$, and Q_d creeks. Like the other metals, Al concentration in water is determined largely by pH (Gang and Langmuir, 1974.) Figure B-10 (Appendix B) presents the results of analyses.

Lead concentrations (Table XVI) did not seem to vary from disturbed to undisturbed watershed streams. Indeed, baseline streams often had higher concentrations of Pb than systems severely affected by surface mining. Figure B-11 (Appendix B) presents the results of analyses.

Sulfate. Sulfate concentrations (Table XVII), another useful indicator of mine drainage, clearly were higher in streams affected by surface mining. Again, it was highest in $Ranger_d$, Q_d and $Jenkins_d$ creeks. Figure L presents the results of analyses (Appendix B-12.)

TABLE XIV

CHARACTERISTIC STREAM BEHAVIOR
FOR TOTAL Co AND Cd (ppb)

		Minimum	Maximum	Median	Mean
$Armstrong_b$	Co	nd	nd	nd	nd
	Cd	nd	nd	nd	nd
Big_m	Co	3.2	5.8	4.5	4.8
	Cd	nd	nd	nd	nd
$Black_m$	Co	1.6	4.5	2.6	2.8
	Cd	nd	.17	nd	nd
$Elkhead_b$	Co	nd	nd	nd	nd
	Cd	nd	nd	nd	nd
$Firescald_B$	Co	nd	nd	nd	nd
	Cd	nd	nd	nd	nd
$Frogspring_b$	Co	nd	nd	nd	nd
	Cd	nd	nd	nd	nd
$Jenkins_d$	Co	2.3	151.0	5.5	37.6
	Cd	nd	.30	.10	.06
$Piney_B$	Co	nd	nd	nd	nd
	Cd	nd	nd	nd	nd
Q_d	Co	17.9	250.0	24.9	52.0
	Cd	nd	.10	nd	.01
$Ranger_d$ 1	Co	135.0	375.0	230.0	264.1
	Cd	nd	.09	.04	.04
$Ranger_d$ 2	Co	57.9	106.6	82.2	82.7
	Cd	nd	.02	.05	.04

NOTE: nd = no detection.

TABLE XV

CHARACTERISTIC STREAM BEHAVIOR
FOR TOTAL Zn AND Al (ppm)

		Minimum	Maximum	Median	Mean
Armstrong$_b$	Zn	nd	.06	nd	nd
	Al	nd	nd	nd	nd
Big$_m$	Zn	nd	.02	nd	.01
	Al	nd	nd	nd	nd
Black$_m$	Zn	nd	nd	nd	nd
	Al	nd	nd	nd	nd
Elkhead$_b$	Zn	nd	nd	nd	nd
	Al	nd	nd	nd	nd
Firescald$_B$	Zn	nd	.04	nd	nd
	Al	nd	nd	nd	nd
Frogspring$_b$	Zn	nd	nd	nd	nd
	Al	nd	nd	nd	nd
Jenkins$_d$	Zn	nd	.95	nd	.14
	Al	nd	nd	2.1	6.8
Piney$_B$	Zn	nd	nd	nd	nd
	Al	nd	nd	nd	nd
Ranger$_d$ 1	Zn	.08	.24	.12	.12
	Al	nd	3.8	2.8	2.6
Ranger$_d$ 2	Zn	.05	.18	.11	.11
	Al	nd	2.8	2.3	1.9

NOTE: nd = no detection.

TABLE XVI

CHARACTERISTIC STREAM BEHAVIOR
FOR TOTAL LEAD (ppb)

	Minimum	Maximum	Median	Mean
$Armstrong_b$	1.5	3.7	2.9	2.7
Big_m	.4	1.4	1.0	.9
$Black_m$	nd	1.5	nd	.2
$Elkhead_b$	nd	4.8	1.8	1.9
$Firescald_B$	1.0	4.4	1.8	2.1
$Frogspring_b$	nd	3.0	1.1	1.1
$Jenkins_d$	nd	5.8	.7	1.3
$Piney_B$	nd	29.0	5.0	8.7
Q_d	nd	3.2	nd	.6
$Ranger_d$ 1	nd	2.7	.5	.9
$Ranger_d$ 2	nd	2.6	2.0	1.5

NOTE: nd = no detection.

TABLE XVII

CHARACTERISTIC STREAM BEHAVIOR
FOR SULFATE (MG/L)

	Minimum	Maximum	Median	Mean
$Armstrong_b$	nd	13	nd	3.2
Big_m	23	33	29	28.6
$Black_m$	23	50	27	29.3
$Elkhead_b$	nd	9	3	3.9
$Firescald_B$	nd	17	nd	3.3
$Frogspring_b$	nd	27	17	16.5
$Jenkins_d$	12	285	41	65.9
$Piney_B$	2	3	2	1.9
Q_d	57	440	90	143.1
$Ranger_d$ 1	158	395	240	247.8
$Ranger_d$ 2	63	190	138	130.1

NOTE: nd = no detection.

Streams

The streams surveyed can be separated into streams in watersheds undisturbed by surface mining, streams marginally affected by surface mining and streams seriously influenced by the effects of surface mining. Among the streams in watersheds undisturbed by surface mining, $Piney_B$ and $Firescald_B$ creeks are the two plateau streams most similar in all other variable to those streams disturbed by surface mining. Both exhibit low alkalinity typical of the plateau with a pH that oscillates about pH 6. Both are low in all other measured constitutents. Of the two, $Firescald_B$ has greater concentrations of Mn, Fe, and Mg which perhaps suggests greater human activity within its watershed (Brown, 1977.)

$Frogspring_b$ and $Elkhead_b$ were studied as they provide some information about the drainage which occurs from off of the plateau. $Frogspring_b$ was clearly a system dominated by its limestone setting: high alkalinity, a stable high pH, and high concentrations of Ca and Mg. Concentrations of the other constituents measured were consistently low. $Elkhead_b$ drained a much larger watershed than $Frogspring_b$; however, the boundaries of this watershed could not be determined. The alkalinity of $Elkhead_b$ was about twice as great as the plateau baseline streams, unlike $Frogspring_b$ with an alkalinity ten times as high as that of $Firescald_B$ and $Piney_B$ creeks. Elkhead's pH oscillated about pH 7. Despite an initially high reading of Fe, all other constituents remained consistently low.

$Armstrong_b$ Creek, which drained a clearcut watershed disturbed the year prior to sampling, showed some of the same effects as those observed in the Hubbard Brook Forest experiment (Likens, 1970.) In these studies

a decrease in pH and sulfate and an increase in Ca, Mg, and Al concentrations were measured. Both pH and sulfate concentrations of $Armstrong_b$ Creek were depressed from those found in $Piney_B$ and $Firescald_B$ creeks. The alkalinity and iron had great oscillations. However, without available data on water conditions prior to clearcutting, it is not possible to determine which chemical parameters are responding to clearcutting.

Big_m and $Black_m$ creeks were the two streams marginally affected by surface mining. $Black_m$ Creek had a small number of abandoned mines and a coal tipple upstream from the sampling station. Big_m Creek's southerly tributaries drain an intensely disturbed abandoned mine area. This drainage was diluted by $Armstrong_b$ Creek and other smaller streams upstream from the sampling site. $Black_m$ Creek has a pH and alkalinity similar to those of $Piney_B$ and $Firescald_B$ creeks. Big_m Creek had a pH oscillating about pH 5 with a complementary low alkalinity. Both streams had similar sulfate concentrations which were elevated from undisturbed streams. Again, both Big_m and $Black_m$ creeks had similar results for Fe, Mg, and Mn, the latter always greater than the state drinking water quality standards. Both streams had detectable amounts of cobalt while only Big_m Creek had detectable amounts of zinc. Cd was found in $Black_m$ Creek.

The other streams studied are in watersheds greatly affected by active and abandoned surface mining. $Ranger_d$ 1 and 2 are different stations on $Ranger_d$ Creek, one above and the other below the Big Creek Utility District reservoir. Mining has not occurred within the watershed for seven years, yet the unreclaimed mines continue to leach great amounts of acid and metals. The pH of $Ranger_d$ Creek has dipped down to pH 2.4. The station below the reservior had slightly improved water quality which suggests that the reservoir has some affect on the water quality of incom-

ing drainage, another focus of additional research. The buffering capacity of the system has been destroyed. $Ranger_d$ Creek had high concentrations of all metals, especially Co, Ca, and Fe. $Ranger_d$ I had the highest sulfate concentrations, except for a peak in Q_d Creek.

Active mining occurred throughout the sampling period of Q_d Creek. Unlike $Ranger_d$ Creek its pH oscillated about pH 6, a sign that the substratum may be different. The alkalinity of Q_d Creek paralleled those of streams with similar pH. Concentrations were higher than those recorded for marginally affected streams for Zn, Cd, Co, and Fe and especially high for Mg, Ca, Mn, and sulfate.

Precipitation

An important factor in determining the fluctuations within the different parameters measured was precipitation and the resultant changes in discharge. Since flow was not measured an indication of this variable was derived from summation of precipitation events a prior to sampling dates from data collected at the Monteagle Climatological Station, a station within 22 km of the furthest sampling point. At the top of Figures A through L (Appendix B) appears a graph summarizing precipitation events during the sampling period. Generally, concentration levels for Zn, Co, Cd, Fe, Mn, and Sulfate paralleled rainfall events. Both pH and alkalinity increased during periods of great precipitation, the most disturbed streams exhibiting the greatest oscillations. Summary of a two way analysis of variance appears in Appendix C. Much of the difference among sampling data is most likely due to precipitation variability.

Percentage of Parameters Not in Compliance with State and Federal Standards by Sampling Date

The percentage of parameters not in compliance with state and federal standards was determined by sampling date. Table XVIII presents the results of this analysis. Table IV (page 37) enumerates these two standards. As the drinking water quality standards are naturally much more strict than are those for surface mine effluents, more sampling dates are not in compliance for drinking water standards than are for NPDES standards. Non-compliance of water to drinking water standards is only of concern when the background exceeds the standards, and the raw water then requires costly pre-treatment. Only pH standards are the same for each. As can be seen the three streams ($Ranger_d$, $Jenkins_d$ and Q_d creeks) which have been the most disturbed by surface mining are the most out of compliance. Streams from undisturbed watershed are the most in compliance with the occassional exception of pH and Fe, possible examples of the limitations of the existing standards. Big_m and $Black_m$ creeks, marginally disturbed streams, are not in compliance for drinking water quality standards but meet the NPDES standards except for pH.

Relative Comparison of Sedimentation Losses

Results of the computation using the Universal Soil Loss equation for the watersheds surveyed which have been disturbed by surface mining are shown in Table XIX. Within both the $Ranger_d$ and $Black_m$ creek watersheds are impoundments upstream from sampling stations which would affect the amount of sedimentation at the sampling site. In the field the stations with obvious sedimentation problems were

TABLE XVIII

PERCENTAGE OF PARAMETERS NOT IN COMPLIANCE WITH STATE AND FEDERAL STANDARDS BY SAMPLING DATES

Stream	No. of Sampling Dates	State Standards (%)					NPDES Standards (%)		
		Fe	Mn	SO_4	Cd	pH	Fe	Mn	pH
$Frogspring_b$	10								
$Elkhead_b$	10	20				10			10
$Armstrong_b$	9	11	33			89			89
$Firescald_B$	11	27	18			18			18
$Piney_B$	11					9			9
Big_m	8		100			100			100
$Jenkins_d$	10	70	90	10	60	100	10	10	100
$Ranger_d$ 1	11	100	100	45	91	100	27	100	100
$Ranger_d$ 2	11	100	100		73	100		100	100
Black	9	22	100		11	22			22
Q_d	11	100	100	18	27	27		45	27

SOURCE: Division of Water Quality, Department of Public Health. 1972. State Drinking Water Standard, Nashville, Tennessee.

Office of Surface Mining, Department of Interior. 1977. NPDES Standards. Washington, D.C.

TABLE XIX

UNIVERSAL SOIL LOSS EQUATION RESULTS FROM DISTURBED WATERSHEDS

Stream	Metric Tons Per Hectare	Hectares Disturbed	Metric Tons Per Watershed
$Ranger_d$ 2	1249.1	160.3	200,233.6
Q_d	748.3	80.2	60,012.5
$Black_m$	553.2	103.4	57,199.9
$Ranger_d$ 1	965.5	46.5	44,895.8
$Jenkins_d$	1892.9	18.1	34,261.0
Big_m	96.6	351.6	33,949.6

$Ranger_d$, Q_d, and $Jenkins_d$ creeks. $Black_m$ Creek appeared to have only a thin silt layer covering the rock substrate in a limited riffle section of the stream; elsewhere, the substrate consisted of sediment intermixed with a gravely coal mixture, the coal most likely being washed in from the coal tipple a short distance upstream. Big_m Creek appeared to be free of sediment at the area of sampling. This observation suggests that either the mine drainage had been diluted by incoming clear water or that the sampling station was sufficiently removed from the disturbed site to have recovered from the effects of sedimentation. Undisturbed watersheds were not included in this analysis as the equation pertains only to disburbed areas.

Acid mine drainage and sedimentation were present in several of the streams surveyed. Chemical analysis of the waters of $Ranger_d$ $Jenkins_d$, and Q_d creeks, Big_m and $Black_m$ creeks indicated that stresses were present in these streams when compared to baseline streams among the various parameters studied: depressed pH and alkalinity and elevated concentrations of metals and sulfate. The Student-Newman-Keuls test, multiple comparisons among means, was applied to the results of analyses (Sokal and Rohlf, 1969). Although the sensitivity of the test was decreased because of the significant variation among sampling dates, the results of this test distinguished the severely disturbed streams from the less disturbed and baseline streams (Appendix D.) Both precipitation and pH seemed to determine the metals and sulfate concentration; precipitation seemed to influence pH.

This survey of the effects of surfacemining of water quality in Grundy County showed that the effects of acid mine drainage and sedimentation are prevalent in surface waters draining the orphan mined

areas surrounding Coalmont and in watersheds with current mining operations. Results of this survey differ from those of the New River Basin study (Minear and Tschantz, 1978) as represented in Table XX. Baseline streams compare closely with $Piney_B$ and $Firescald_B$ Creeks. Escarpment stations and $Armstrong_b$ Creek have elevated values in such constituents as alkalinity and sulfates. Disturbed streams from both study areas not only contrast with the baseline streams but also with each other. (Table XXI.) The alkaline mine drainage of the New River study area produces much higher concentrations of Ca and Mg than does the acid mine drainage in the Grundy County study area which is characterized by higher concentrations of trace metals (cobalt and zinc) and manganese. Higher sulfate concentrations were found in Grundy County streams affected by acid mine drainage.

B. Aquatic Insects Survey

Quantitative

The quantitative parameters analyzed were numbers of individuals, number of taxa and diversity index for Big_m, $Firescald_B$, and $Piney_B$, creeks. The results are presented in Table XXII. The results of the one way analysis of variance in the three parameters are presented in Table XXIII. T-tests on the three parameters were performed for the samples collected from Big_m and $Firescald_B$ Creeks on February 2, 1978 and Big_m and $Piney_B$ Creeks on April 3, 1978. Significant differences at the .05 level were found for both the analysis of variances and the T-tests on the three parameters analyzed. Table XXIV presents the results of analysis. The results suggested significant differences among the community structures of the streams surveyed. Because of

TABLE XX

COMPARISONS BETWEEN NEW RIVER BASIN AND
GRUNDY COUNTY STUDY AREAS: BASELINE STREAMS
(Mean Values of Measured Parameters)

	New River Basin	$Firescald_B$	$Piney_B$	$Elkhead_b$	$Armstrong_b$
pH 9	6.1	6.4	6.4	6.8	5.9
Alkalinity	6.4	12.9	13.1	53.5	16.8
Sulfates	9.	3.3	1.9	3.9	3.2
Total Fe	0.47	.17	.03	.15	.4
Total Mn	0.01	.03	.01	0.000	.07
Total Ca	1.12	2.6	2.7	13.3	4.5
Total Mg	1.34	.5	.4	2.1	.4
Total Zn	0.002	0.000	0.000	0.000	0.00
Total Cd	0.002	0.000	0.000	0.000	0.000
Total Co	0.000	0.000	0.000	0.000	0.000
Total Pb	0.0010	0.00021	0.0087	0.0019	0.0027

SOURCE: Minear, R.A. and Tschantz, B.A. 1978. Impact of Coal Surface Mining on Water Quality of Mountain Drainage Basin Streams. Final report to Tennessee Department of Public Health, Water Quality Division.

TABLE XXI

COMPARISON OF DISTURBED STREAMS
OF THE NEW RIVER BASIN AND GRUNDY
COUNTY STUDY AREAS
(Mean Values)

	New River Basin	Ranger 1_d	Ranger 2_d	Jenkins$_d$	Q_d
Total Cd	.00020	.00004	.00004	.00006	.00001
Total Co	.00585	.26400	.08270	.03760	.05200
Total Pb	.00385	.00090	.00150	.00130	.00060
Total Zn	.0342	.1200	.1100	.1400	0.0000
Total Ca & Mg	440.0	74.5	34.8	4.4	38.2
Total Mn	<.3	17.5	7.7	1.9	10.7

SOURCE: Minear, R.A. and Tschantz, B.A. 1978. Impact of Coal Surface Mining on Water Quality of Mountain Drainage Basin Streams. Final report to Tennessee Department of Public Health, Division of Water Quality.

TABLE XXII

RESULTS OF QUANTITATIVE SAMPLING

Stream	Sampling Date	No. Of Species	No. Of Individuals/ .305 m^2	Indices (H')
Big_m	2/27/78	15	50.9	1.37
	4/ 3/78	17	28.6	1.21
$Piney_B$	4/ 3/78	36	187.6	2.47
$Firescald_B$	2/28/78	26	75.9	2.20

TABLE XXIII

ANALYSIS OF VARIANCE SUMMARIES FOR THE QUANTITATIVE PARAMETERS EXAMINED

Source	D.F.	S.S.	M.S.	F_s
Species Diversity Index				
Between groups	2	1.124	.562	43.23
Within groups	1	.013	.013	
TOTAL	3	1.137		
Numbers of Individuals				
Between groups	2	941,156.8	470,578.4	29.70
Within groups	1	15,842.0	15,842.0	
TOTAL	3	956,998.8		
Number of Taxa				
Between groups	2	288	144	72
Within groups	1	2	2	
T TOTAL	3	290		

NOTE: F_s = 18.5 at .05 probability level.

TABLX XXIV

T-TEST RESULTS FOR BETWEEN SAMPLING DATES

Streams Compared	Sampling Date(s)	D.F.	T
Big Piney	2/11/78 2/11/78	319	13.9[1]
Big Firescald	2/27/78 2/28/78	909	10.6[1]
Big Piney	4/ 9/78 4/ 9/78	263	10.4[1]

[1]Value of T exceeds the 5% probability level.

the limited sampling period and differences in stream characteristics, it is not possible to conclude that the differences in community structure were due to watershed disturbances by surface mining. However, the marginal water quality differences and mining activities in the Big_m Creek watershed are possible explanations for community differences. If so, then the opportunity to study the effects of marginal acid mine drainage upon the benthos in a sediment free system is possible in Big_m Creek.

The percent composition of the major insect orders for each of the three study streams was analyzed. The results are presented in Figure 5. During the season sampling occurred Diptera, Plecoptera, and Ephemeroptera were of the greatest predictable abundance (Tebo and Hassler, 1961). Clearly the dipteran order was the most abundant. 75.3% of the Diptera in Big_m Creek were of the family Simuliidae. Both of the families Simuliidae and Chironomidae were the most abundant during the earliest sampling dates; however, Chironomidae maintained large populations throughout the sampling period.

Big_m Creek, however, had less than 1% of mayflies while $Firescald_B$ and $Piney_B$ creeks had 9.6% and 12.1% respectively. This pattern was closely repeated among the Trichoptera in Big_m (2.1%), $Firescald_B$ (13.2%) and $Piney_B$ (18.3%) creeks. The Ephemeroptera is the order most sensitive to the impacts of acid mine drainage (Warnick and Bell, 1969; Patrick, 1974).

Among the Plecoptera Brachyptera accounted for 88.0% of the stoneflies in Big_m 54.2% in $Firescald_B$, and 16.9% in $Piney_B$ creeks. The changes in community structure between the baseline streams and the marginally affected Big_m Creek were most evident in the presence

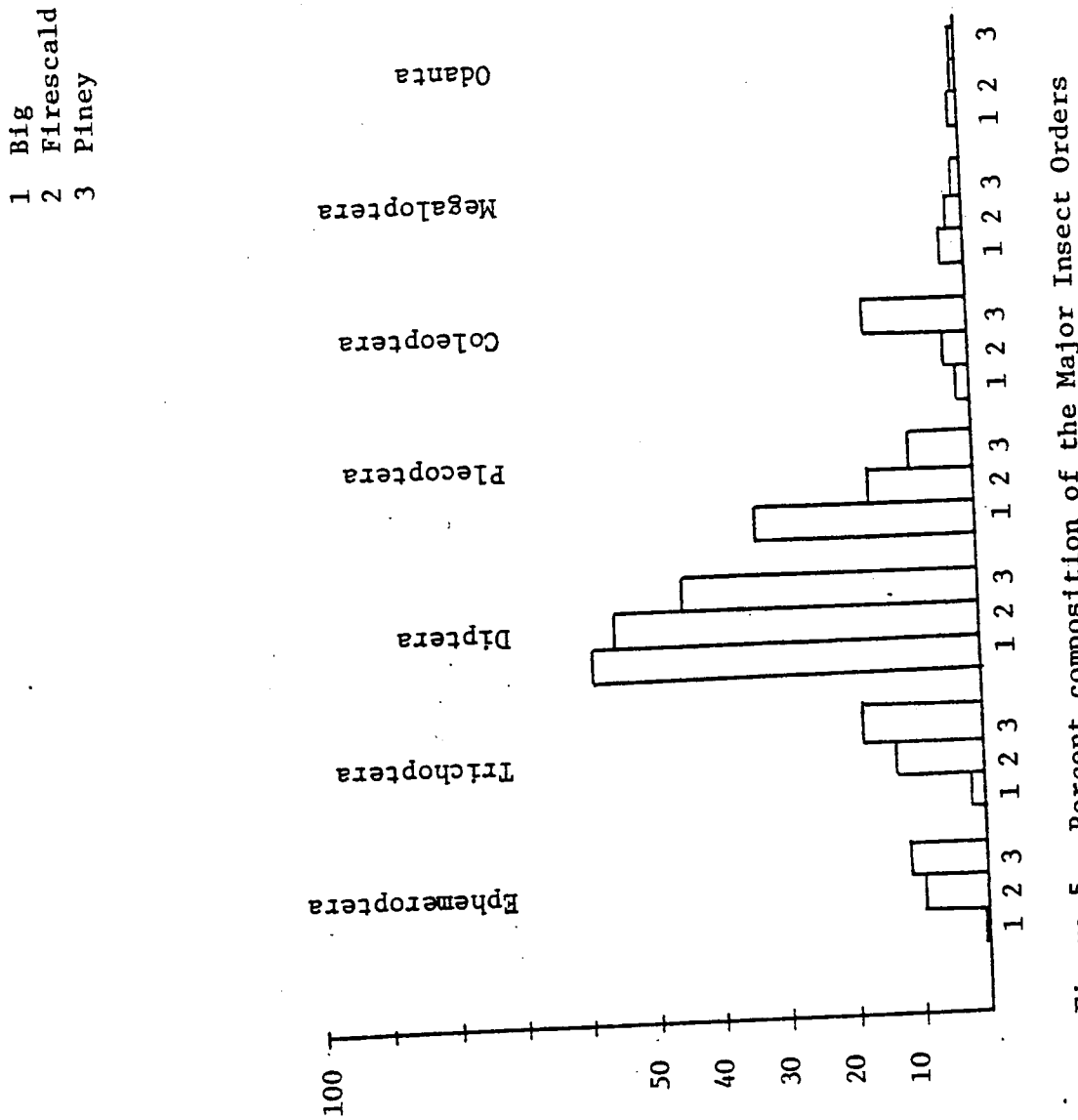


Figure 5. Percent composition of the Major Insect Orders

or absence of certain pollution intolerant organisms. The preponderance of certain taxa in Big_m Creek such as the Simuliidae and Brachyptera may be explained by the phenomenon described by Hynes (1970a) who observed that once the more intolerant organisms are removed due to stress within the system, the population of the more tolerant forms are permitted to greatly increase in absence of competition.

Qualitative Results

Figure 6 describes the number of taxa found in each stream. Again, baseline streams, marginally affected streams and seriously disturbed streams can be isolated. Among the plateau streams $Firescald_B$ and $Piney_B$ creeks exhibited the most diverse community structure. Communities within $Armstrong_b$ Creek did appear to be as diverse yet neither siltation nor chemical toxicities prevented the strong representation of the Ephemeroptera.

Each mayfly genus in Big_m Creek present was represented by a single individual. It is possible that these examples represented drift organisms. Although Big_m Creek did not seem to experience serious siltation problems, the benthos of $Black_m$ Creek was covered by a layer of siltation. The small number of mayflies found in these streams isolated Big_m and $Black_m$ creeks from the baseline streams.

The seriously affected watershed streams - $Ranger_d$, Q_d and $Jenkins_d$ creeks - had the compounding problem of severe sedimentation. Without an adequate substrate, only an impoversished community structure could persist. Chironomidae, Tipulidae and surface skimming members of the Hemiptera predominated the benthos of these streams. Conditions at the $Ranger_d$ 1 station were so severe that no individuals were collected. The Ephemeroptera were not collected from any of these streams.

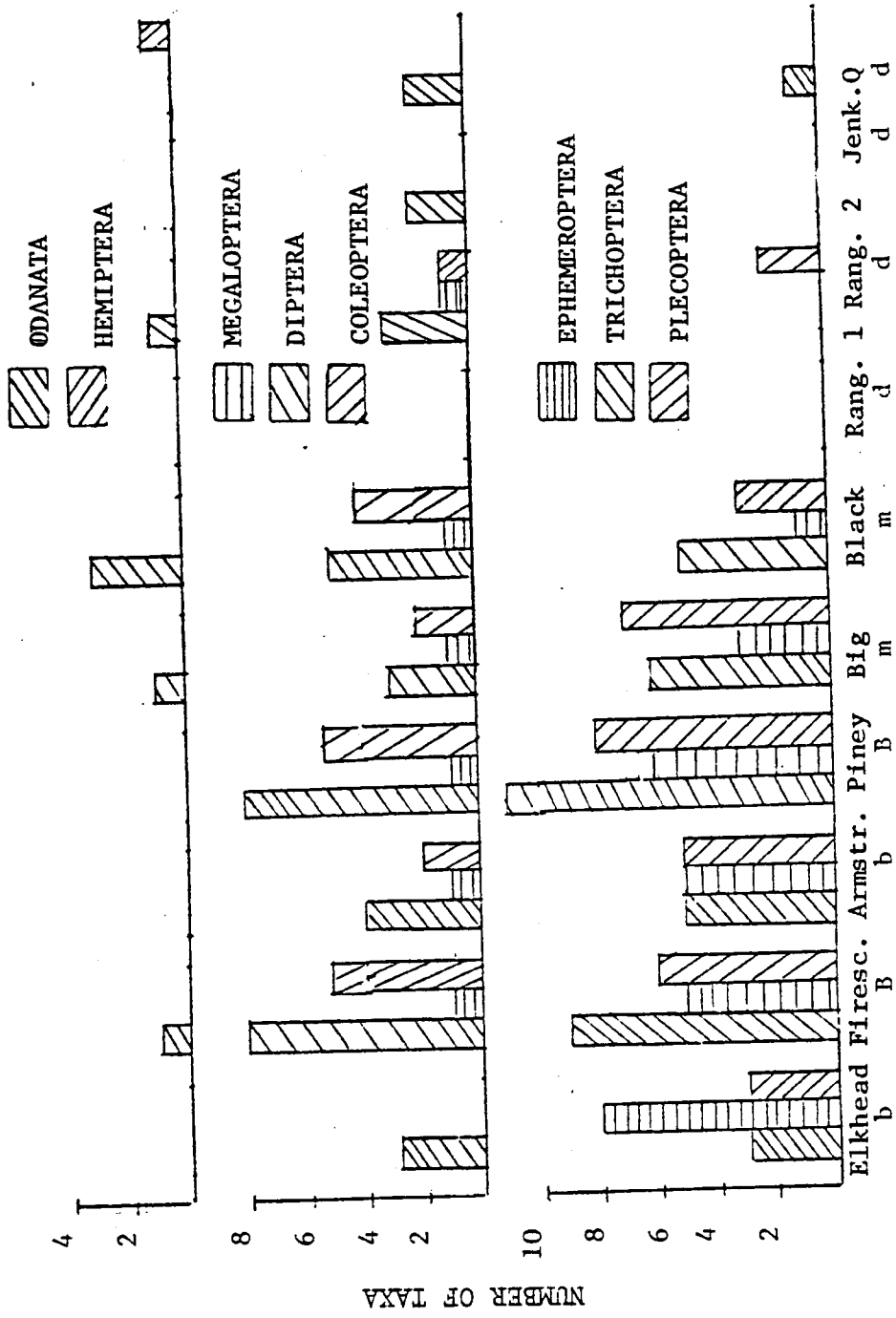


Figure 6. Number of Taxa by order Collected Qualitatively.

Table XXV lists the taxa identified which were collected from streams which were sampled quantitatively and qualitatively. Using Cummins (1973) classification of aquatic insects into shredders, collectors, scrapers, and predators, the various taxa were appropriately categorized by feeding habit. The results of this categorization appears in Table XXVI. Streams were differentiated into baseline streams ($Piney_B$ and $Firescald_B$ creeks), disturbed watershed streams ($Ranger_d$, $Jenkins_d$, and Q_d creeks), and marginally disturbed streams (Big_m and $Black_m$ creeks). $Armstrong_b$ Creek and $Elkhead_b$ were classed together as they represented reference systems unlike $Firescald_B$ and $Piney_B$ creeks.

The streams within watersheds undisturbed by surface mining had the various functional niches filled. Minimal redundancy seemed to exist among the shredders at this season. Among the collectors, however, great redundancy of function was observed especially in the plateau baseline streams. Both the scrapers and predators appeared in fewer numbers.

In the marginal streams the scrapers as a functional group did not exist which may be due to ferric hydroxide deposits in Big_m Creek and siltation in $Black_m$ Creek which inhibited the growth of periphytic mosses, algae, and diatoms. Numbers of collectors were also reduced.

The streams most seriously affected by acid mine drainage and sedimentation lacked both scrapers and shredders. The number of collectors was much reduced. Only the predator group maintained a comparable redundancy with the other stream groups. With the exception of the stonefly Isogenus, the predators are large insects which must depend on the impoverished detritivores and herbivores or upon each other for their food sources.

TABLE XXV

TAXA LIST AND COLLECTION LOCALITIES[1]

PLECOPTERA

FILIPALPIA

Nemouridae

Nemoura sp. 1, 2, 3, 4, 5, 8, 9

Taeniopterygidae

Brachyptera sp. 2, 3, 4, 5, 9

Taeniopteryx sp. 5

Leuctridae

Leuctra sp. 3

Allocapnia sp. 3

SETIPALPIA

Perlodidae

Isogenus sp. 1, 2, 3, 4, 5, 8, 9

Isoperla sp. 2, 3, 4, 5

Perlidae

Acroneuria sp. 3, 4

Chloroperlidae

Chloroperla sp. 1, 2, 3, 4, 5

Alloperla sp. 3

TABLE XXV
(Continued)

MEGALOPTERA

Corydalidae

Chauliodinae

Nigronia serricornis 2, 3, 4, 5, 8, 9

EPHEMEROPTERA

Ephemerellidae

Ephemerellinae

Ephemerella

Eurylophella sp. 1, 2, 3, 4, 5

Seratella sp. 3, 5

Ephemerella sp. 1

Dannella sp. 1, 2

Siphlonuridae

Ameletus lineatus 1, 2, 3, 4

Leptophlebiidae

Paraleptophlebia sp. 1, 3

Baetidae

Baetis sp. 1, 2, 3, 4

Heptageniidae

Stenacron sp. 1, 2, 4, 5

Stenonema sp. 3, 4, 9

Cinygmula sp. 1

TABLE XXV
(Continued)

ODONATA

ANISOPTERA

Cordulegasteridae

Cordulegaster sp. 8, 9

Aeshnidae

Boyeria vinosa 3, 4, 5, 9

ZYGOPTERA

Agrionidae (Callopterygidae)

Agrion (*Callopteryx*) sp. 9

TRICHOPTERA

Hydroptilidae

Octrotrichia sp. 1, 3

Rhyacophilidae

Rhyacophila sp. 1, 2, 3, 4, 5

Glossosamitidae

Agapetus sp. 1, 2, 3, 4

Hydropsychidae

Cheumatopsyche sp. 3, 4, 5, 9, 10

Diplectrona sp. 2, 3, 4, 5, 9

Hydropsyche sp. 3, 4, 5, 9

Philopotamidae

Chimarra sp. 3, 5, 9

Dolophilodes sp. 4

Wormaldia sp. 4

TABLE XXV
(Continued)

Phryganeidae

Ptilostomis sp. 2

Limnephilidae

Neophylax sp. 3

Pycnopsyche sp. 2, 5, 9

Ironquia sp. 3

Leptoceridae

Triaenodes sp. 3

Brachycentridae

Brachycentrus sp. 3

Lepidostomatidae

Lepidostoma sp. 3, 4

DIPTERA

Chironomidae 1, 2, 3, 4, 5, 8, 9

Tipulidae

Hexatoma sp. 3, 4

Antocha sp. 1, 2, 3, 4, 9

Tipula sp. 1, 2, 3, 4, 6, 8

Eriopterini sp. 3

Elliptera sp. 4

Longuiro sp. 5, 6, 9

Limnophila sp. 4

Limonia sp. 9

TABLE XXV
(Continued)

Simuliidae 2, 3, 4, 5

Psychodidae

Pericoma sp. 3

Rhagionidae

Atherix variegata 3

COLEOPTERA

Elmidae

Stenelmis sp. 3, 4

Optioservus sp. 2, 3, 4, 5

Promoresia tardella 3

Promoresia sp. 3, 4

Oulimnius latiusculus 4

Gyrinidae

Dineutus sp. 8

Psphenidae

Ectopria nervosa 2

HEMIPTERA

Gerridae

Gerris sp. 10

[1]Stations: 1 - Elkhead$_b$, 2 - Armstrong$_b$, 3 - Piney$_B$, 4 - Firescald$_B$, 5 - Big$_m$, 6 - Jenkins$_d$, 7 - Ranger$_d$ 1, 8 - Ranger$_d$ 2, 9 - Black$_m$, 10 - Q$_d$ creek.

TABLE XXVI

COMPARISON OF FUNCTIONAL GROUPS

	Armstrong and Elkhead	Baseline	
Shredders	Pycnopsyche	Ironquia	
Collectors	Diplectrona	Cheumatopsyche	Tipula
	Eurylophella	Diplectrona	
	Ephemerella	Hydropsyche	Eriopterini
	Dannella	Chimarra	Elliptera
	Paraleptophlebia	Wormaldia	Longurio
	Baetis	Dolophilodes	Simuliidae
	Stenacron	Triaenodes	Stenelmis
	Cinygmula	Brachycentrus	Optioservus
	Optioservus	Lepidostoma	Promoresia tardella
	Nemoura	Chloroperla	Promoresia
	Brachyptera	Nemoura	Ouliminius latiusculus
	Chloroperla	Brachyptera	Eurylophella
	Chironomidae	Leuctra	Seratella
	Simuliidae	Allocapnia	Paraleptophlebia
	Antocha	Chironomidae	Baetis
	Tipula	Hexatoma	Stenonema
		Antocha	Stenacron
Scrapers	Ochrotrichia	Ochrotrichia	
	Agapetus	Agapetus	
	Ectopria nervosa	Neophylax	
	Ameletus lineatus	Ameletus lineatus	
Predators	Rhycophila	Rhycophila	
	Ptilostomis	Isogenus	
	Isogenus	Isoperla	
	Isoperla	Acroneuria	
	Nigronia serricornis	Nigronia serricornis	
		Boyeria	

TABLE XXVI (Continued)

	Marginally Affected	Seriously Affected
Shredders	Pycnopsyche	
Collectors	Cheumatopsyche	Nemoura
	Diplectrona	Chironomidae
	Hydropsyche	Tipula
	Chimarra	Cheumatopsyche
	Optiosenus	
	Nemoura	
	Brachyptera	
	Taeniopteryx	
	Chloroperla	
	Chironomidae	
	Antocha	
	Simuliidae	
	Eurylophella	
	Seratella	
	Stenonema	
	Stenacron	
Scrapers		
Predators	Rhycophila	Dineutus
	Isogenus	Isogenus
	Isoperla	Nigronia serricornis
	Nigronia serricornis	Cordulegaster
	Cordulegaster	Gerris
	Boyeria	
	Agrion	

Distinctions can be made between organisms tolerant or intolerant to the effects of acid mine drainage and sedimentation. As an order, the Ephemeroptera is the most sensitive. The numbers of individual and taxa are much reduced in Big_m and $Black_m$ creeks. The order is non-existent in streams most severely affected by acid mine drainage and sedimentation.

Among the stoneflies, species of Nemoura and Isogenus appeared the least sensitive to the effects of siltation and acid mine drainage. Brachyptera sp., as mentioned earlier, were found in great numbers in Big Creek.

Trichoptera, an order usually considered less sensitive than Plecoptera to the effects of surface mining on surface waters, appeared to parallel the distribution of Ephemeroptera in the streams surveyed. Roback (1962) studied the effects of varying concentrations of iron and pH upon different caddisfly genera. His work suggested that Cheumatopshyche, Hydropsyche, and Chimmara are the most tolerant genera to wide ranges of chemical conditions. Roback's results paralleled those of this study as three of the four genera found in the marginal stream were Cheumatopsyche, Hydropsyche, and Chimarra. Only Cheumatopsyche was collected from streams most severely affected by surface mining.

Odonates were some of the most numerous forms collected in both the marginally and seriously affected streams. Cordulegaster and Boyeria were commonly found among the cattails of $Ranger_d$ Creek and within a silted rocky stretch of $Black_m$ Creek. These results were similar to those of Bick et al., (1953) in their study of acid waters.

Coleopterans are commonly found in sites stressed by acid mine drainage. Dineutus, a surface skimming beetle, was collected in

Ranger$_d$ Creek. Optioservus larvae were found in Big$_m$ and Black$_m$ creeks.

The megalopteran Nigronia serricornis was present in all the stream groups. This species appeared to be tolerant to both low pH and heavy sedmentation.

Among the dipterans the Chironomidae and Tipulidae seemed to be the most resistant families to the effects of surface mining. In improved water quality situations the diversity and numbers of Tipulidae increased. Tipula seemed to be the most tolerant to sedimentation and low pH. Chironomidae is a very large family and was present under most conditions.

This study afforded the opportunity to compare the effectiveness of determining stressed systems by chemical and biotic indicators. Aquatic insects have a distinct advantage in that they represent conditions over an extended period of time rather than instantaneous conditions which a sample taken for chemical analysis represents. Studies of the environmental requirements for aquatic insects remain, however, in early stages. Because of this factor and endemic community structure, chemical or bacteriological analysis are necessary to determine the source of the stress. Further, the severe effects of sedimentation upon the benthos limits the usefulness of aquatic insect sampling in determining water quality per se of sedimented streams, a condition prevalent in many disturbed watersheds. As an initial survey technique, however, sampling streams for insects would be useful to determine severity of the stress placed upon the system by acid mine drainage and sedimentation. Chemical analysis then could routinely monitor the stress source and fluctuations. Biotic sampling would be

useful over time to detect community response to water chemistry and changes in sedimentation as was studied by Tolbert (1978) and Talak (1977) in the New River Basin study.

The benthic organisms are not routinely monitored currently by regulatory agencies nor have criteria been adopted for measuring aquatic insect populations to assist in determining water quality. Recently, the Division of Water Quality of the State Department of Public Health proposed sampling aquatic insects to aid in the determination of how to protect streams with intermittent flow and to prevent further degradation of streams with perennial flow.

This study has limitations. The near absence of hydrological characterization of the sampling area diminished the understanding of the dynamics involved. Such a short sampling period for both the chemical and biotic parameters limits the conclusions that can be drawn from the results. Plass (1975) states that conclusions based upon less than two years of data are presumptuous. Lotic studies further require locating stations with comparable environmental variables. This limitations makes it difficult to conclude that differences between streams are due to the studied factor rather than to another independent variable.

CHAPTER VI

SUMMARY

The Southern Cumberland coal field in which Grundy County lies is distinquished from the northern coal fields both by less rugged topography and the presence of acid mine drainage. Area mining is the major form of surface removal of coal in this area. In Grundy County, 85% of the strippable reserves were mined prior to the 1967 state surface mine legislation which means that over 4,000 acres of the county are unreclaimed mined lands.

Water quality data collection began in August, 1977 and ended in January, 1978 in Grundy County, Tennessee at eleven stations on ten different streams. Five of the streams were disturbed by current or abandoned mining activities. The experimental design enabled comparison of baseline aquatic systems with disturbed systems.

In general, the water quality of the undisturbed watersheds is near or at pristine conditions while the areas disturbed by surface mining show significantly depressed pH and elevated concentrations of most constituents. The acid mine drainage of the Grundy County study area contrasts with the alkaline mine drainage of the New River Basin study area. Depressed pH values were found in $Ranger_d$, $Jenkins_d$, and Q_d creeks (Table XI).

The aquatic insect communities of baseline streams were more diverse with more abundant populations than were those communities of disturbed streams. Sedimentation was an important factor in this study area as in the New River basin, influencing both diversity and abundance.

The brevity of this survey provides only an estimate of the biotic and chemical water quality in the area. Sources of error in the biotic sampling may be too great to declare that the significant differences found between Big_m Creek and the two plateau baseline streams are due to surface mining: differences in stream order and riparian vegetation may be more responsible for differences in insect population than is water quality.

CHAPTER VII

CONCLUSIONS

1. Significant differences were found among disturbed and undisturbed stream and sampling dates. Differences are likely due to the effects of surface mining.
2. Acid mine drainage prevails in streams most severely affected by surface mining. High concentrations of some metals were detected.
3. The Grundy County study area is unlike the New River basin study area which is characterized by alkaline mine drainage.
4. Significant differences were found among Big Creek and Piney and Firescald creeks in diversity and abundance of the aquatic insects sampled. The difference is likely attributable to the effects of surface mining.
5. Sedimentation is a significant factor determining diversity and abundance of aquatic insects.

CHAPTER VIII

SUGGESTIONS FOR FURTHER STUDY

Several avenues for further study have become apparent as a result of this survey. First, adequate gaging of streams to determine discharge is necessary. Also, a study design to determine the extent and rate of sedimentation is suggested. This research could be most interesting as it might be possible to compare rates of stream sedimentation in area mined watershed with those which are contour mined. Leaching from spoil banks and strip pits also could be monitored.

This survey suggests that the reservoir of the Big Creek Utility District on Ranger Creek affects the water quality of the incoming water. Differences in water quality were measured between $Ranger_d$ 1 and 2 suggesting that certain dynamics within the reservoir are affecting water quality. Data from over several years are available from the utility itself on water quality of the raw and finished water. Big_m Creek and possibly other streams in the area might afford the opportunity to study marginally affected sediment free systems. The Big Creek watershed which flows into Savage Gulf would provide an excellent study area as it drains areas both affected and unaffected by surface mining. $Armstrong_b$, $Firescald_B$, $Piney_B$, and $Ranger_d$ creeks are included within the Big watershed.

Because of the intensifying interest in the Savage Gulf area, it would be profitable to study this system. Finally, some of the results suggest that within Grundy County, the lower Tennessee basin drains an area with more calcareous material than do the Elk or Upper Cumberland River basins. Both Black and Q creeks maintained a relatively higher alkalinity than did the other basin streams which were disturbed by surface mining.

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APPENDICES

APPENDIX A

TABLE A-1

SAMPLING DATA FOR ARMSTRONG$_b$ CREEK

		pH	Water Temp. C	Alkali-nity*	Sulfate mg/l	Fe ppm	Ca ppm	Mg ppm	Mn ppm	Zn ppm	Pb ppm	Co ppm	Cd ppm	Al ppm
9/3/77	T	6.8	23	106.6	6	3.3	36.5	1.35	.41	.06	.0034	D.L.	D.L.	D.L.
	D					.1	36.0	1.40	.41	.11	.0032	D.L.	D.L.	D.L.
9/17/77	T	5.5	18	2.1	10	.1	1.0	.25	.04	D.L.	.0025	D.L.	D.L.	D.L.
	D					.1	1.0	.95	.03	D.L.	D.L.	D.L.	D.L.	D.L.
10/1/77	T	5.9	16	3.0	D.L.	.1	.5	.20	D.L.	D.L.	.0022	D.L.	D.L.	D.L.
	D					.1	1.0	.25	D.L.	D.L.	.0025	D.L.	D.L.	D.L.
10/15/77	T	5.3	9	5.6	D.L.	D.L.	.5	.20	D.L.	D.L.	.0030	D.L.	D.L.	D.L.
	D					D.L.	1.0	.25	D.L.	D.L.	D.L.	D.L.	D.L.	D.L.
10/29/77	T	5.5	11	3.7	13	D.L.	.5	.20	D.L.	D.L.	.0037	D.L.	D.L.	D.L.
	D					D.L.	.5	.25	.04	D.L.	.0014	D.L.	D.L.	D.L.
11/13/77	T	5.1	9	3.8	D.L.	D.L.	.4	.30	.10	D.L.	.0033	D.L.	D.L.	D.L.
	D					D.L.	.4	.30	D.L.	D.L.	.0014	D.L.	D.L.	D.L.
11/26/77	T	5.5	7	8.4	D.L.	D.L.	.3	.20	.10	D.L.	.0015	D.L.	D.L.	D.L.
	D					D.L.	.5	.30	D.L.	.02	.0023	D.L.	D.L.	D.L.
12/10/77	T	5.2	5	5.7	D.L.	D.L.	.4	.30	D.L.	D.L.	.0019	D.L.	D.L.	D.L.
	D					D.L.	.5	.40	D.L.	D.L.	.0013	D.L.	D.L.	D.L.
1/2/78	T	5.8	3	12.0	D.L.	D.L.	.4	.30	D.L.	D.L.	.0029	D.L.	D.L.	D.L.
	D					D.L.	.6	.40	D.L.	.02	.0014	D.L.	D.L.	D.L.

NOTE: D.L. = detection limit; T = total; D = dissolved; -- = not available.

*mg/l as CaCo3

TABLE A-2

SAMPLING DATA FOR BIG$_m$ CREEK

		pH	Water Temp. C	Alkali-nity*	Sulfate mg/l	Fe ppm	Ca ppm	Mg ppm	Mn ppm	Zn ppm	Pb ppm	Co ppm	Cd ppm	Al ppm
9/17/77	T	5.7	19	2.1	31	.3	4.5	4.15	.60	.01	.0010	.003	D.L.	D.L.
	D					.2	3.5	4.05	.60	.02		.004	D.L.	D.L.
10/1/77	T	4.9	16	1.7	32	.2	3.0	4.20	.70	D.L.	.0004	.004	D.L.	D.L.
	D					.1	3.5	4.05	.70	.02		.005	D.L.	D.L.
10/15/77	T	5.0	9	.9	29	.2	3.0	4.02	.80	.01	.0004	.006	D.L.	D.L.
	D					.1	3.0	3.95	.80	.02		.006	D.L.	D.L.
10/29/77	T	5.4	12	5.0	29	.2	2.5	3.05	.50	D.L.	.0014	.003	D.L.	D.L.
	D					.2	2.5	2.95	.50	D.L.		.003	D.L.	D.L.
11/13/77	T	4.6	8	1.4	24	.2	2.4	3.90	.80	D.L.	.0008	.005	D.L.	D.L.
	D					.2	2.5	3.80	.80	D.L.		.005	D.L.	D.L.
11/26/77	T	5.3	8	7.9	23	.2	2.2	3.50	.70	D.L.	.0011	.005	D.L.	D.L.
	D					.1	2.6	3.60	.70	.02		.006	.0009	D.L.
12/10/77	T	5.6	4	6.0	28	--	--	--	--	--	--	--	--	--
	D													
1/2/78	T	5.3	4	9.1	33	.2	3.0	4.70	.90	.02	.0011	.006	D.L.	D.L.
	D					.2	3.1	4.40	.90	.03		.006	.00009	D.L.

NOTE: D.L. = detection limit, T = total, D = dissolved, -- = not available.

*mg/l as $CaCo_3$

TABLE A-3

SAMPLING DATA FOR BLACK$_m$ CREEK

		pH	Water Temp. C	Alkali-nity	Sulfate mg/l	Fe ppm	Ca ppm	Mg ppm	Mn ppm	Zn ppm	Pb ppm	Co ppm	Cd ppm	Al ppm
9/3/77	T	6.4	22	18.8	50	.6	8.5	3.60	.34	D.L.	D.L.	.003	D.L.	D.L.
	D					.3	8.5	4.00	.50	.05	--	.004	D.L.	D.L.
9/17/77	T	6.3	18.5	12.5	32	.4	10.5	3.00	.18	D.L.	D.L.	.005	D.L.	D.L.
	D					.2	--	3.00	.25	D.L.	--	.005	D.L.	D.L.
10/1/77	T	5.8	19	20.2	27	.3	10.0	3.4	.14	D.L.	D.L.	.002	D.L.	D.L.
	D					.2	10.5	3.70	.25	D.L.	D.L.	.003	D.L.	D.L.
10/15/77	T	6.4	10	14.2	27	.2	8.0	3.60	.13	D.L.	D.L.	.003	D.L.	D.L.
	D					.2	8.0	3.90	.28	D.L.	--	.004	D.L.	D.L.
10/29/77	T	6.9	13	13.7	29	.2	6.5	3.80	.13	D.L.	D.L.	.002	D.L.	D.L.
	D					.1	7.0	3.10	.23	D.L.	--	.004	D.L.	D.L.
11/13/77	T	6.6	9	11.5	25	.2	7.6	3.30	.10	D.L.	D.L.	.003	D.L.	D.L.
	D					.2	5.6	3.30	.20	D.L.	--	.003	D.L.	D.L.
11/26/77	T	6.2	7	27.5	26	.3	4.6	2.90	.10	D.L.	D.L.	.003	D.L.	D.L.
	D					D.L.	6.0	3.20	.20	D.L.	--	.005	D.L.	D.L.
12/10/77	T	5.8	3	8.1	25	.3	5.8	3.40	.20	D.L.	.0015	.003	D.L.	D.L.
	D					.2	6.0	3.20	.20	D.L.	--	.006	D.L.	D.L.
1/2/78	T	6.5	4	27.0	23	.2	5.6	2.90	.20	D.L.	D.L.	.003	.00017	D.L.
	D					.1	6.0	3.30	.20	.02		.005	.00025	D.L.

NOTE: D.L. = detection limit; T = total; D = dissolved; -- = not available.

*mg/l as CaCo3

TABLE A--4

SAMPLING DATA FOR ELKHEAD$_b$ CREEK

		pH	Water Temp. C	Alkali-nity*	Sulfate mg/l	Fe ppm	Ca ppm	Mg ppm	Mn ppm	Zn ppm	Pb ppm	Co ppm	Cd ppm	Al ppm
8/22/77	T	6.5	14	52.3	D.L.	.5	16.0	2.50	D.L.	D.L.	.0010	D.L.	D.L.	D.L.
	D					.1	16.5	2.50	D.L.	.05		D.L.	D.L.	D.L.
9/3/77	T	6.9	14	71.1	9	.6	21.5	3.30	D.L.	D.L.	.0014	D.L.	D.L.	D.L.
	D					D.L.	21.5	3.30	D.L.	D.L.		D.L.	D.L.	D.L.
9/17/77	T	6.5	11	52.0	8	.3	11.0	1.50	D.L.	D.L.	D.L.	D.L.	D.L.	D.L.
	D					.1	11.0	1.50	D.L.	D.L.		D.L.	D.L.	D.L.
10/1/77	T	7.5	14	37.8	9	.1	11.0	1.70	D.L.	D.L.	.0022	D.L.	D.L.	D.L.
	D					.1	11.5	1.80	D.L.	D.L.		D.L.	D.L.	D.L.
10/15/77	T	6.8	12	21.1	5	D.L.	13.0	2.00	D.L.	D.L.	.0029	D.L.	D.L.	D.L.
	D					D.L.	13.0	2.10	D.L.	D.L.		D.L.	D.L.	D.L.
10/29/77	T	7.1	12	38.7	8	D.L.	10.5	1.70	D.L.	D.L.	.0048	D.L.	D.L.	D.L.
	D					D.L.	11.5	1.90	D.L.	D.L.		D.L.	D.L.	D.L.
11/13/77	T	6.2	13	48.2	D.L.	D.L.	12.6	2.00	D.L.	D.L.	.0027	D.L.	D.L.	D.L.
	D					D.L.	13.0	2.10	D.L.	D.L.		D.L.	D.L.	D.L.
11/26/77	T	6.6	12	81.5	D.L.	D.L.	12.8	2.00	D.L.	D.L.	.0019	D.L.	D.L.	D.L.
	D					D.L.	12.8	2.00	D.L.	D.L.		D.L.	D.L.	D.L.
12/10/77	T	6.2	9	45.9	D.L.	D.L.	12.8	2.10	D.L.	D.L.	D.L.	D.L.	D.L.	D.L.
	D					D.L.	12.2	2.10	D.L.	D.L.		D.L.	D.L.	D.L.
1/2/78	T	5.9	8	86.5	D.L.	D.L.	12.2	2.20	D.L.	D.L.	.0016	D.L.	D.L.	D.L.
	D					D.L.	13.0	2.30	D.L.	.02		D.L.	D.L.	D.L.

NOTE: D.L. = detection limit; T = total; D = dissolved; -- = not available.
*mg/l as $CaCo_3$.

TABLE A-5

SAMPLING DATA FOR FIRESCALD$_B$ CREEK

		pH	Water Temp. C	Alkali-nity*	Sulfate mg/l	Fe ppm	Ca ppm	Mg ppm	Mn ppm	Zn ppm	Pb ppm	Co ppm	Cd ppm	Al ppm
7/26/77	T	6.5	23	14.7	D.L.	.6	4.0	.65	.05	D.L.	.0010	D.L.	D.L.	D.L.
	D						--	--	--		--	D.L.	D.L.	D.L.
8/22/77	T	6.2	18	2.3	D.L.	.5	6.0	.70	.14	.04	.0044	D.L.	D.L.	D.L.
	D					.1	6.5	.70	.12	.02		D.L.	D.L.	D.L.
9/3/77	T	7.2	22	56.3	6	.7	16.0	1.05	.14	D.L.	.0018	D.L.	D.L.	D.L.
	D					.1	16.5	1.10	.06	.01		D.L.	D.L.	D.L.
9/17/77	T	6.2	18	6.3	5	.2	1.5	.45	D.L.	D.L.	.0022	D.L.	D.L.	D.L.
	D					.1	1.0	.50		D.L.		D.L.	D.L.	D.L.
10/1/77	T	6.2	16	3.7	8	.1	1.0	.35	D.L.	D.L.	.0012	D.L.	D.L.	D.L.
	D					.1	1.0	.35	D.L.	D.L.		D.L.	D.L.	D.L.
10/15/77	T	6.4	8	3.0	D.L.	D.L.	.5	.35	D.L.	D.L.	.0011	D.L.	D.L.	D.L.
	D					D.L.	.5	.35	D.L.	D.L.		D.L.	D.L.	D.L.
10/29/77	T	6.5	11	5.0	17	D.L.	.3	.30	.04	D.L.	.0020	D.L.	D.L.	D.L.
	D					D.L.	.5	.35	.04	D.L.		D.L.	D.L.	D.L.
11/13/77	T	5.5	83	2.9	D.L.	D.L.	.4	.30	D.L.	D.L.	.0039	D.L.	D.L.	D.L.
	D					D.L.	.5	.40	D.L.	D.L.		D.L.	D.L.	D.L.
11/26/77	T	6.3	7	10.5	D.L.	D.L.	.4	.30	D.L.	D.L.	.0012	D.L.	D.L.	D.L.
	D					D.L.	.4	.30	D.L.	.01		D.L.	D.L.	D.L.
12/10/77	T	5.9	4	3.4	D.L.	D.L.	.4	.30	D.L.	D.L.	.0028	D.L.	D.L.	D.L.
	D					D.L.	.6	.50	D.L.	D.L.		D.L.	D.L.	D.L.
1/2/78	T	6.0	4	12.9	D.L.	D.L.	.5	.30	D.L.	D.L.	.0012	D.L.	D.L.	D.L.
	D					D.L.	.6	.40	D.L.	D.L.		D.L.	D.L.	D.L.

NOTE: D.L. = detection limit, T = total, D = dissolved, -- = not available,

*mg/l as CaCo3

TABLE A-6

SAMPLING DATA FOR FROGSPRING CREEK

		pH	Water Temp. C	Alkali-nity*	Sulfate mg/l	Fe ppm	Ca ppm	Mg ppm	Mn ppm	Zn ppm	Pb ppm	Co ppm	Cd ppm	Al ppm
7/26/77	T	--	--	--	--	--	--	--	--	--	--	--	--	--
	D													
8/22/77	T	7.6	17	198.6	19	.1	52.0	14.00	D.L.	D.L.	.0013	D.L.	D.L.	D.L.
	D					.1	52.0	14.00	D.L.	D.L.	.0013	D.L.	D.L.	D.L.
9/3/77	T	7.7	18	403.4	27	D.L.	52.0	14.00	D.L.	D.L.	.0030	D.L.	D.L.	D.L.
	D					D.L.	51.0	13.50	D.L.	.06	.0034	D.L.	D.L.	D.L.
9/17/77	T	--	16	213.2	14	D.L.	58.0	14.00	D.L.	D.L.	.0010	D.L.	D.L.	D.L.
	D					D.L.	58.0	13.50	.10	.01	D.L.	D.L.	D.L.	D.L.
10/1/77	T	7.6	16	226.6	23	.1	58.0	15.00	D.L.	D.L.	D.L.	D.L.	D.L.	D.L.
	D					.1	58.0	14.50	D.L.	.01	D.L.	D.L.	D.L.	D.L.
10/15/77	T	7.8	12	211.6	13	D.L.	59.0	14.50	.04	D.L.	.0034	D.L.	D.L.	D.L.
	D					D.L.	56.0	14.50	.06	D.L.	.0016	D.L.	D.L.	D.L.
10/29/77	T	7.8	14	243.9	23	D.L.	63.0	17.50	D.L.	D.L.	D.L.	D.L.	D.L.	D.L.
	D					D.L.	62.0	17.50	.05	D.L.	D.L.	D.L.	D.L.	D.L.
11/13/77	T	7.8	12	263.9	17	D.L.	60.0	17.00	D.L.	D.L.	D.L.	D.L.	D.L.	D.L.
	D					D.L.	62.0	17.00	D.L.	D.L.	D.L.	D.L.	D.L.	D.L.
11/26/77	T	7.8	13	483.3	17	D.L.	54.0	15.30	D.L.	D.L.	D.L.	D.L.	D.L.	D.L.
	D					D.L.	56.0	15.00	D.L.	D.L.	D.L.	D.L.	D.L.	D.L.
12/10/77	T	7.8	12	367.6	D.L.	D.L.	62.0	16.90	D.L.	D.L.	.0012	D.L.	D.L.	D.L.
	D					D.L.	58.0	17.60	D.L.	.02	.0027	D.L.	D.L.	D.L.
1/2/78	T	7.9	12	491.2	12	D.L.	56.0	16.70	D.L.	D.L.	.0013	D.L.	D.L.	D.L.
	D					D.L.	58.0	17.00	D.L.	D.L.	.0027	D.L.	D.L.	D.L.

NOTE: D.L. = detection limit; T = total; D = disolved; -- = not available.

*mg/l as CaCo3

TABLE A-7

SAMPLING DATA FOR JENKINS$_d$ CREEK

		pH	Water Temp. C	Alkali-nity*	Sulfate mg/l	Fe ppm	Ca ppm	Mg ppm	Mn ppm	Zn ppm	Pb ppm	Co ppm	Cd ppm	Al ppm
8/22/77	T	3.7	20	0	285	10.0	24.0	D.L.	11.00	.95	.0058	.151	.00030	44.7
	D					7.0	24.5	D.L.	11.00	.95		.155	.00006	32.5
9/3/77	T	4.4	19	0	90	.8	3.5	D.L.	2.50	.10	.0015	.065	.00015	2.3
	D					.6	4.0	D.L.	3.00	.10		.066	.00001	1.8
9/17/77	T	4.5	20	0	65	1.4	2.0	D.L.	.72	.12	.0005	.029	.00005	5.2
	D					1.2	2.0	D.L.	.80	.08		.031	.00008	5.2
10/1/77	T	3.7	18	0	60	2.4	3.5	D.L.	3.50	.27	.0041	.108	.00009	11.9
	D					.6	3.5	D.L.	3.00	.26		.105	.00004	4.2
10/15/77	T	4.6	10	1.7	43	.7	1.5	D.L.	.23	D.L.	D.L.	.006	D.L.	2.3
	D					.4	2.0	D.L.	.16	D.L.		.005	.00005	D.L.
10/29/77	T	5.2	12	0	40	.3	1.5	D.L.	.05	D.L.	D.L.	.004	.00002	1.9
	D					.2	2.0	D.L.	.10	D.L.		.004	.00003	D.L.
11/13/77	T	5.2	9	1.9	13	.4	1.2	.90	.10	D.L.	D.L.	.003	D.L.	D.L.
	D					.3	1.3	1.00	.20	D.L.		.003	D.L.	D.L.
11/26/77	T	5.4	5	6.7	12	.3	1.2	.90	.10	D.L.	.0005	.002	D.L.	D.L.
	D					.3	1.3	.90	.10	D.L.		.003	.00023	D.L.
12/10/77	T	4.6	4	2.6	13	.4	1.0	.90	.10	D.L.	.0007	.003	D.L.	D.L.
	D					.4	1.3	1.20	.20	D.L.		.004	D.L.	D.L.
1/2/78	T	5.2	4	6.5	38	.7	.9	1.20	.30	D.L.	.0011	.005	.00003	D.L.
	D					.6	1.2	1.30	.30	D.L.		.005	.00006	D.L.

NOTE: D.L. = detection limit; T = total; D = dissolved; -- = not available.

*mg/1 as CaCo3

TABLE A-8

SAMPLING DATA FOR PINEY$_B$ CREEK

		pH	Water Temp. C	Alkali-nity*	Sulfate mg/l	Fe ppm	Ca ppm	Mg ppm	Mn ppm	Zn ppm	Pb ppm	Co ppm	Cd ppm	Al ppm
7/26/77	T	6.4	20.0	12.6	5	.15	4.5	.55	.05	D.L.	.0018	D.L.	D.L.	D.L.
	D					--	--	--	--	--	--	--	--	--
8/22/77	T	6.1	18	16.7	24	.10	4.5	.70	D.L.	D.L.	.0016	D.L.	D.L.	D.L.
	D					.10	5.0	.70	D.L.	D.L.	.0032	D.L.	D.L.	D.L.
9/3/77	T	6.8	20	29.3	29	.15	8.5	.80	.05	D.L.	.0021	D.L.	D.L.	D.L.
	D					.10	8.5	.80	.05	D.L.	.0021	D.L.	D.L.	D.L.
9/17/77	T	6.5	19	9.4	7	.10	3.0	.50	D.L.	D.L.	.0022	D.L.	D.L.	D.L.
	D					.10	2.3	.45	D.L.	D.L.	D.L.	D.L.	D.L.	D.L.
10/1/77	T	6.2	16	7.7	14	.10	2.0	.35	D.L.	D.L.	.0018	D.L.	D.L.	D.L.
	D					.05	2.0	.40	D.L.	D.L.	D.L.	D.L.	D.L.	D.L.
10/15/77	T	6.4	8	27.7	D.L.	D.L.	1.5	.35	D.L.	D.L.	.0025	D.L.	D.L.	D.L.
	D					D.L.	2.0	.35	D.L.	D.L.	.0009	D.L.	D.L.	D.L.
10/29/77	T	6.2	15	6.7	17	D.L.	1.5	.35	D.L.	D.L.	.0015	D.L.	D.L.	D.L.
	D					D.L.	1.0	.35	D.L.	D.L.	.0018	D.L.	D.L.	D.L.
11/13/77	T	5.8	8	5.7	D.L.	D.L.	1.1	.30	D.L.	D.L.	.0018	D.L.	D.L.	D.L.
	D					D.L.	1.0	.30	D.L.	D.L.	.0022	D.L.	D.L.	D.L.
11/26/77	T	6.5	8	13.4	D.L.	D.L.	.9	.30	D.L.	D.L.	.0020	D.L.	D.L.	D.L.
	D					D.L.	.9	.30	D.L.	D.L.	.0015	D.L.	D.L.	D.L.
12/10/77	T	6.1	4	5.0	D.L.	D.L.	.9	.30	D.L.	D.L.	.0023	D.L.	D.L.	D.L.
	D					D.L.	1.0	.40	D.L.	D.L.	.0007	D.L.	D.L.	D.L.
1/2/78	T	6.3	3	10.3	D.L.	D.L.	.9	.30	D.L.	D.L.	.0015	D.L.	D.L.	D.L.
	D					D.L.	1.0	.50	D.L.	.04	.0027	D.L.	D.L.	D.L.

NOTE: D.L. = detection limit; T = total; D = disolved; -- = no available.

*mg/l as CaCo3

TABLE A-9

SAMPLING DATA FOR Q_d CREEK

		pH	Water Temp. C	Alkali-nity*	Sulfate mg/l	Fe ppm	Ca ppm	Mg ppm	Mn ppm	Zn ppm	Pb ppm	Co ppm	Cd ppm	Al ppm
7/26/77	T	6.3	21	12.6	155	1.8	--	16.0	7.0	.11	D.L.	.047	D.L.	2.8
	D					--	--	--	--	--	--	--	--	--
8/22/77	T	5.0	21	2.1	350	2.5	60.0	77.0	46.0	.23	.0015	.250	.00003	D.L.
	D					2.0	61.0	77.0	44.0	.25		.250	.00003	D.L.
9/3/77	T	6.6	19	64.8	440	.4	121.0	95.0	45.0	D.L.	D.L.	.062	D.L.	D.L.
	D					.2	114.0	95.0	44.0	D.L.		.057	D.L.	D.L.
9/17/77	T	4.5	18	0	90	.6	12.5	10.0	3.5	D.L.	D.L.	.018	D.L.	D.L.
	D					.5	14.0	10.0	3.5	D.L.		.017	.00005	D.L.
10/1/77	T	6.2	18	15.7	135	.8	15.5	15.0	6.5	D.L.	D.L.	.043	D.L.	D.L.
	D					.5	16.0	14.0	6.5	D.L.		.038	D.L.	D.L.
10/15/77	T	6.6	10	13.3	105	1.0	14.5	11.0	5.5	D.L.	.0010	.039	D.L.	D.L.
	D					.6	14.5	13.0	5.0	D.L.		.033	.00005	D.L.
10/29/77	T	6.8	13	15.0	83	.7	12.5	10.0	4.0	D.L.	D.L.	.024	D.L.	D.L.
	D					.4	12.5	10.0	4.0	D.L.		.024	D.L.	D.L.
11/13/77	T	6.2	8.0	12.0	51	.6	11.0	10.0	.1	.04	D.L.	.022	D.L.	D.L.
	D					.4	10.4	9.4	.2	.05		.019	.00003	D.L.
11/26/77	T	6	7	28.2	52	.5	10.1	9.0	.1	.07	.0011	.018	.00003	D.L.
	D					.3	9.4	8.7	.1	D.L.		.017	.00003	D.L.
12/10/77	T	5.9	2	12.9	54	.8	10.2	10.2	.1	D.L.	.0032	.024	.0001	D.L.
	D					.6	10.6	10.0	.2	D.L.		.024	.00015	D.L.
1/2/78	T	6.2	4	28.0	59	1.0	12.4	11.1	.3	D.L.	D.L.	.025		D.L.
	D					.7	13.0	11.0	.3	D.L.		.026		D.L.

NOTE: D.L. = detection limit; T = total, D = dissolved; -- = not available.

*mg/l as CaCo3

TABLE A-10

SAMPLING DATA FOR RANGER$_d$ 1 CREEK

		pH	Water Temp. C	Alkali-nity*	Sulfate mg/l	Fe ppm	Ca ppm	Mg ppm	Mn ppm	Zn ppm	Pb ppm	Co ppm	Cd ppm	Al ppm
7/26/77	T	3.1	21	0	310	9	39.0	55.0	22.5	.12	.0017	.325	.00004	3.8
	D					--	--	--	--	--	--	--	--	--
8/22/77	T	3.5	23	0	340	8.8	46.0	62.0	25.5	.12	.0027	.365	.00005	3.3
	D					8.8	45.5	62.0	25.0	.12		.340	.00006	3.3
9/3/77	T	3.5	23	0	395	10.8	49.0	68.0	27.0	.09	.0013	.375	.00004	3.3
	D					10.6	49.0	68.0	26.0	.48		.375	.00009	3.3
9/17/77	T	3.5	21	0	265	5.4	24.5	35.0	14.5	.11	.0007	.215	.00009	--
	D					.5	23.5	34.0	14.0	.12		.210	.00014	--
10/1/77	T	2.6	19	0	240	3.8	24.0	36.0	14.0	.08	.0026	.225	.00004	2.8
	D					3.8	24.0	34.0	14.0	.12		.220	.00005	2.8
10/15/77	T	3.6	12	0	158	4.2	23.0	34.0	13.5	.12	D.L.	.215	.00003	2.3
	D					4.1	22.5	34.0	13.5	.08		.215	.00006	2.8
10/29/77	T	3.8	12	0	208	2.4	16.0	24.0	9.5	.08	.0005	.135	.00003	2.3
	D					2.3	16.0	24.0	9.5	.11		.140	.00003	1.9
11/13/77	T	3.5	7	0	158	2.9	17.8	33.6	12.1	.08	.0004	.175	D.L.	2.3
	D					2.7	17.8	31.4	11.7	.11		.175	.00005	2.3
11/26/77	T	3.4	6	0	180	2.8	22.0	38.8	14.2	.18	D.L.	.230	.00003	D.L.
	D					2.6	20.5	38.6	13.9	.15		.260	.00013	1.9
12/10/77	T	3.4	2	0	250	5.0	33.5	60.3	21.7	.24	.0004	.365	.00005	2.8
	D					5.4	33.0	57.8	20.3	.21		.340	.00009	2.3
1/2/78	T	3.4	4	0	223	4.3	27.0	50.3	18.0	.12	D.L.	.280	.00008	2.8
	D					4.6	25.5	49.1	16.7	.16		.265	.00015	2.3

NOTE: D.L. = detection limit; T = total; D = disolved; -- = not available.

*mg/l as CaCo3

TABLE A-11

SAMPLING DATA FOR RANGER$_d$ 2 CREEK

		pH	Water Temp. C	Alkali-nity*	Sulfate mg/l	Fe ppm	Ca ppm	Mg ppm	Mn ppm	Zn ppm	Pb ppm	Co ppm	Cd ppm	Al ppm
7/26/77	T	5.5	25	2.1	175	.4	26.0	22.0	8	.12	.0008	.069	.00006	D.L.
	D					--	--	--	--	--	--	--	--	--
8/22/77	T	4.5	26	0	190	1.8	20.5	22.0	10.5	.17	.0001	.107	.00007	2.3
	D					.3	21.5	23.0	9.5	.18	--	.092	.00008	2.3
9/3/77	T	4.5	24	0	165	.5	21.0	23.0	9.5	.14	.0011	.097	.00006	2.3
	D					.4	21.0	23.0	9.5	.12	--	.093	.00006	2.3
9/17/77	T	5.1	22	0	160	1.3	18.5	19.0	9.7	.11	.0020	.102	.00005	2.3
	D					.5	20.0	18.0	7.7	.11	--	.080	.00005	D.L.
10/1/77	T	3.4	19	0	170	.4	20.0	23.0	9.7	.12	.0019	.098	.00006	2.8
	D					.2	20.0	21.0	9.5	.11		.091	.00004	2.3
10/15/77	T	4.0	14	0	138	.4	17.0	20.0	7.5	.08	D.L.	.085	.00002	2.3
	D					.4	16.5	19.0	8.0	.12		.085	D.L.	2.3
10/29/77	T	4.2	13	0	63	.4	15.5	18.0	7.5	.1	.0022	.084	D.L.	2.3
	D					.3	15.0	17.0	6.7	.07		.083	D.L.	2.3
11/13/77	T	4.2	12	0	85	.4	11.2	16.1	5.9	.11	.0021	.068	D.L.	1.9
	D					.3	10.6	15.8	5.8	.05		.068	D.L.	2.3
11/26/77	T	4.6	9	0	82.5	.5	7.2	11.5	4.4	.06	.0020	.058	D.L.	1.9
	D					.3	6.2	11.0	4.1	.08		.051	.00025	2.3
12/10/77	T	4.0	6	0	95	.4	8.8	13.9	5.1	.1	.0026	.062	.00003	2.3
	D					.3	9.2	13.9	5.0	.09		.064	.00005	2.3
1/2/78	T	4.0	4	0	108	.5	10.8	18.3	6.8	.12	.0008	.082	.00005	2.3
	D					.5	10.8	17.9	6.3	.13		.080	.00006	2.3

NOTE: D.L. = detection limit; T = total; D = dissolved; -- = not available.

*mg/l as CaCo3

APPENDIX B

SAMPLING DATES

The following sampling dates correspond to the identifying numbers for the figures in this appendix.

Identifying number	Sample date
203	July 22, 1977
238	August 26, 1977
246	September 3, 1977
260	September 17, 1977
274	October 1, 1977
288	October 15, 1977
302	October 29, 1977
317	November 13, 1977
330	November 26, 1977
344	December 10, 1977
367	January 2, 1978

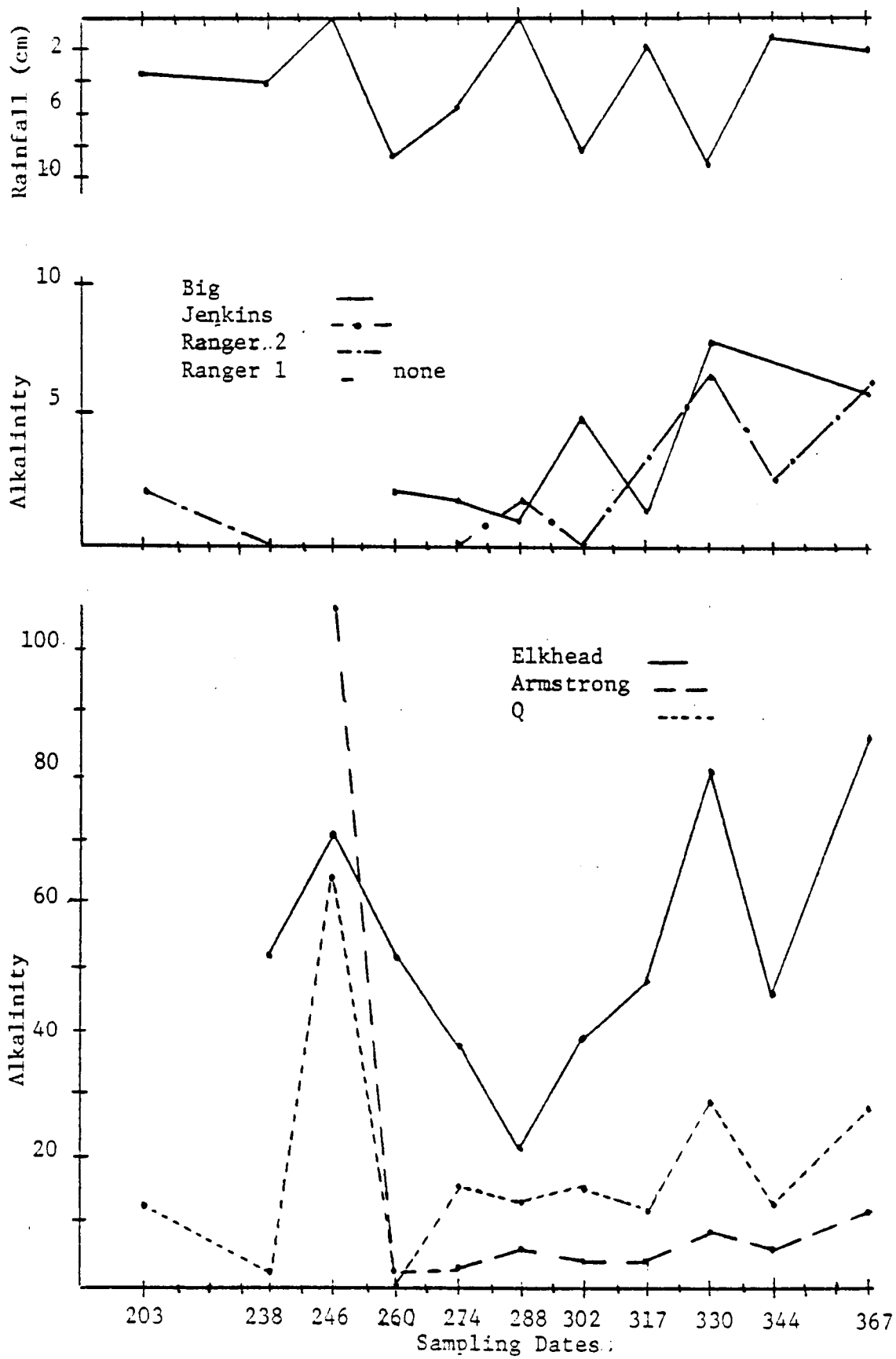


Figure B-1. Alkalinity as mg/l $CaCo_3$

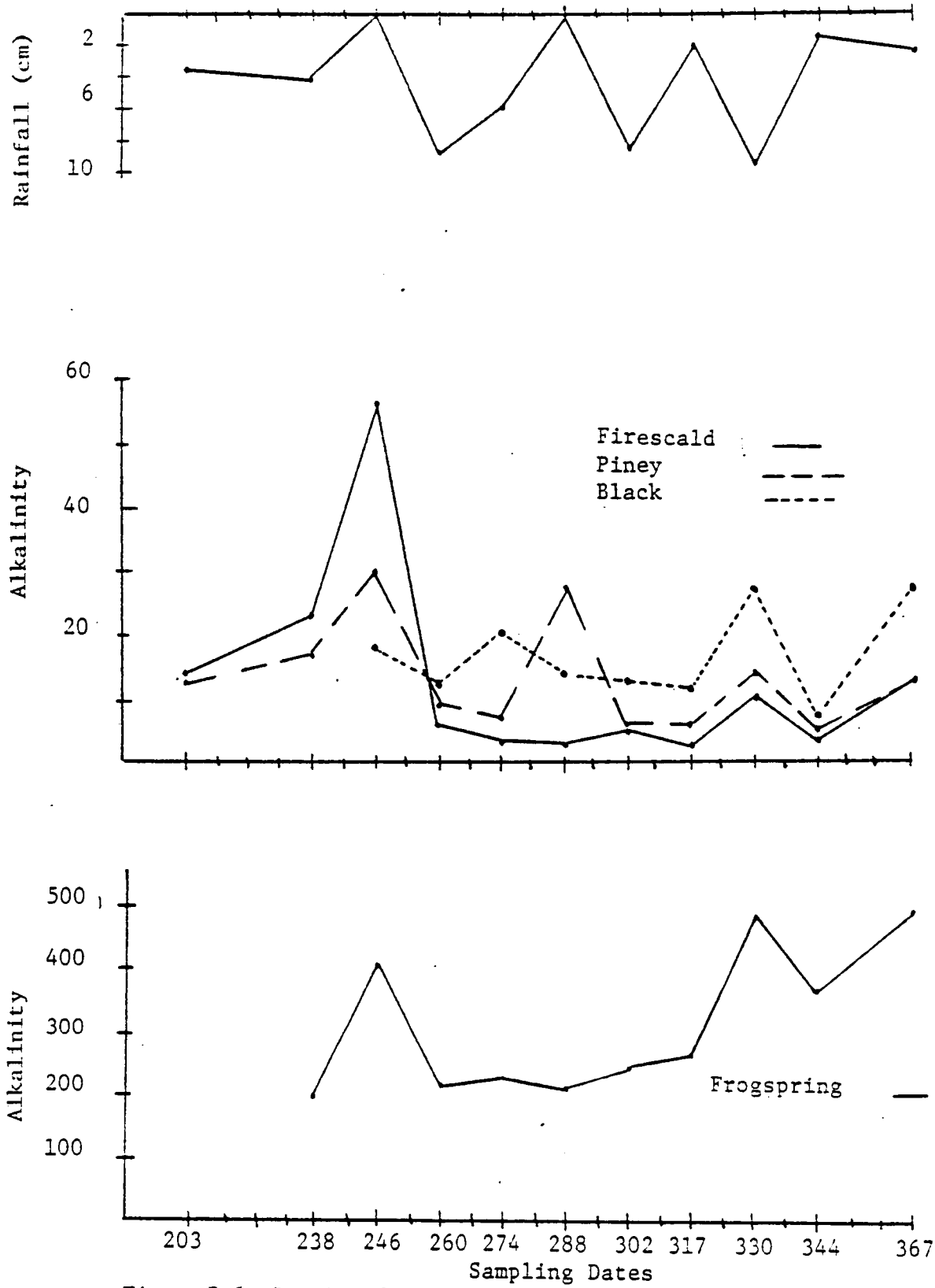


Figure B-1 Continued

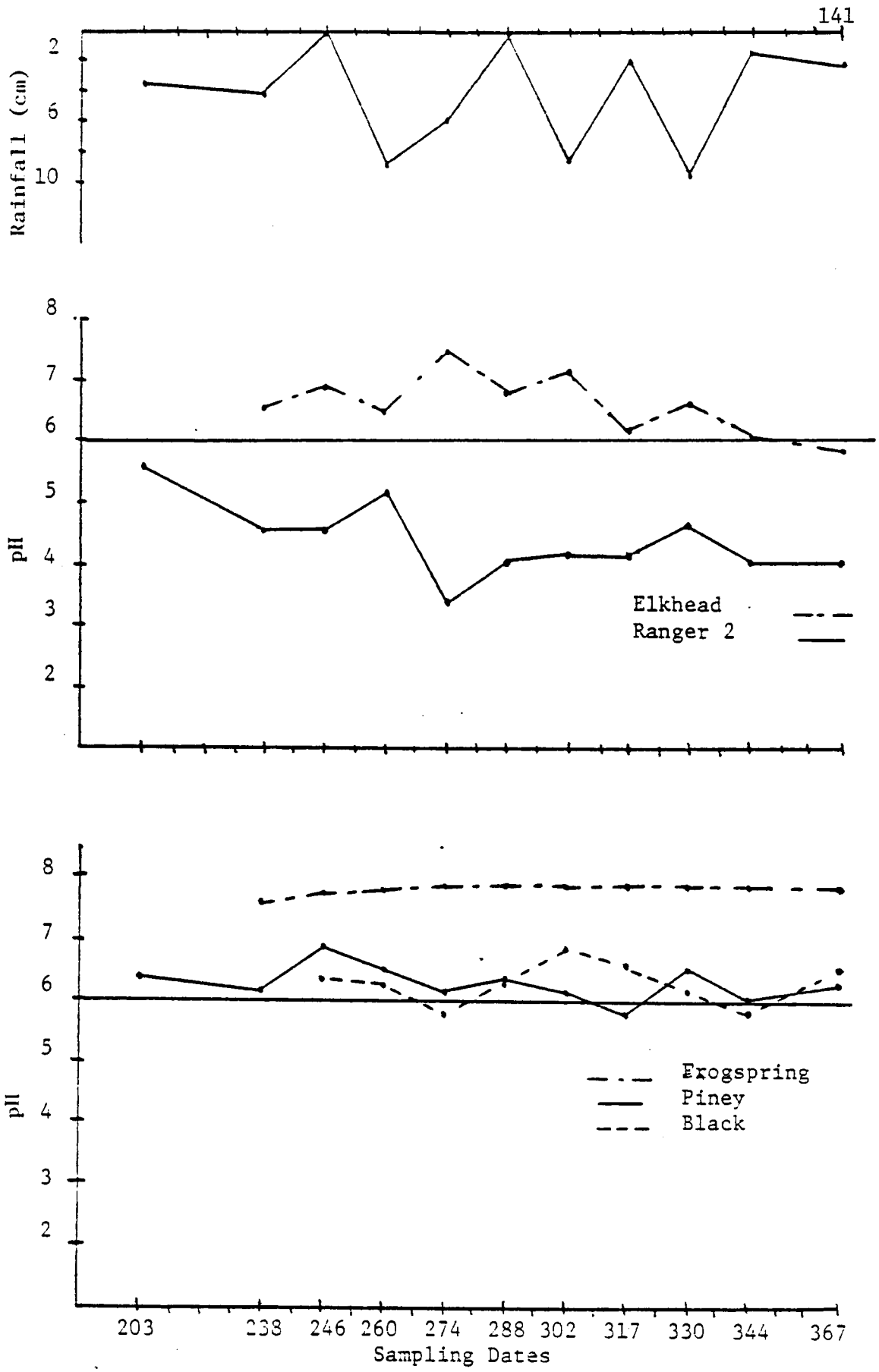

Rainfall (cm)
2
6
10
pH
8
7
6
5
4
3
2
Elkhead
Ranger 2
Frogspring
Piney
Black
203
238
246
260
274
288
302
317
330
344
367
Sampling Dates

Figure B-2 pH

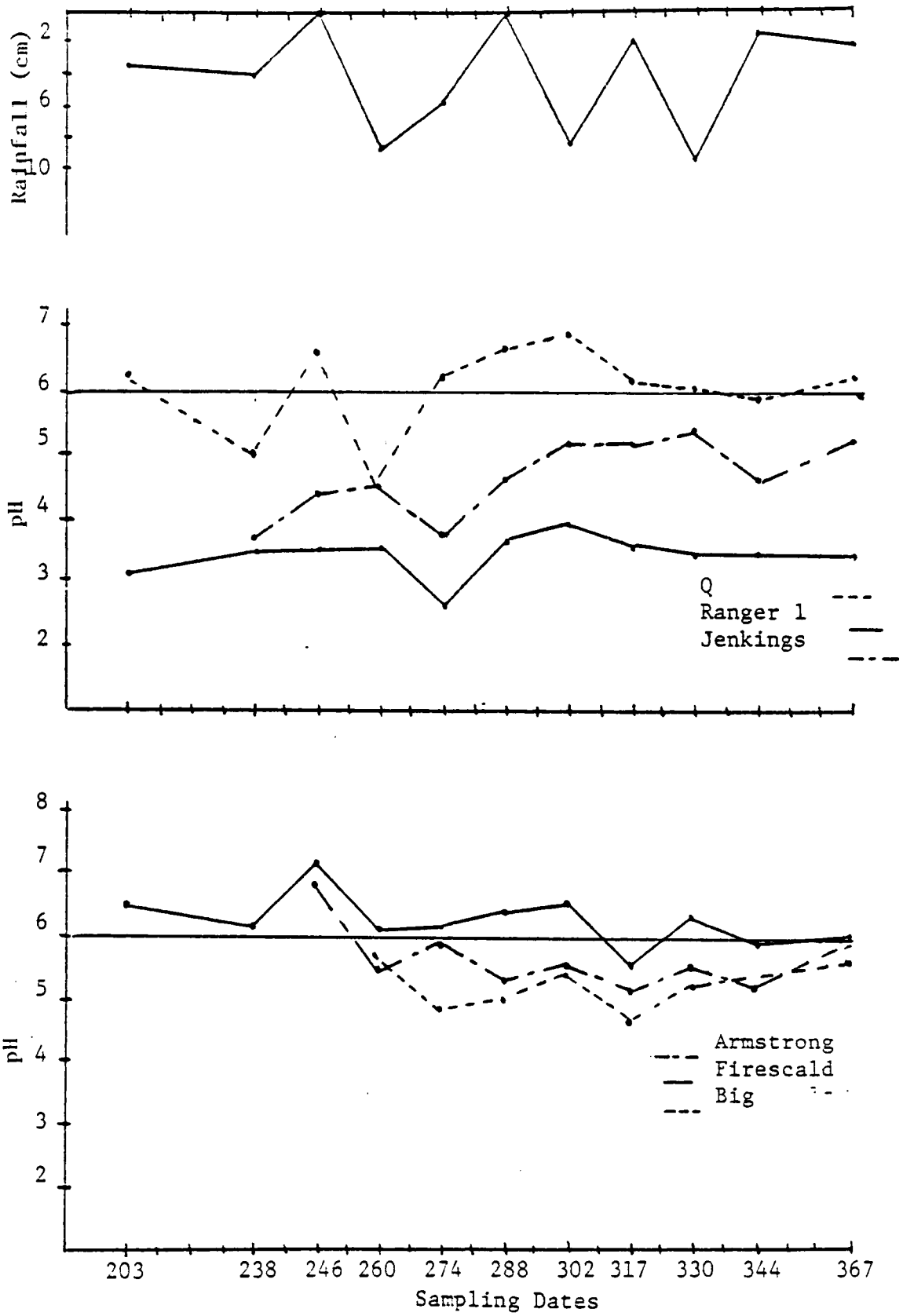


Figure B-2 Continued

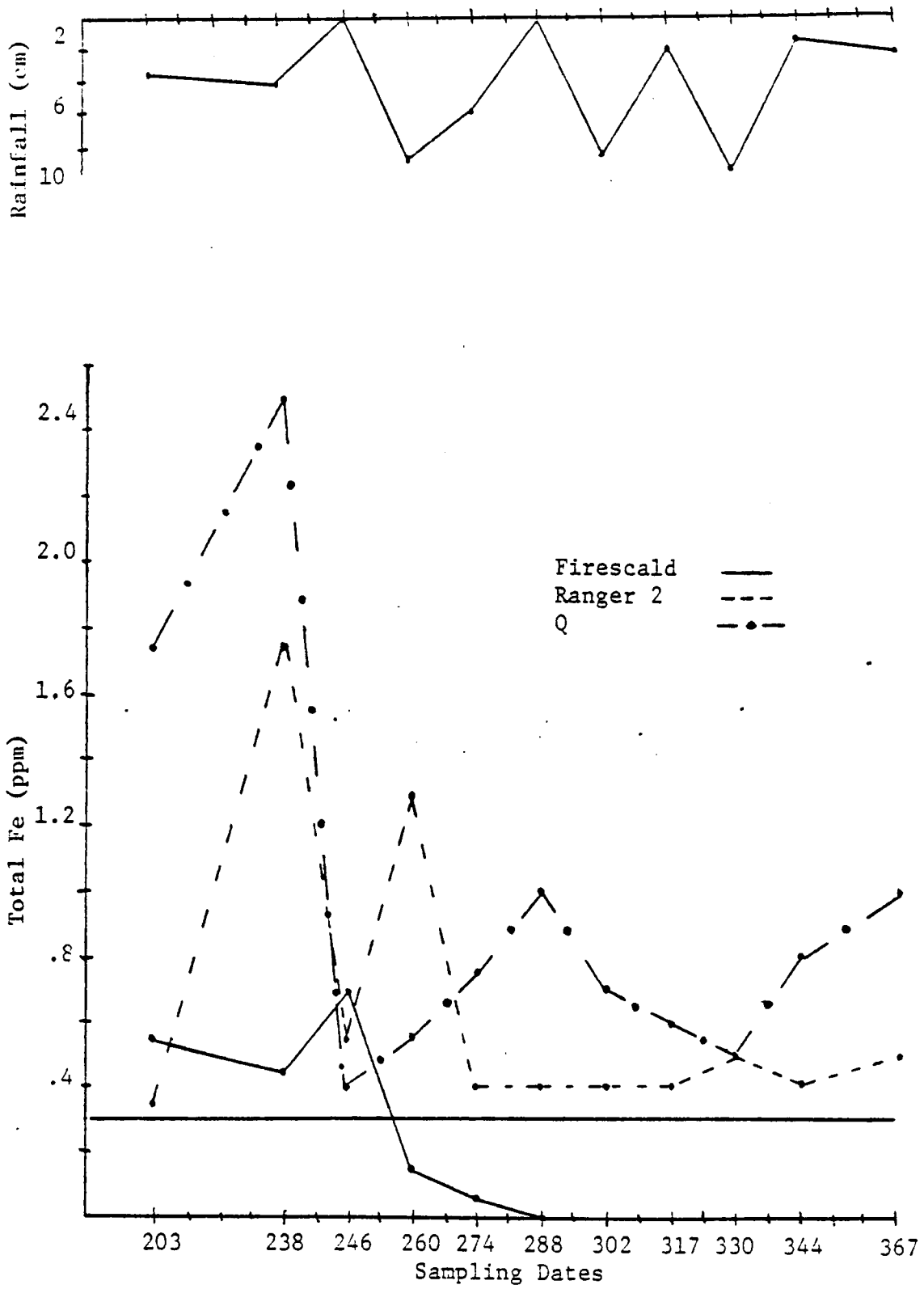


Figure B-3 Total Iron

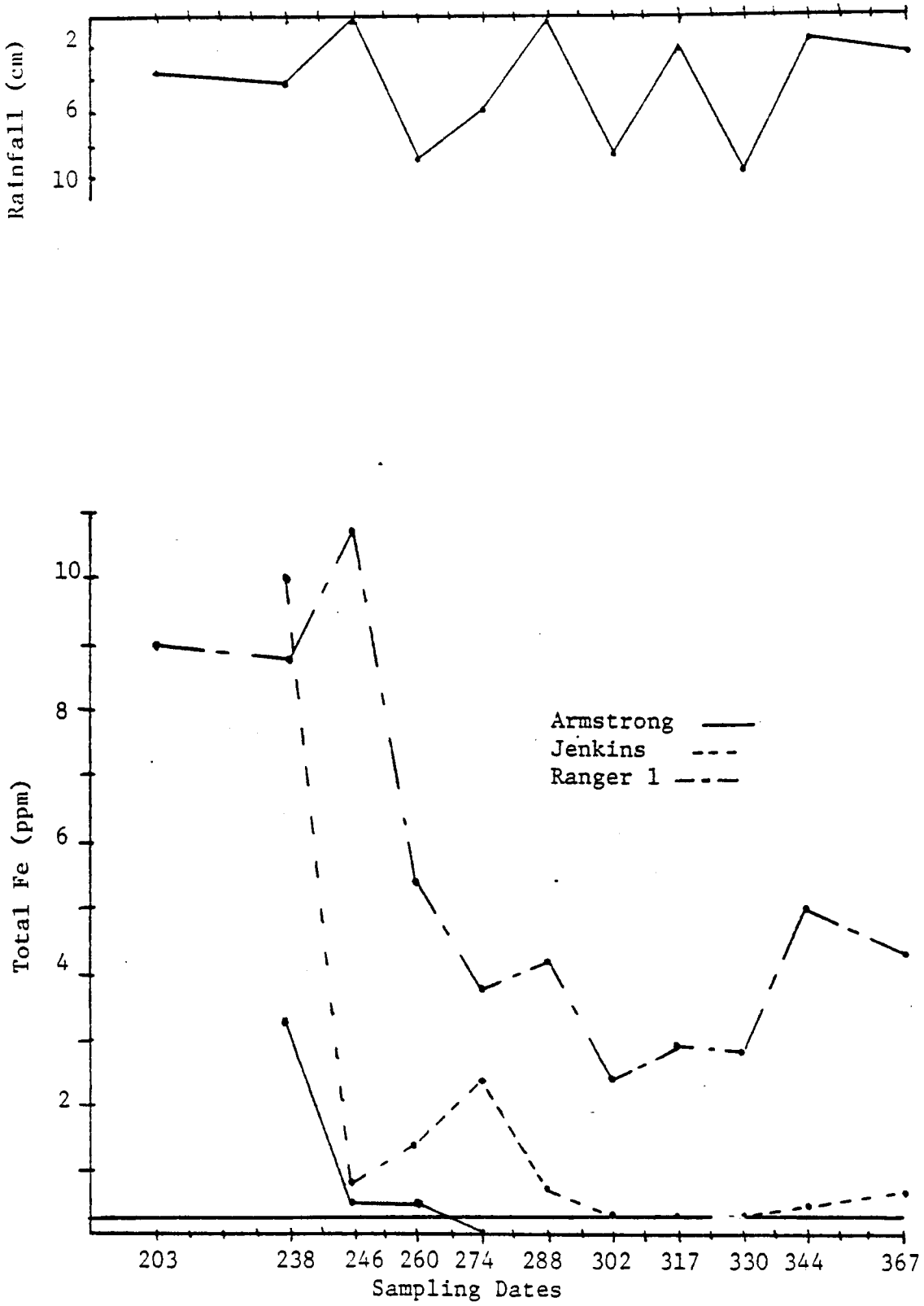


Figure B-3 Continued

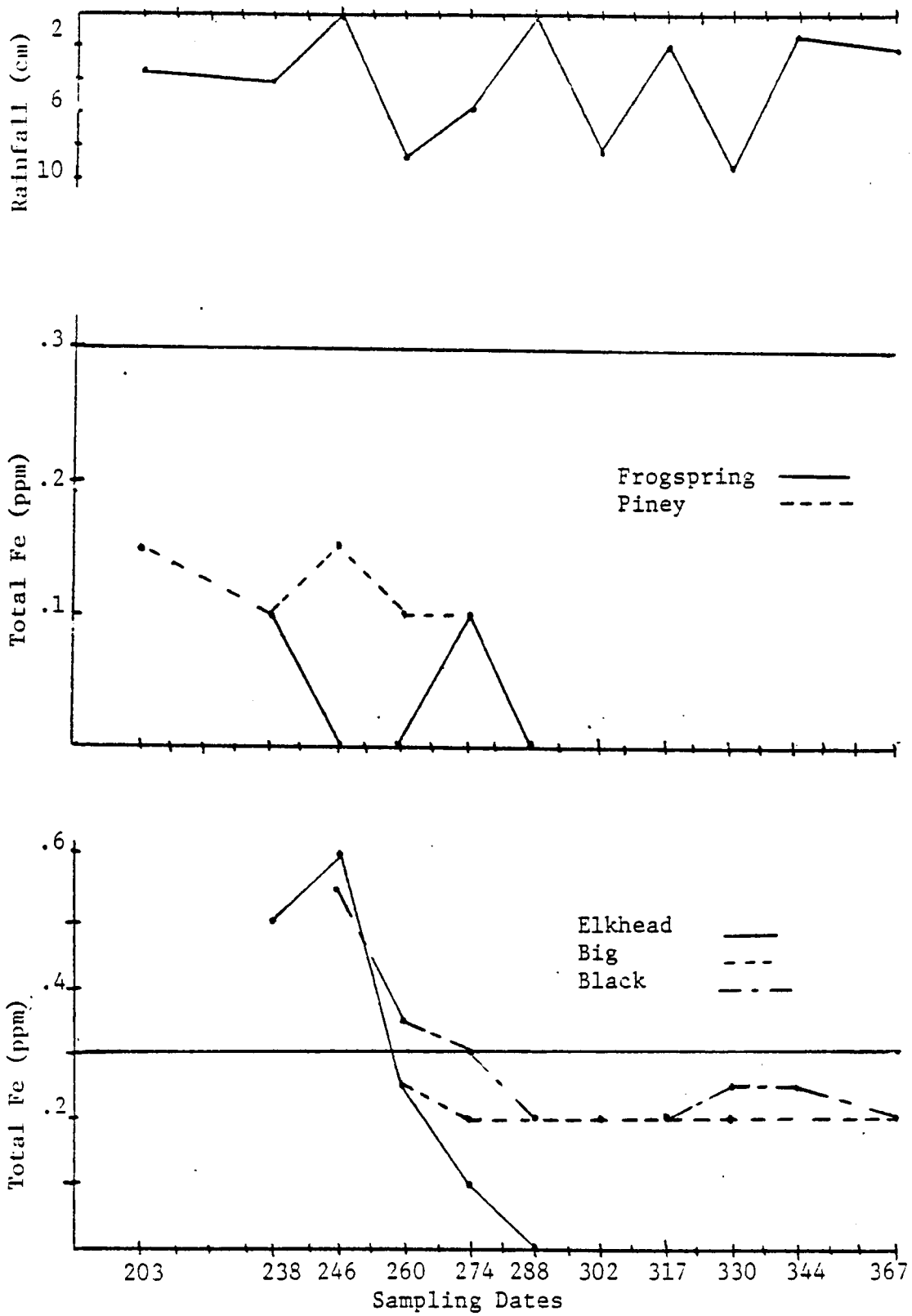


Figure B-3 Continued

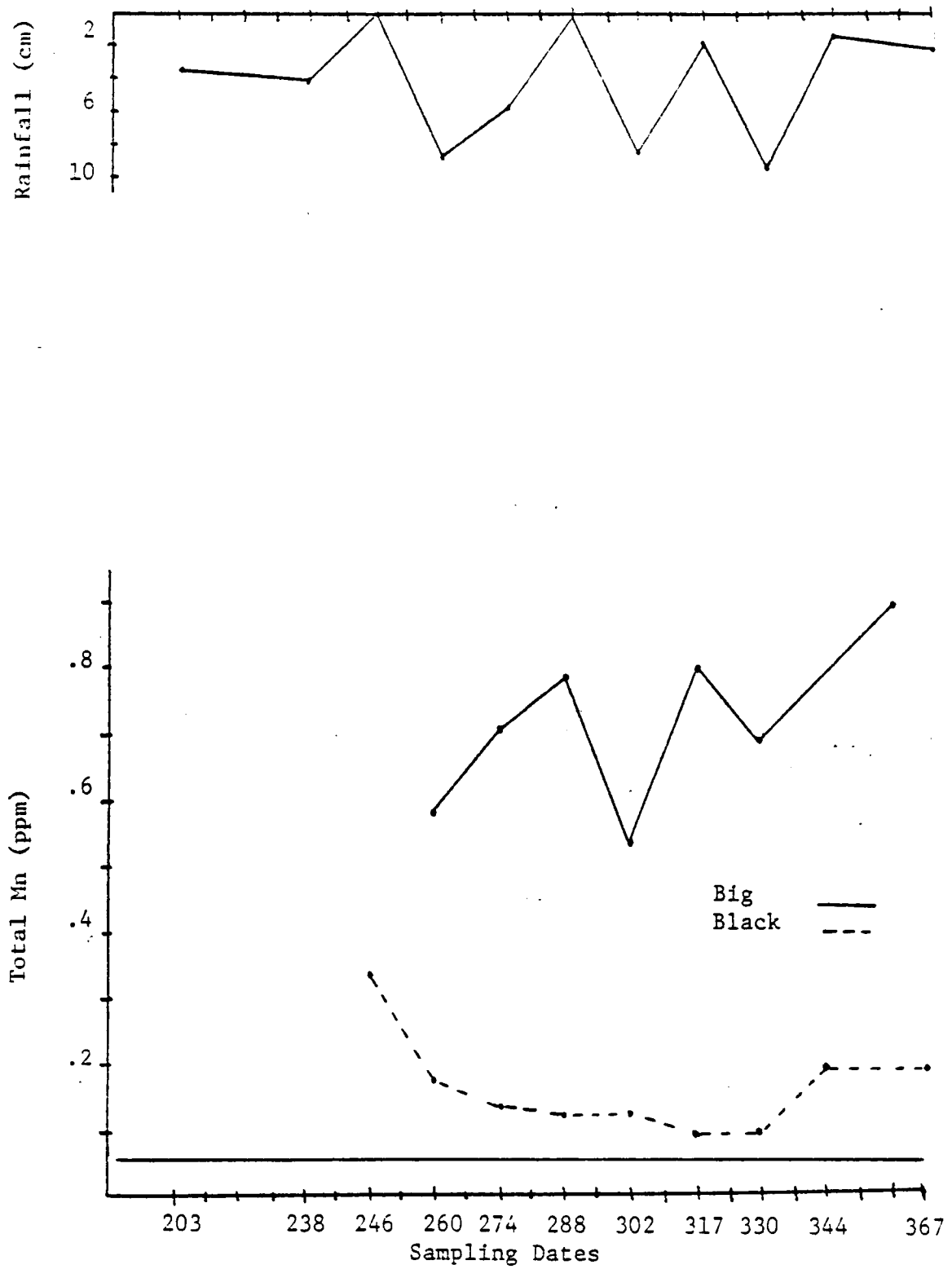


Figure B-4 Mn (total)

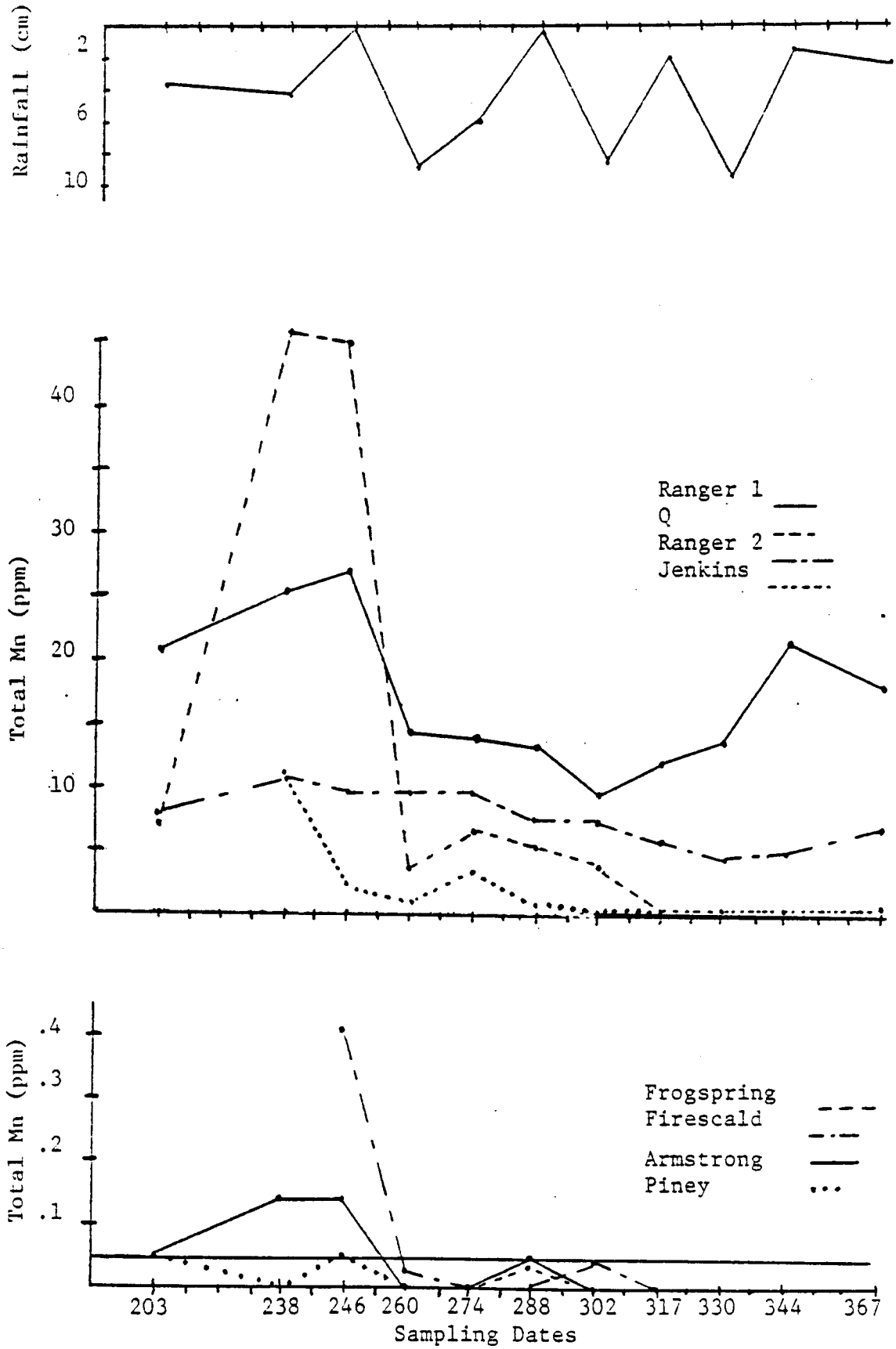


Figure B-4 Continued.

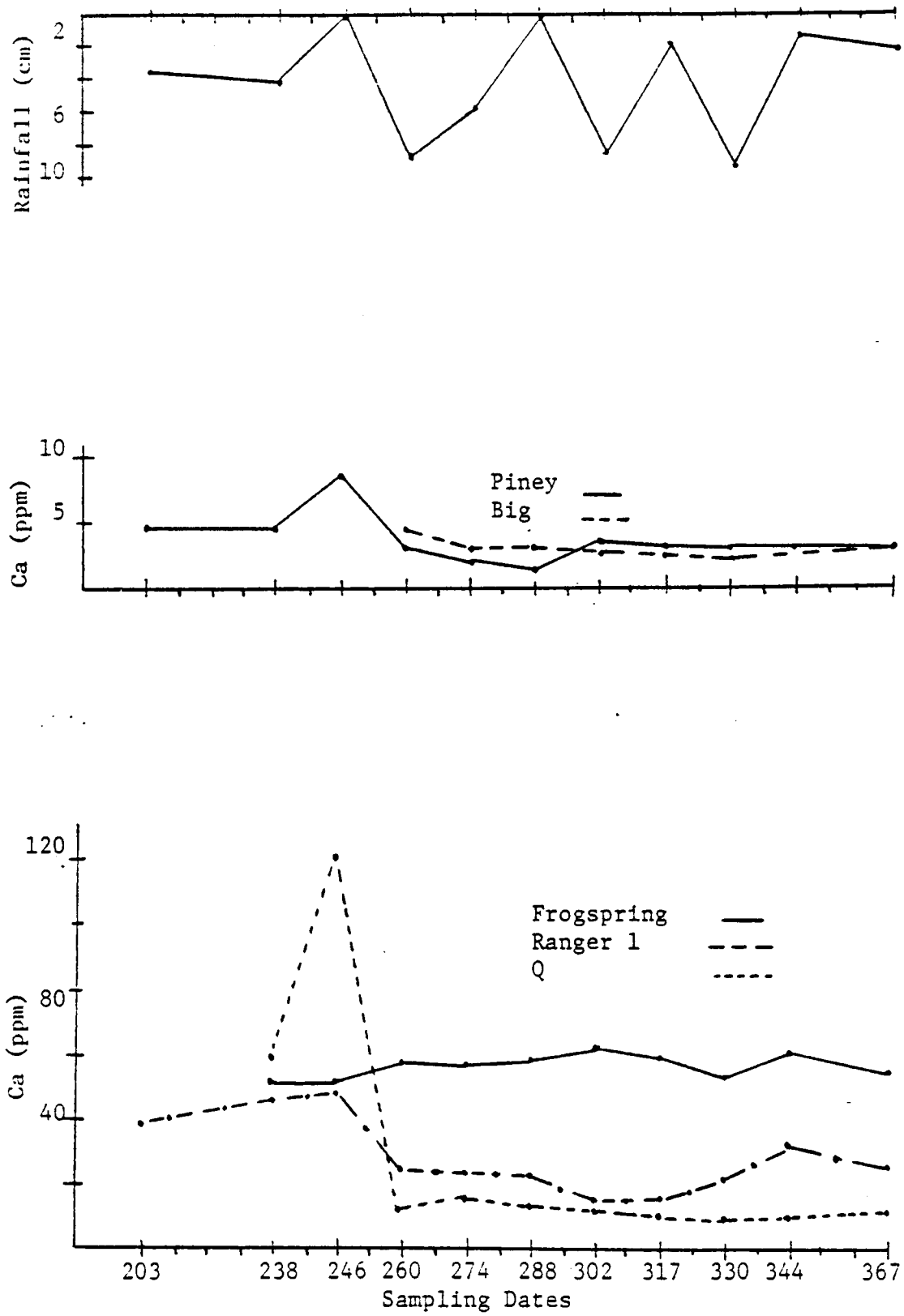


Figure B-5 Total Calcium

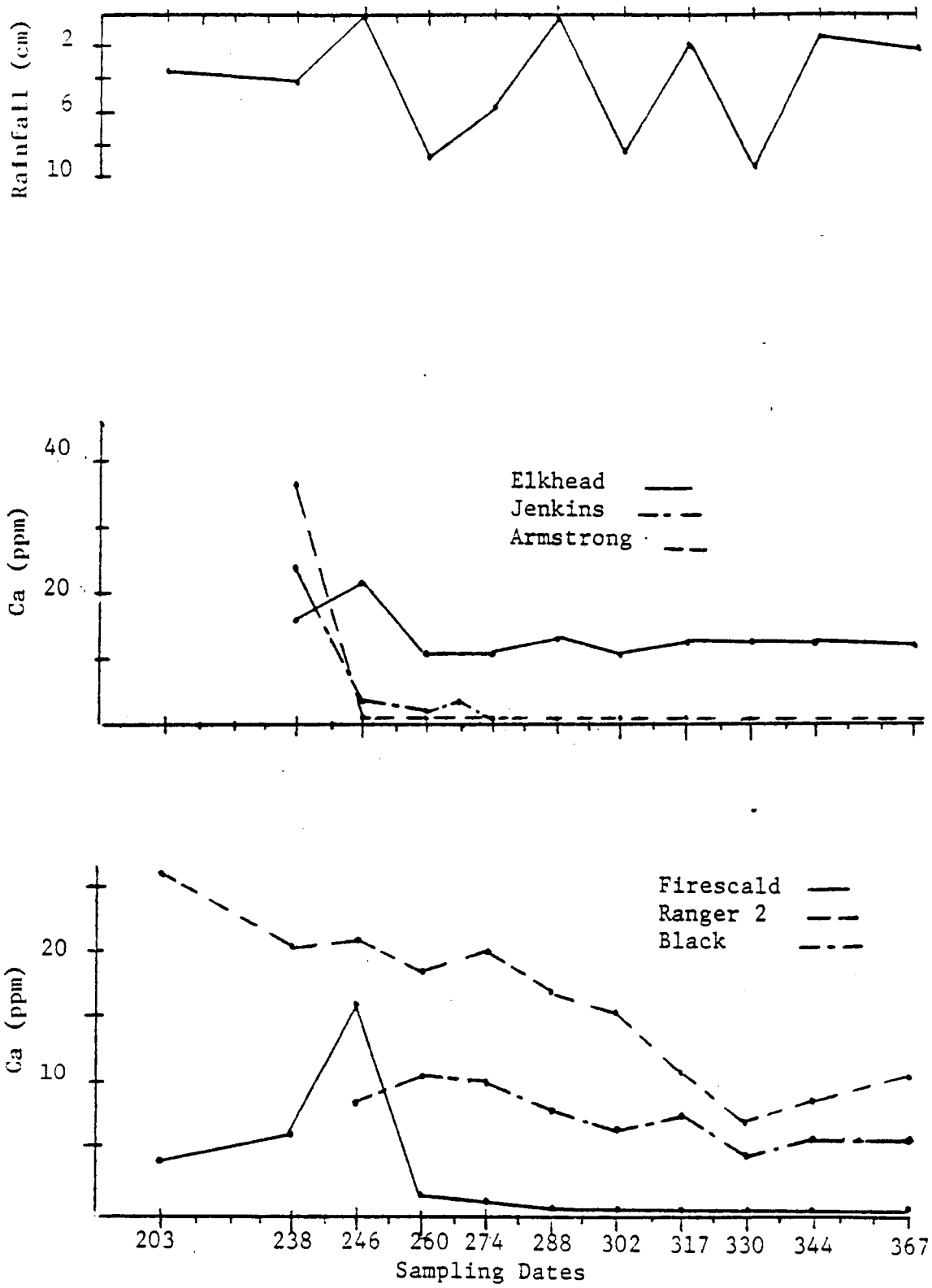


Figure B-5 Continued

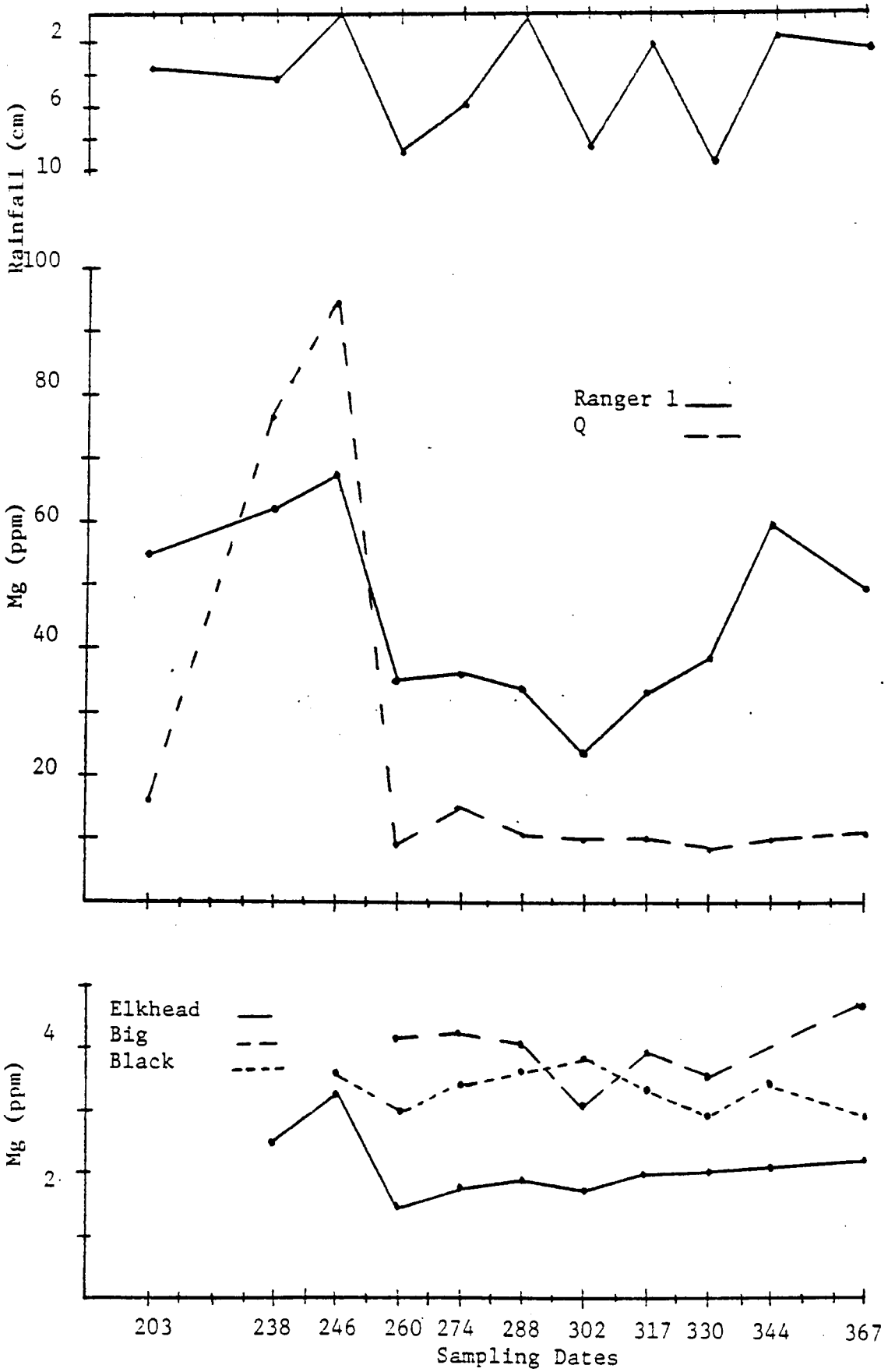


Figure B-6 Total Mg

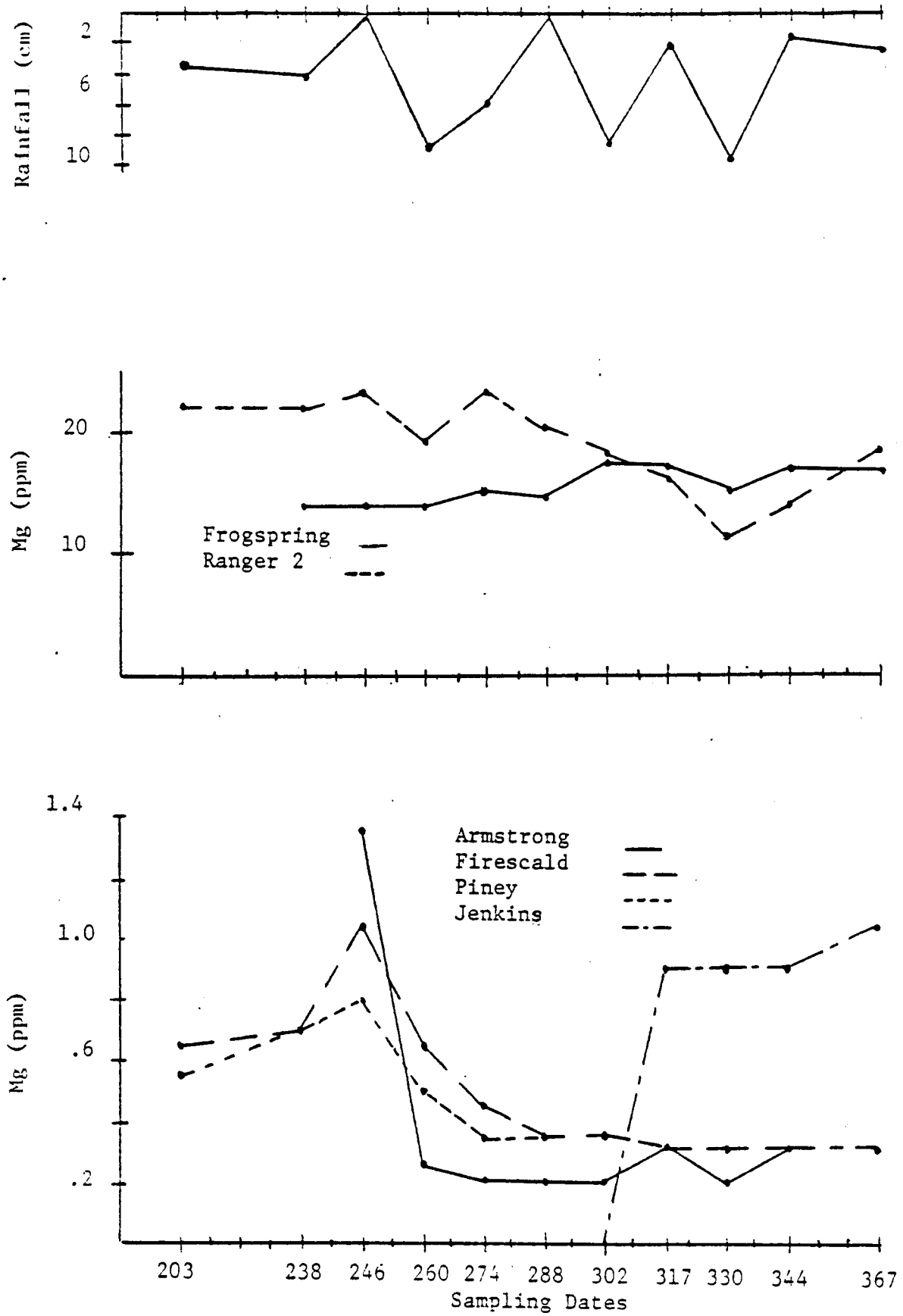


Figure B-6 Continued

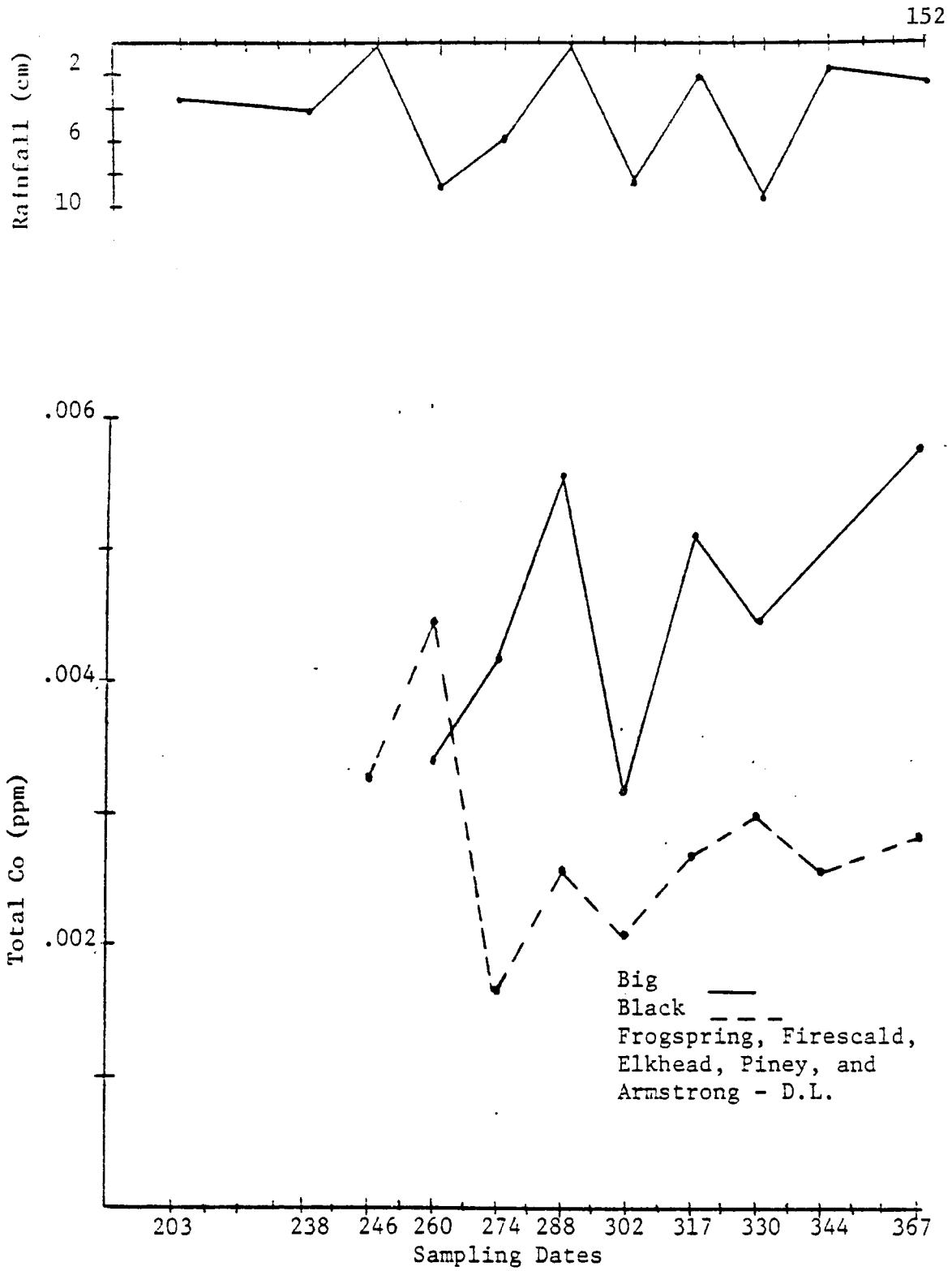


Figure B-7 Total Cobalt

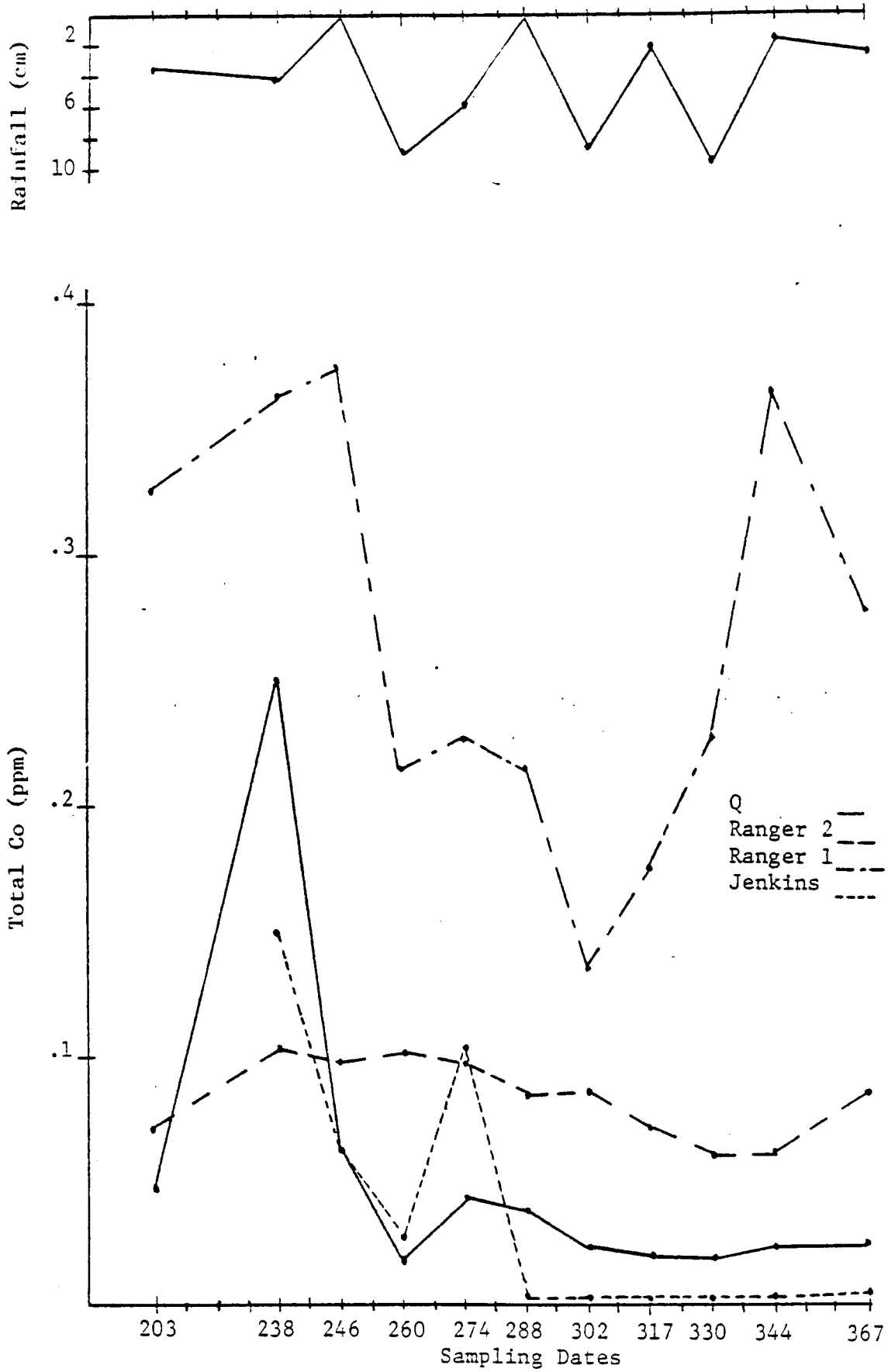


Figure B-7 Continued

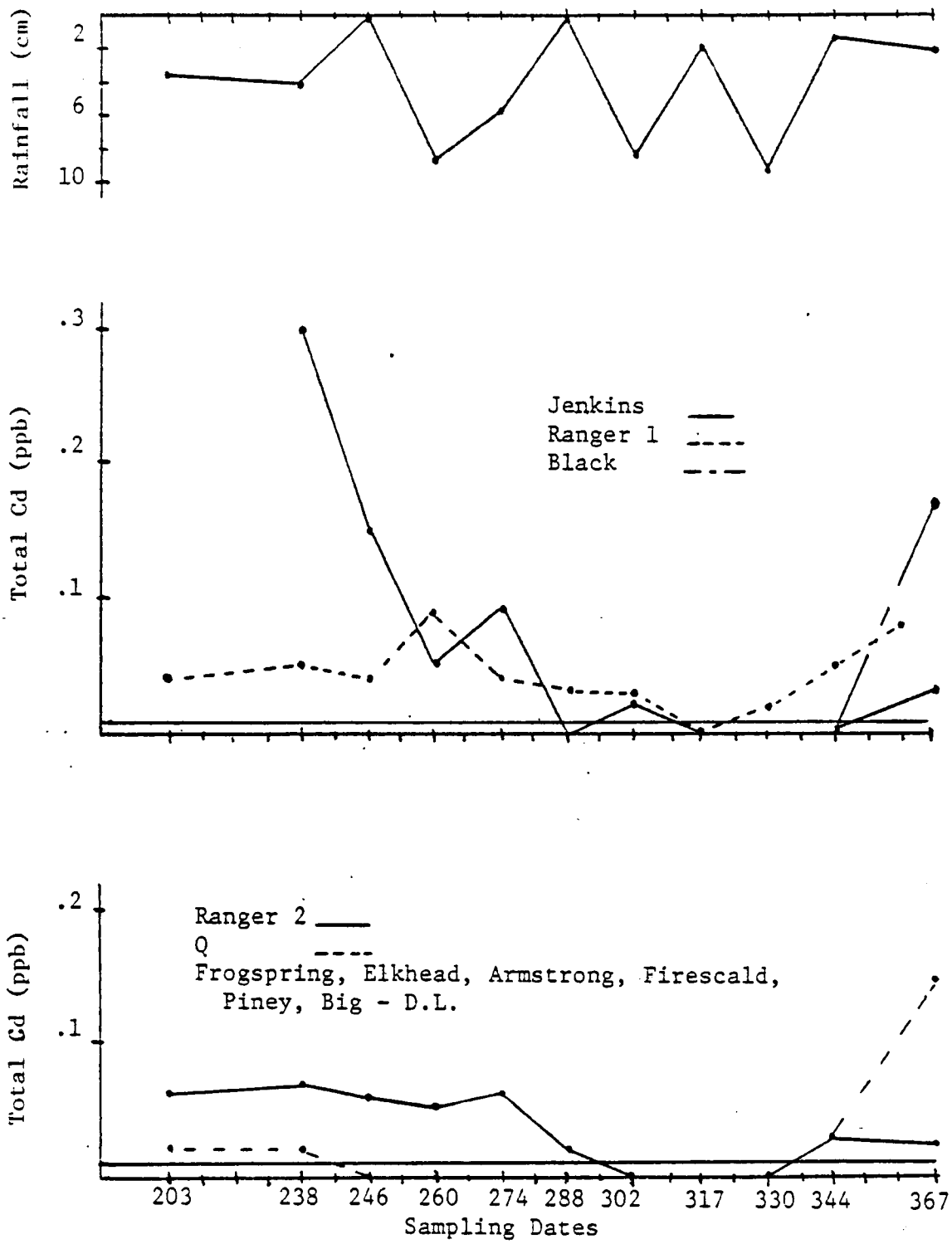


Figure B-8 Total Cd

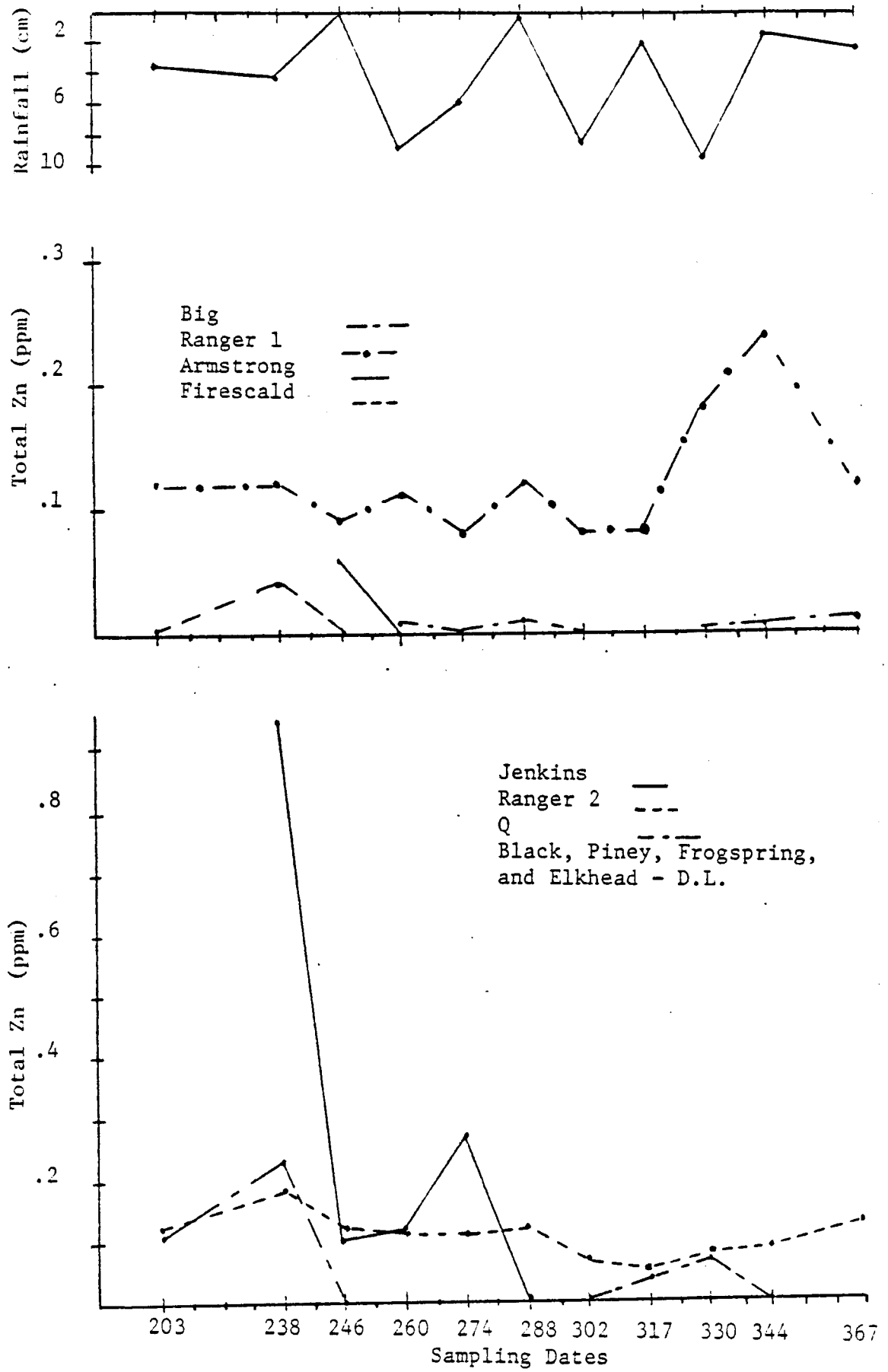
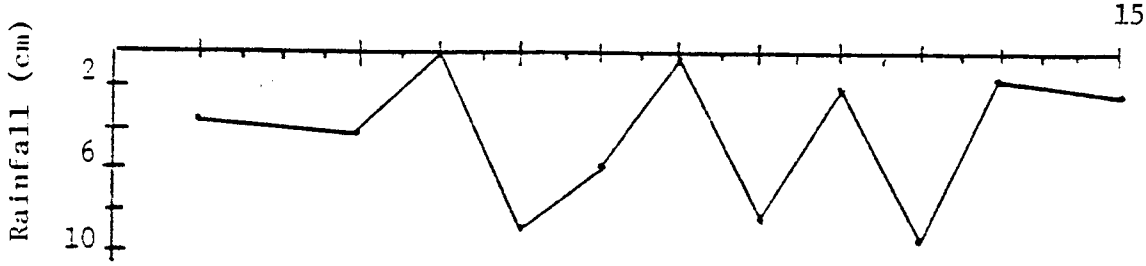


Figure B-9 Total Zn.



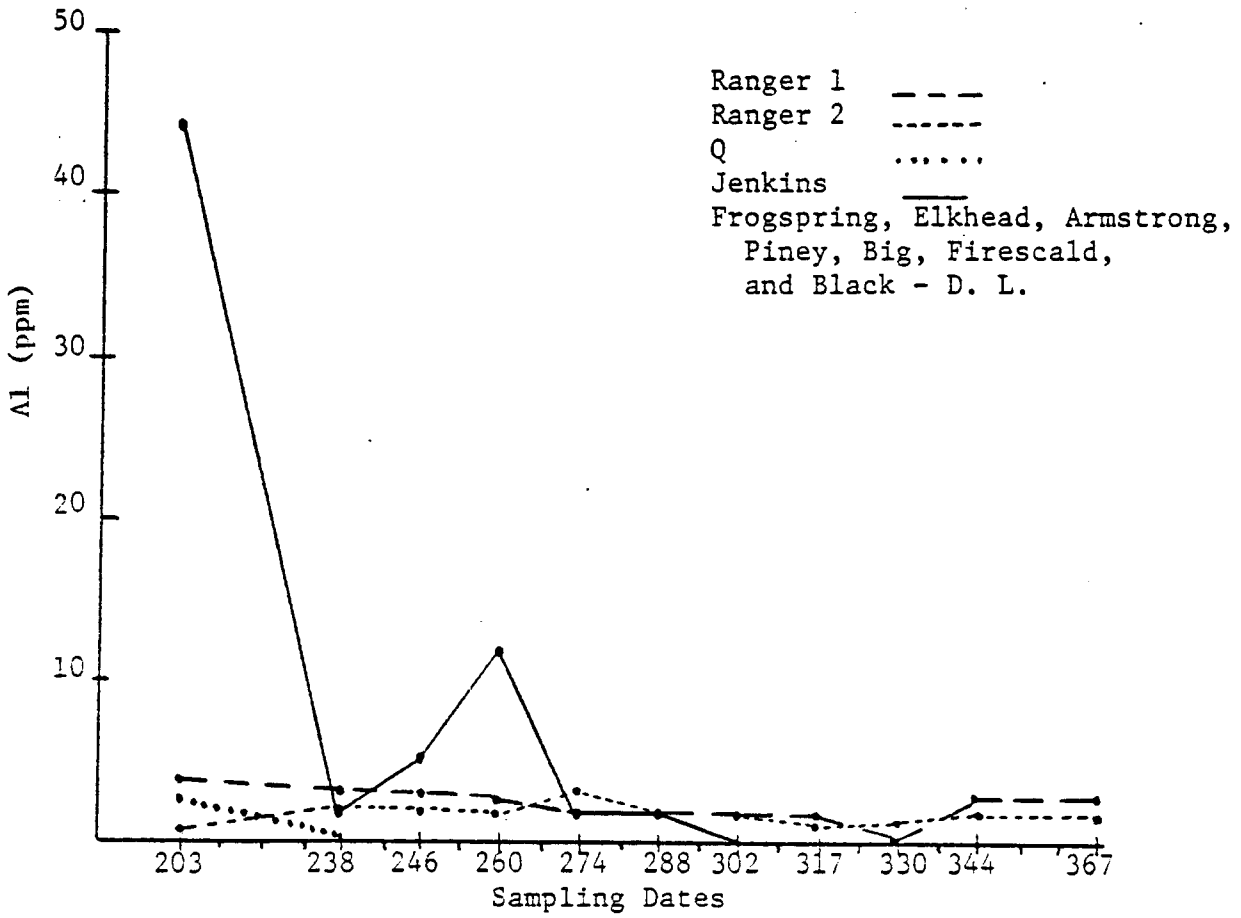


Figure B-10Total Aluminum.

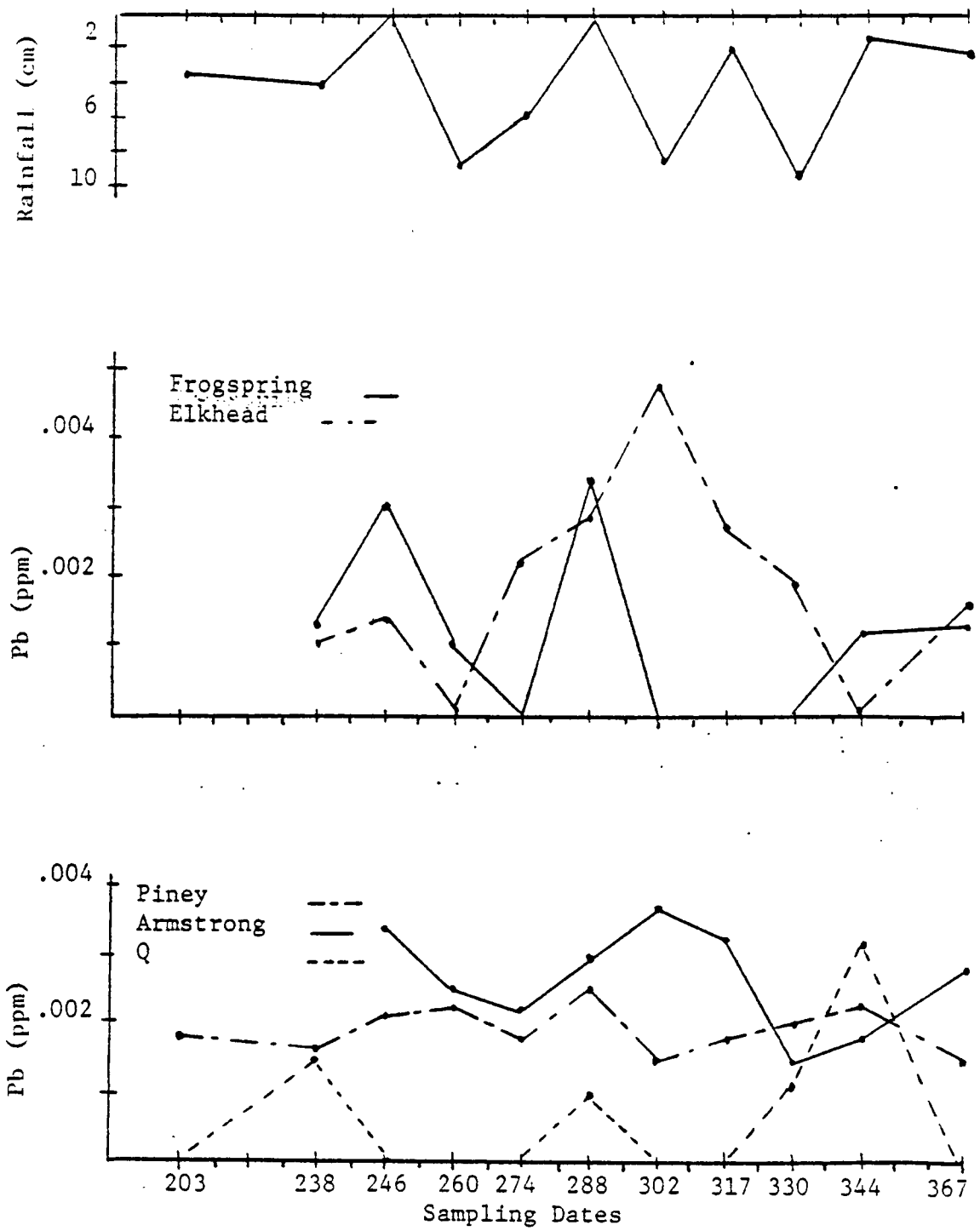
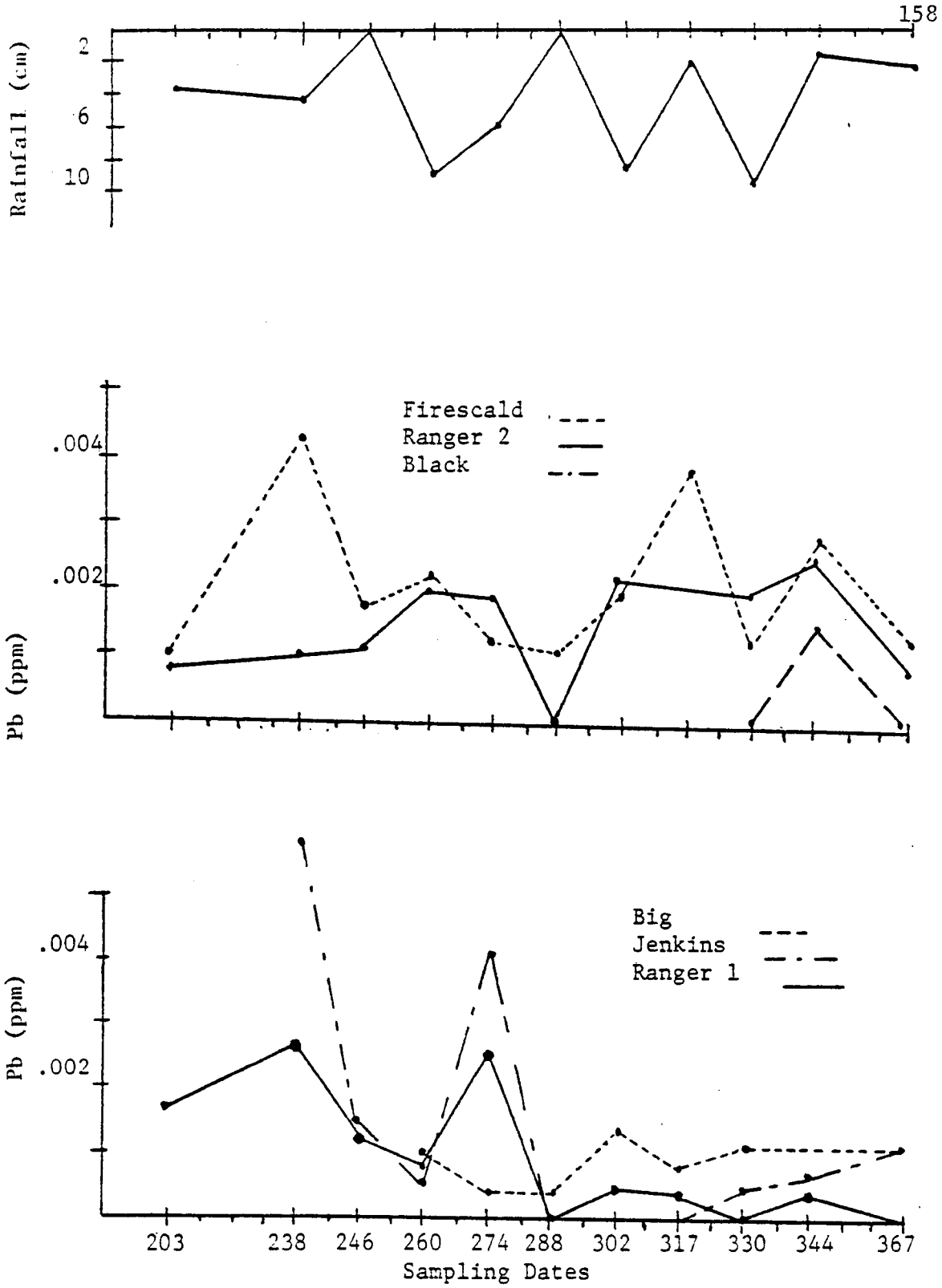


Figure B-11 Total Lead



FigureB-11 Continued

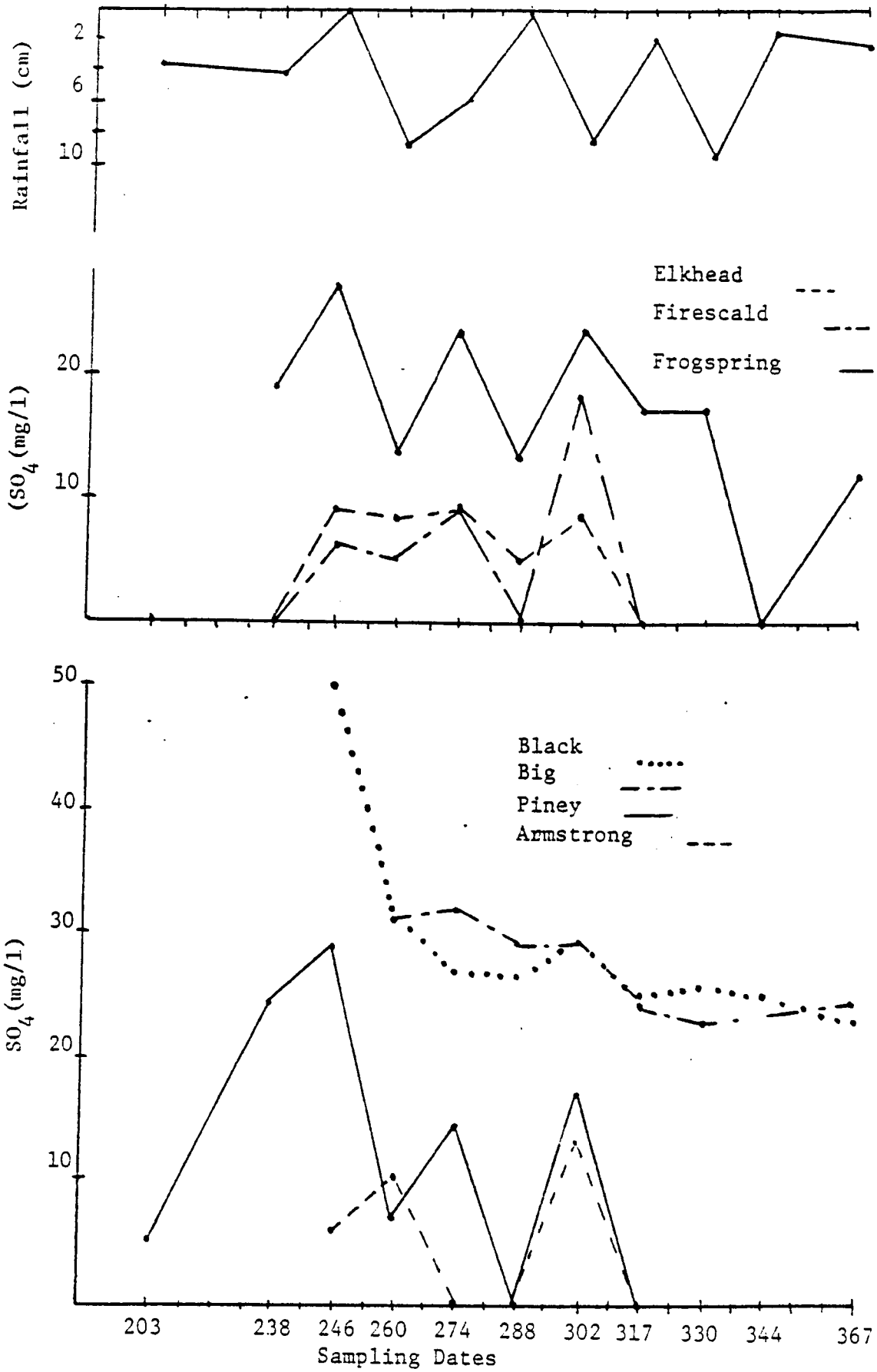


Figure B-12 SO_4

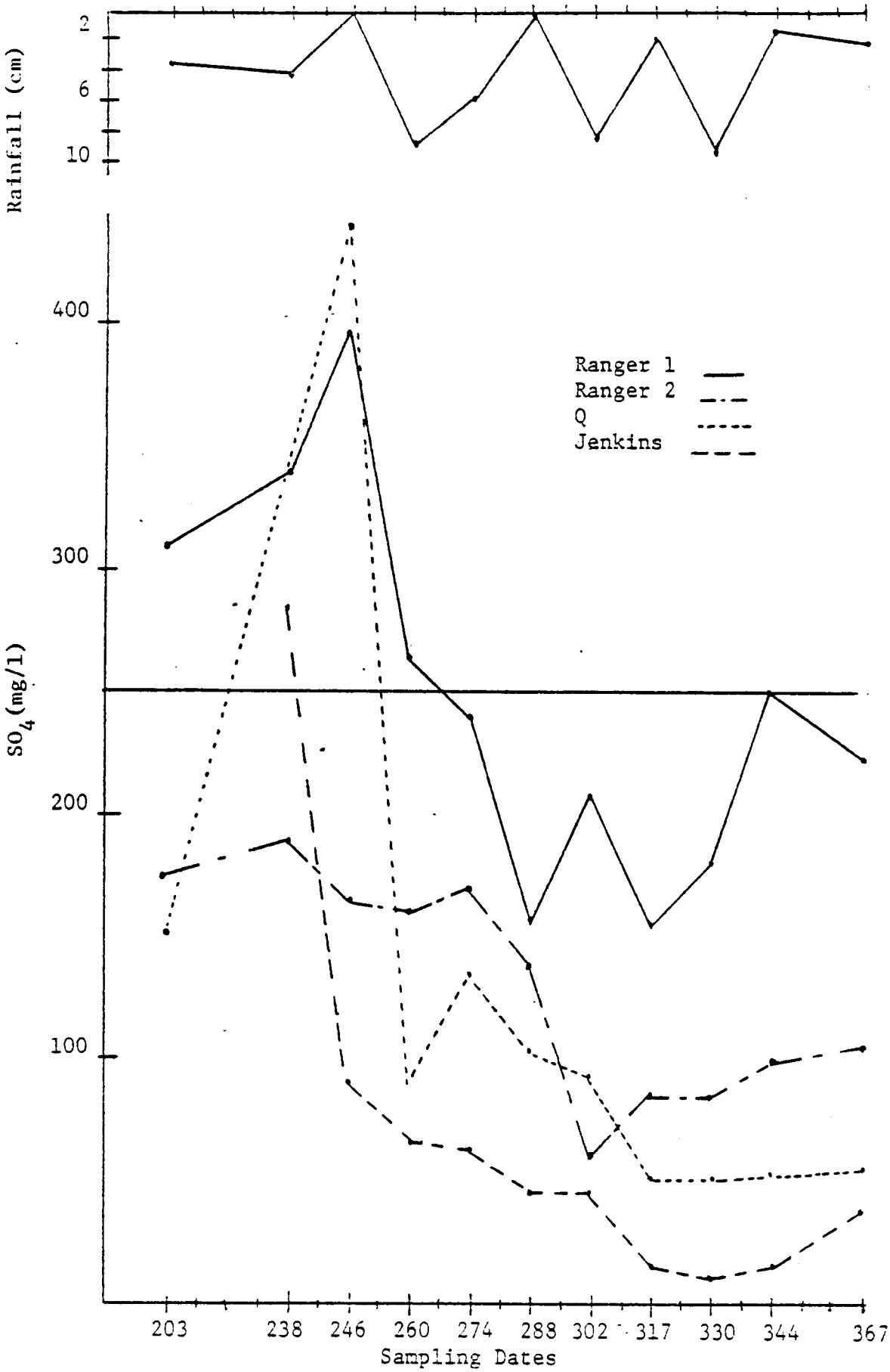


Figure B-12 Continued

APPENDIX C

SUMMARY OF RESULTS OF TWO WAY ANALYSIS OF VARIANCE

	df	SS	MS	F_s[a]
pH				
Among Streams	10	2,670,271.134	267,027.1	*10,854,0
Dates	10	109,344.78	10,934.5	*444.0
Within	100	2,460.39	24.6	
ALKALINITY				
Among Streams	10	821,140.4	82,114	*64.86
Dates	10	19,761,7	1,976	1.56 N.S.
Within	100	126,604.1	1,266	
Fe				
Among Streams	10	286	28.6	*30.8
Dates	10	82.21	8.22	*8.8
Within	100	93.5	.935	
Ca				
Among Streams	10	29,981.9	2,998.2	*32.17
Dates	10	5,105.4	510.5	*5.48
Within	100	9,318.8	93.19	
Mg				
Among Streams	10	2,239.5	2,239.5	*23.6
Dates	10	2,586.5	2,58.7	*2.96
Within	100	8,734.8	87.35	

	df	SS	MS	F_s
		Mn		
Among Streams	10	3,711	371.1	*14.9
Dates	10	1,018.2	101.8	*4.08
Within	100	2,489.9	24.90	
		Pb		
Among Streams	10	51	5.1	*5.18
Dates	10	17.6	1.76	1.71 N.S.
Within	100	98.37	.984	
		Al		
Among Streams	10	443	44.3	*2.96
Dates	10	245.2	24.52	1.64 N.S.
Within	100	1,497.2	14.97	
		Co		
Among Streams	10	675,341.8	67,534.2	*499.1
Dates	10	128.639.6	12,864.0	*95.1
Within	100	13.526	135.3	
		Cd		
Among Streams	10	.231	.0231	*442.5
Dates	10	.01684	.001684	*32.3
Within	100	.00522	.0000522	
		Zn		
Among Streams	10	.323	.032	*5.182
Dates	10	.24533	.0246	*3.98
Within	100	.61747	.006175	
		SULFATE		
Among Streams	10	468,571.6	46,857.2	*12.5
Dates	10	132,556.5	13,255.7	*3.5
Within	100	364,120.3	3,741.20	

*Fs = 1.96 at .05 probability level.

APPENDIX D

STUDENT-NEWMAN-KEULS MEANS SEPARATION TEST
SIGNIFICANT RESULTS

1. Zn

Frogspring	Elkhead	Piney	Black	Firescald	Big	Armstrong	Q	Ranger 2	Ranger 1	Jenkins
b	b	B	m	B	m	b	d	d	d	d

2. Fe

Frogspring	Piney	Elkhead	Firescald	Big	Black	Armstrong	Ranger 2	Q	Jenkins	Ranger 1
b	B	b	B	m	m	b	d		d	d

3. Cd

Elkhead	Armstrong	Frogspring	Firescald	Piney	Big	Black	Q	Ranger 2	Ranger 1	Jenkins
b	b	b	B	B	m	m	d	d	d	d

4. Pb

Black	Q	Big	Ranger 1	Frogspring	Ranger 2	Jenkins	Elkhead	Piney	Firescald	Armstrong
m	d	m	d	b	d	d	b	B	B	b

5. Alkalinity

Ranger 1	Ranger 2	Jenkins	Big	Firescald	Piney	Armstrong	Black	Q	Elkhead	Frogspring
d	d	d	b	B	B	b	m	d	b	b

VITA

Louise Eva Gorenflo was born in Buffalo, New York on March 22, 1948. She attended elementary schools in Amherst, New York and graduated valedictorian from Amherst Central Senior High School in June 1966. The following September she entered Vassar College, and in May 1970 she received a Bachelor of Arts degree in History.

After two years as Project Alternative director of a program at Amherst Central Senior School and four years conducting free lance research for various environmental groups in the Washington, D.C. area, she entered Middle Tennessee State University in 1976 to complete prerequisites for graduate school. She entered the graduate school of the University of Tennessee, Knoxville in January 1977. She received the Masters in Science degree with a major in Ecology in December 1978.

The author is a member of the American Association for the Advancement of Science and the Citizens Advisory Committee for 208 State Water Planning. She will be employed with the Appropriate Technology program of the Agricultural Marketing Project after graduation.

She is married to Dennis Gregg. They reside in Pelham, Tennessee.